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

Abstract

The study aims to investigate participants' aesthetic experience in response to environments with curvilinear boundaries that are presented in two different virtual environments (VEs), namely immersive (IVE) and desktop-based virtual environments (DTVE). To this end, 60 participants were presented with 360-degree 32 VE visualizations that had either horizontal or vertical curvilinear boundaries and possessed various architectural properties (size/ light/ texture/ color) using a head-mounted display and a desktop computer. The aesthetic experience in response to these visualizations was measured in terms of the three key dimensions identified in a previous study (Elver Boz et al., 2022): familiarity, excitement, and fascination. In addition, participants' sense of presence in the two different environments was measured. The results show that familiarity and excitement dimensions were significantly higher in IVE than in DTVE, whereas the two environments did not significantly differ from each other in terms of the fascination dimension. As for the boundary types, the familiarity dimension was significantly higher in horizontal curvilinear boundaries than in vertical ones. In contrast, excitement and fascination dimensions were significantly higher in vertical curvilinear boundaries than in horizontal ones. The only dimension that showed an interaction between boundary types and the type of virtual environment was excitement. Finally, IVE induced a higher presence feeling than DTVE. Overall, results suggest that people's aesthetic experiences toward built environments change as a function of the boundary types and the medium they are presented with these environments and that different dimensions of the aesthetic experience are affected differently by these variables.

Keywords: Aesthetic experience, Architectural variables, Virtual reality, Immersive virtual environments, Desktop-based virtual environments

1. Introduction

With the development of virtual reality (VR) technology, the awareness of virtual built environment systems increased rapidly. The game industry and the education, design, architecture, and construction sectors have used this technology dynamically. When applied to a built environment, the most significant feature of VR is its ability to provide users with a sense of immersion and presence. The idea of VR systems in physical environments is to depict and look like architectural environments that do not exist in reality (Bertol, 1997; Obeid & Demirkan, 2023). It enables designers to examine the environment in many aspects before construction.

VR systems include many components in one area, such as a three-dimensional (3D) model, displays, interaction devices, and software (Paes et al., 2023). There are many types to express the 3D model, which can be immersive or non-immersive. With the development of new technologies, many scholars have recently investigated human perception and presence factors in immersive and non-immersive environments (Paes et al., 2017; Paes et al., 2021; Paes et al., 2023). The immersive virtual environments represent the high-end system; while sensors follow the operator's actions in the real world, the display collects stereoscopic views of a model. The non-immersive virtual environments represent the low-end system. The display mode provides monoscopic views of a digital model, and interaction devices are limited to easy-to-use equipment (e.g., mouse and keyboard) (Bertol, 1997; Obeid & Demirkan, 2023). While the immersive stereoscopic display, such as head-mounted equipment, enables a complete virtual reality experience (Castruccio et al., 2019), the non-immersive monoscopic display, such as a computer screen, provides a vision that only presents a virtual representation (Woods et al., 2003). Therefore, aesthetic perception differences between the two environments can be observed in the designed virtual environments. This study investigates the relationship between immersive and non-immersive perception and presence in curvilinear boundaries with various space properties in the virtual environment.

2. Literature review

2.1. Architectural Aesthetic Experience

Many studies emphasized that architecture's aesthetic qualities greatly impact people's cognitive judgment, emotional wellness, and behavior patterns (Adams, 2014; Cooper et al., 2014; Fischl & Garling, 2004; Gorichanaz et al., 2023; Gifford, 2002; Hartig, 2008; Joye, 2007; Lochner et al., 2010). In the literature, several theoretical models specify various components in explaining the importance of architectural aesthetic experience (Chatterjee & Vartanian, 2014, 2016; Coburn et al., 2017, 2020; Elver Boz et al., 2022; Hekkert, 2006; Leder et al., 2004; Weinberger et al., 2021, 2022).

Firstly, Chatterjee (2013) questioned the relationship between aesthetics and art and described the aesthetic experience as a triad composed of sensations, emotions, and meaning. Chatterjee and Vartanian's (2014) characterization of the cognitive, emotional, and behavioral elements provides a more holistic approach in the aesthetic field. Later, Coburn et al. (2017) explained how the aesthetic triad created for aesthetic experiences can be applied to the neuroscience of architecture and frame the human aesthetic experiences in architecture.

Furthermore, Coburn et al. (2020) investigated the key psychological components of architectural experience (coherence/ fascination/hominess) in a psychological framework rooted in the aesthetic triad (Chatterjee & Vartanian, 2014, 2016). Concerning this psychological framework, the study utilized sixteen aesthetic adjective scales that capture essential aspects of architectural experience. These scales are complexity, organization, naturalness, beauty, personalness, interest, modernity, valence stimulation, vitality, comfort, relaxation, hominess, uplift, approachability, and explorability. Their study identified three key aesthetic components: *"(1) coherence; the ease with which one organizes and comprehends a scene, (2) fascination; a scene's informational richness and generated interest; and (3) hominess; the extent to which a scene reflects a personal space."* (p.231). The coherence component was associated with organization, modernity, and beauty scales, the fascination component with explorability, complexity, interest, and stimulation, and the hominess component with naturalness, personalness, relaxation, hominess, and comfort. Coburn et al. (2020) also showed how these key components could be matched with neural activity.

In the literature, there are studies related to interior and exterior architectural space variables using the three aesthetic key components in evaluating the architectural responses of the participants. In Coburn et al. (2020) study, they investigated the real interior images comprised of ceiling height, enclosure, and curvature as space variables. Likewise, Chatterjee et al. (2021) investigated the perceived ceiling height, enclosure, and contour of architectural interiors as the space variables of architectural interiors with the same sixteen aesthetic adjective scales. In the Weinberger et al. (2021) study, the same sixteen adjectives were applied to different subtypes of exterior architecture and natural landscapes using the Vessel et al. (2018) visual images. In all three studies, the key aesthetic components, coherence, fascination, and hominess, explained the aesthetic responses of participants.

Also, some studies investigated the impact of individual differences in evaluating the aesthetic experience of the participants using the three key components. Vartanian et al. (2021) investigated the perceived ceiling height, enclosure, and contour of architectural interiors with participants having individual differences. They found that coherence was the only key component for design students. However, for participants with autism spectrum disorder, preference for architectural interiors was driven by key components of hominess and coherence. Weinberger et al. (2022) investigated the differences in responses to aesthetic key components among expert and novice design professionals. They found that expertise affects the interrelatedness of the three aesthetic components. Also, the coherence component of design experts was more strongly associated with fascination and hominess components and had a greater influence on their overall aesthetic experience.

Elver Boz et al. (2022) studied an extensive and empirically driven model that describes human aesthetic experience for built environments. Their study mainly investigated the significant dimensions of aesthetic experience and how these dimensions affect different properties of the built environment. Instead of fully designed real environment images, they created 3D 360-degree simulations of different architectural variables in order not to lose controlling factors with other elements (e.g., the furniture shape, color, and arrangement, the window openings and sunlight effect, and the compositions of the mural) study conducted with a space. By leveraging virtual reality, they systematically manipulated various space variables (curvilinear boundaries and four space properties: size, light, texture, and color). Their studies emphasized that three dimensions of aesthetic scale, which are (1) familiarity, (2) excitement, and (3) fascination, identified the aesthetic experiences in spaces with curved boundaries and different architectural characteristics. The findings reveal that three key aesthetic dimensions had different relationships between architectural spaces with curved boundaries.

Elver Boz et al. (2022) described three key aesthetic dimensions as follows: Familiarity is *"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."* (p.10); excitement is *"How excited, frenzied, jittery or contended one feels in an environment."* (p.10); fascination is *"How mysterious or complex an environment looks or how stimulated one feels in that environment*." (p.10).

Also, these three aesthetic dimensions are compatible with Chatterjee and Vartanian's (2014) cognitive, emotional, and behavioral elements of the triad model. However, two main differences exist between Elver Boz et al. (2022) and Coburn et al.'s (2020) studies. The first is that the parameters of the built environments are different. Chatterjee et al.'s (2021) and Coburn et al.'s (2020) study involved the perceived enclosure (open or closed), ceiling height (high or low), and contour (round or square) levels of the furnished built environment. Elver Boz et al.'s (2022) study systematically involves only the built environment variables (curvilinear boundaries and four space properties: size, light, texture, and color). The second is that the key dimensions of the aesthetic adjectives are formed differently.

2.2. Virtual Environments in Architectural Design

Much research investigates people's responses between virtual and real environments by comparing cognitive judgment, emotional well-being, and behavioral approaches. De Kort et al. (2003) found that behavioral experience in virtual environments is similar to that in real environments. However, there are also modest significant differences in environmental evaluations, such as height perception of a room. Based on the quantitative result, Kuliga et al. (2015) found few statistically significant differences in user experience between real and virtual building model ratings. However, based on the qualitative results, the "atmospherics" ratings showed substantial significance for each environment. The study uses the meaning of the atmospherics as a holistic approach of interesting, warm, inviting, decorated, varied, complex, and attractive adjectives. The main idea of the study reveals that using VR as a research tool in architecture and psychology has a strong potential. Besides, Brade et al. (2017) emphasized that virtual and real environment presence and user experience features were associated. The idea of the Brade et al. (2017) study indicates that VE can be an alternative to the real environment for the user when a high presence is realized. Higuera-Trujillo et al. (2017) analyzed simulated (photographs, 360-degree scenes, and VR) and real (physical setup) environment relationships with the help of psychological and physiological user responses and sense of presence. The findings reveal that while VR simulations tend to obtain the closest to reality according to physiological measurements, 360-degree panoramas provide the closest to reality according to psychological outcomes.

Moreover, Chamilothori et al. (2018) investigated daylight perception in real and virtual environments. The study's prior aspects are pleasantness, interest, excitement, complexity, and satisfaction. The study shows no significant differences between these environments in perceptual accuracy. They reported that using VR methods in architectural studies seems promising for use as a surrogate for real environments.

2.3. Immersive Virtual Environment (IVE) and Desktop-based Virtual Environment (DTVE)

VR is the technology that immerses a person into a three-dimensional, simulated digital environment. As Sherman and Craig (2003) stated, VR allows users to feel, perceive, and immerse the space as if in an existing environment by imitating the architectural environment. Therefore, users' emotions and actions are consistent with those in the real environment. Adapting various space properties such as size, light, texture, and color of the boundaries of that environment increases the user's sense of space within the created environment. Using various properties enriches the experience by enhancing engagement and meaning for the viewer more than a three-dimensional space. In the virtual environment, increasing user sensations, feelings, and emotions in that space is related to making sense of the created environment.

In the literature, many examples of virtual environments can be experienced using immersive displays (e.g., head-mounted displays (HMD)) or non-immersive displays (e.g., desktop computers). In each virtual environment, the participants could have different experiences and results based on the spatial characteristics of the virtual environment. Paes et al. (2017) compared spatial user perception and presence between an immersive virtual environment and a non-immersive traditional (conventional workstation) virtual environment.

Results indicate that users perceived different features of the created space more accurately than the conventional virtual environment. The study concludes that better spatial perception is provided with the help of an immersive environment. Paes et al. (2021) also compared perception and presence between immersive (HMD), non-immersive (laptop monitor) virtual environments, and physical environments (real environment). The result of the study showed that immersive VR systems provide a greater presence than non-immersive ones. Also, an immersive system provides a more immersive experience, benefits collaborative design review, and increases productivity. Paes et al. (2023) investigated the relationship between perception and presence findings in non-immersive and immersive virtual environments. The study investigated whether three-dimensional perception affects users' presence level in VE. The results of the study indicate no association between presence and perception.

The level of presence score is not related to the display mode of the 3D model. According to the study, incorporating advanced stereoscopic visualization techniques may be optional while creating a 3D model of the built environment. Shu et al. (2019) investigate whether VR appears or feels different to users when different virtual environments (HMD and desktop-based) are used in terms of sense of presence. As a result, users indicated a higher sense of spatial presence and immersion while using VR HMD than desktop VR.

The present study investigates whether a VE (immersive virtual environment-IVE and desktop-based virtual environment-DTVE) affects the aesthetic experience dimensions of the participants in curvilinear space boundaries with different architectural properties (size, light, texture, and color). The study also intends to analyze the effects of IVE and DTVE on participants' sense of presence. Participants rated these VEs based on the findings of Elver Boz et al.'s (2022) research that defined the three dimensions of aesthetic experience: familiarity, excitement, and fascination.

The related research questions (RQ) are posed:

RQ 1. What are the aesthetic experience dimensions associated with virtual environments (VEs) and curvilinear boundaries with various architectural properties of interior spaces?

RQ 1a. Is there a difference in aesthetic experience dimensions based on VEs of interior spaces?

RQ 1b. Is there a difference in aesthetic experience dimensions based on curvilinear boundaries with various architectural properties of interior spaces?

RQ 2. Does interaction between VEs and curvilinear boundaries with various architectural properties affect the aesthetic experience dimensions of interior spaces?

RQ 3. Is there a difference in presence based on VEs of interior spaces?

RQ 4. Do aesthetic experience dimensions have an impact on the presence scores in VE?

3. Method

3.1. Participants

XXXXXXX University Institutional Ethical Review Board approved this study (No: 2018_01_18_04). All the participants signed the informed consent form that stated the purposes of the study and explained the participants' involvement as well as the risk and emergency procedures. Based on a priori G* Power F-test analysis (Faul et al., 2009) for ANOVA: Repeated measures, within factors, were conducted using computed effect size (f) 0.25, $\alpha=0.05$, and a power level of 0.90 (Cohen, 1988), indicating a minimum required sample size of 44 participants for each of the 32 visualizations. At the beginning of the experiment, 76 participants were involved; later, twelve were excluded because of color blindness, virtual reality cybersickness, or not participating in the second VE experiment (IVE or DTVE). A total of 60 university students, 37 females and 23 males, participated in both experiments voluntarily from XXXXXX University. The age range of the participants was 19 to 30 years (M=24.77, SD=3.92). The efficiency of visual perception was found to be high in young adults in the research conducted by Błasiak et al. (2019). Also, they noticed differences in stress between the youngest, middle-aged, and oldest respondents. Therefore, the age range was taken between 19-30 for having the same stress level in explaining their feeling and thoughts about the perceived spaces. Ishihara's electronic color blindness test was used (Color-blindness.com, 2019) to ensure the subjects' complete color perception.

3.2. Virtual environment and stimuli

The experimental stimuli in the virtual environment have two important features: curvilinear horizontal boundaries (HB) and curvilinear vertical boundaries (VB) (see Figure 1).

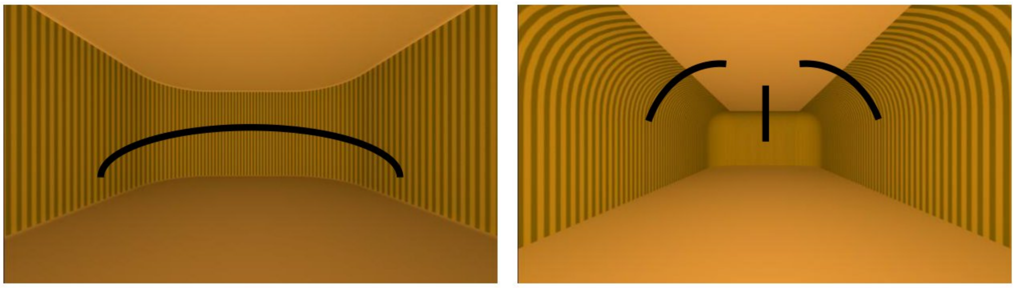


Figure 1. Curvilinear horizontal boundaries (HB) and curvilinear vertical boundaries (VB)

In HB space, four horizontal surfaces are linked with concave connections. In contrast to the standard space connections, there is no 90-degree edge in that space in the horizontal plane. In VB space, each wall is connected to the ceiling as a vertically concave connection. In contrast to the standard space connections, there is no 90-degree link between walls and ceiling. Each boundary type involves four space properties (size, light, texture, and color) of the surrounding surfaces, where each space property is composed of two intensity levels, high and low, namely as size (small-S and large-L), light (dim-D and bright-B), texture (longitudinal-LT and lateral-LR), and color (cool-C and warm-W) shown in Figure 2 for the representation of 32 visualizations. This study's 32 VE visualizations are designed with various architectural properties.

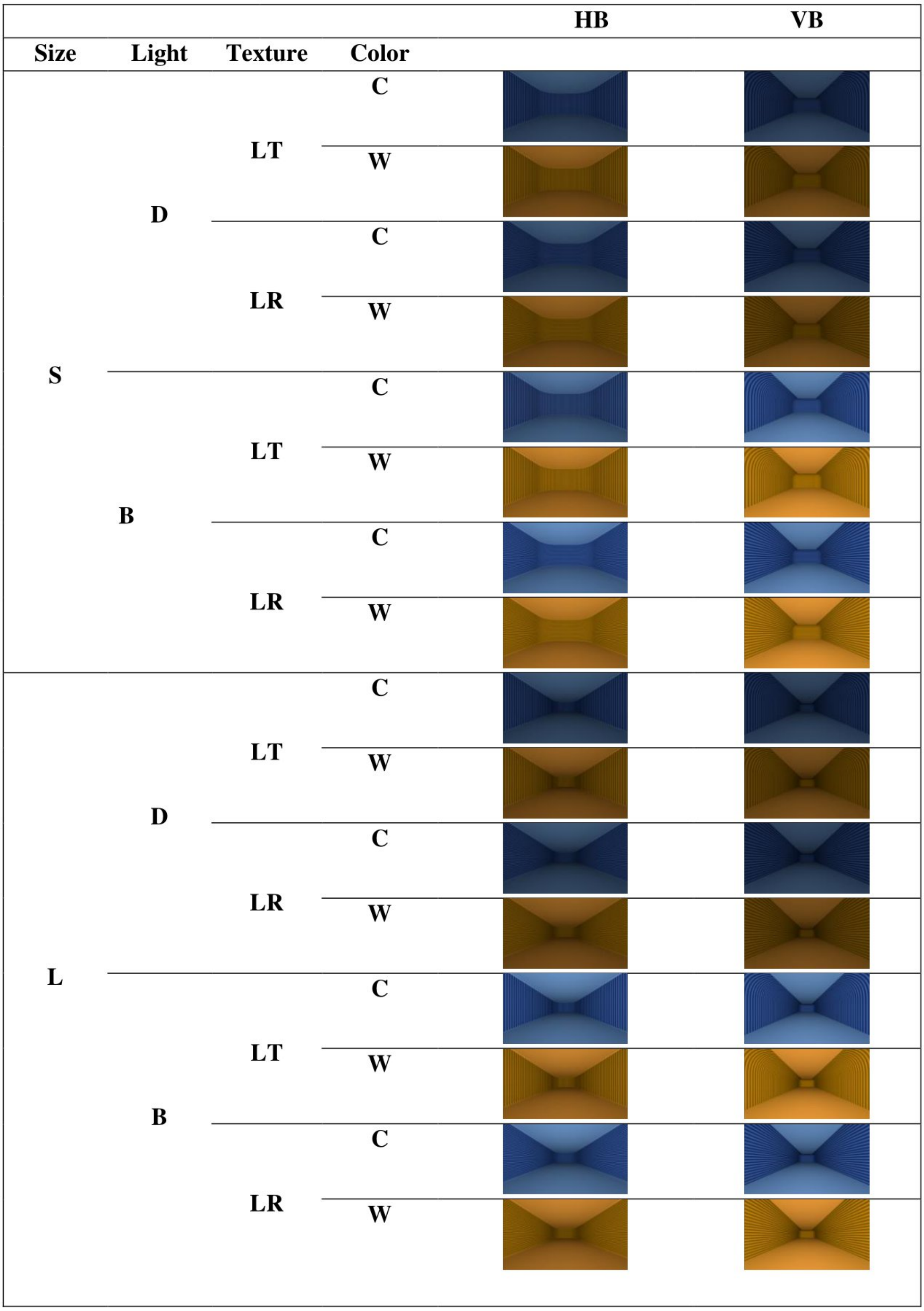


Figure 2. VE visualizations with various space variables (Size as S: small and L: large; Light as B: bright and D: dim; Texture as LT: longitudinal and LR: lateral; and Color as C: cool and W: warm).

3.3. Design and Procedures

The study aims to identify the differences in participants' aesthetic experience perception of the two VEs and the impacts of curvilinear boundaries with various architectural properties on different VEs. The study was conducted in two VEs: (1) an immersive virtual environment (IVE) and (2) a desktop-based virtual environment (DTVE). While immersive (IVE), high-end VR system displays the stereoscopic images of a digital model, non-immersive (DTVE), low-end VR system displays the monoscopic perspective views of a digital model (Bertol, 1997; Paes et al., 2021). Figure 3 presents the experiment setup scheme.

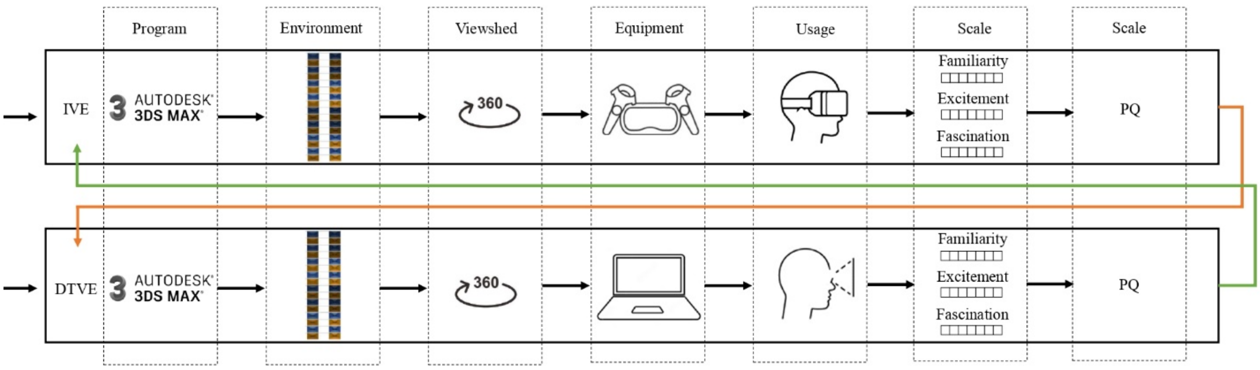


Figure 3. Experiments setup scheme

The study involves 32 VE visualizations with various space variables to be tested by 60 participants. Each participant has to examine the space for 10 seconds and evaluate the three key dimensions of aesthetic adjectives after each space in 10 seconds. The experiment for each participant had two steps. Each participant started the experiment in one of the steps and then moved to the other. The 30 participants initially experienced the IVE and then the DTVE, while the other 30 participants initially experienced the DTVE and then the IVE to eliminate the order effect. The participants evaluated the presence questionnaire after experiencing each environment with no time limitation.

While in DTVE, participants are seated in front of the desktop and the only movements are wrist and fingers used for mouse operation to select responses, in IVE, participants need to stand and turn their heads to move around the scene (left-right and up and down) and reach out to select the responses with controllers. The total duration of the 32 visualizations was 10 minutes in both environments. The IVE experience process lasted 25 to 30 minutes, depending on the virtual glass placement and adaptation, and the DTVE experience process lasted approximately 15 to 20 minutes. To avoid distracting attention, the experimenter leaves the room after a brief introduction about the experiment. Next to the experiment room, another computer simultaneously shows participants' movements and records the responses.

Participants rated these visualizations based on the related findings of the previous research (Elver Boz et al., 2022), which categorized the three dimensions of the aesthetic experience of interior spaces as familiarity, excitement, and fascination. After evaluating the last environment in each step, participants completed the presence questionnaire (PQ) that is adapted from the studies of Paes (2019) and Paes, Irizarry, and Pujoni (2021).

3.4. Instruments

The three aesthetic experience dimensions of thirty-two 360-degree perceived spaces are determined using IVE (HTC Vive Pro) and DTVE (IntelI Core i7-7700U CPU @ 3.60GHz). IVE, as a fully immersive environment, provides a headset and two touch controllers for perceiving the environment and evaluating familiarity, excitement, fascination dimensions, and PQ scores. DTVE, as a monitor-based VR system, was a high-performance 32" full HD monitor for the presentation of the VR environments and a computer mouse as an interaction between the virtual environment and the user. Also, the same desktop computer is used by all participants (Luminance 120; Gamma 2.2; Color temperature 6500K; Color display 24-bit) to prevent differences in perception due to different computer settings (EIZO, 2021; Federal Agencies Digital Guidelines Initiative, 2016) in the IVE participant putting on the headset and being able to turn 360 degrees as an egocentric framework. In the DTVE, the participant was sitting in front of a desk interacting with the DTVE, using the 32” full HD monitor and the mouse.

Qualtrics survey is conducted in both VEs ("Qualtrics XM - Experience Management Software," 2021). The visualizations are randomly assigned in the Qualtrics, and the participants rated the three dimensions of aesthetic experience on a 7-point Likert scale after perceiving each space. Also, a week after completing the first step, the participants were invited once more to participate in the second step of the experiment. After completing 32 visualizations in each VE, participants were administered the presence questionnaire to analyze their perceived level of presence during the 3D perceptions in the VEs (IVE and DTVE). The presence questions are predominantly based on the Slater-Usoh-Steed (SUS) instrument developed by Usoh et al. (2000). Paes (2019) created a collection of VE presence questions adapted from Usoh et al., 2000, Witmer and Singer, 1998, and Zikic, 2007 (see Table 1).

Table 1. VEs Presence questionnaire (PQ) (Adapted from Paes, 2019, pp. 129-130)

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)?

Each question was rated on a scale of 1 (not at all) to 7 (a great deal). Slater (1999) defined the three aspects of virtual presence. The first is related to the feeling of being in the virtual environment as the participant feels that the space is real and immediately declares it**.** The second is the level of becoming a reality from the virtual environment as the participant knows it is not a real environment but states the perceived feelings or acts within that space as real. The third one is to what extent virtual reality is remembered as a 'place,' and the space experience is reported as being experienced in real space. The participant states the first aspect, while the second and the third are observed or listened to as an experience.

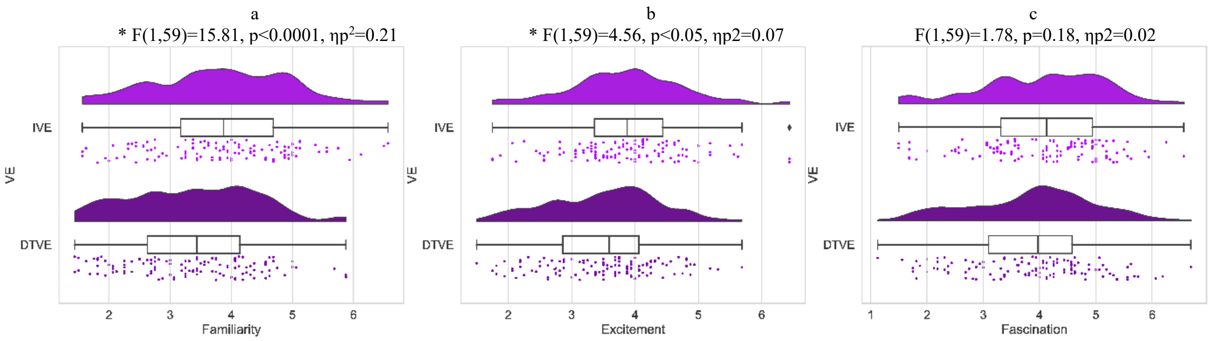
3.5. Data analysis

The study assesses the boundary type (horizontal and vertical), VEs (IVE and DTVE), and their relationships with the three aesthetic experience dimensions based on the ratings of the 60 participants. The study ran a 2 (Boundary type: horizontal and vertical) x 2 (Presentation mode: IVE and DTVE) repeated measures ANOVA for each aesthetic preference dimension. Consequently, the main effect of VEs, the main effect of curvilinear boundaries, and the interaction of VE with curvilinear boundaries were determined. Apart from these analyses, the presence score of the VEs was reported using a pairwise comparison. Also, the study conducted hierarchical multiple regression analysis to determine the percentage of the variance of the architectural variables' dimensions in the presence score.

4. Results

4.1. Aesthetic experience dimensions and VEs

In Figure 4, 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 ($F(1,59)=1.78$, $p=0.18$).



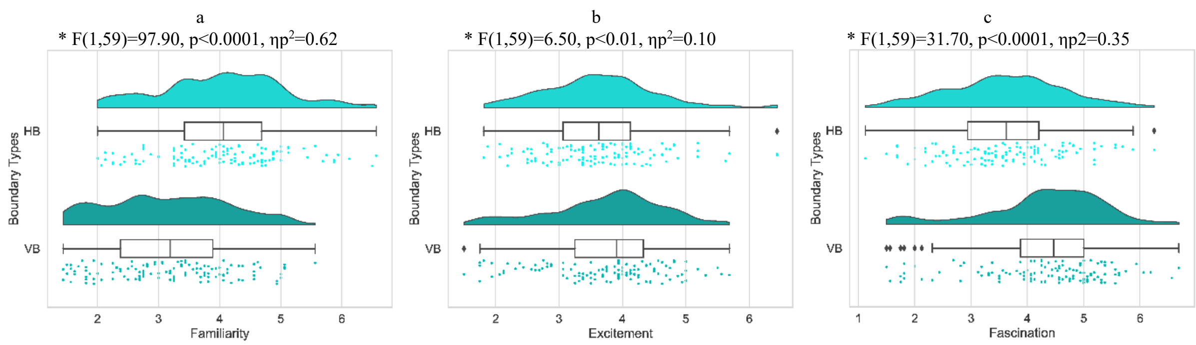
IVE: Immersive virtual environment

DTVE: Desktop-based virtual environment

Figure 4. Raincloud plots of aesthetic experience dimensions (a: Familiarity, b: Excitement, and c: Fascination) and VEs

4.2. Aesthetic experience dimensions and curvilinear boundaries

In Figure 5, the ANOVA on the familiarity dimension showed a main effect of boundaries ($F(1,59)=97.90$, $p<0.0001$, $\eta_p^2=0.62$). 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 boundaries ($F(1,59)=6.50$, $p<0.01$, $\eta_p^2=0.10$). 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 boundary type ($F(1,59)=31.70$, $p<0.0001$, $\eta_p^2=0.35$) as well. Vertical boundaries ($M=4.30$, $SD=0.11$) were more fascinating than horizontal boundaries ($M=3.60$, $SD=0.10$).



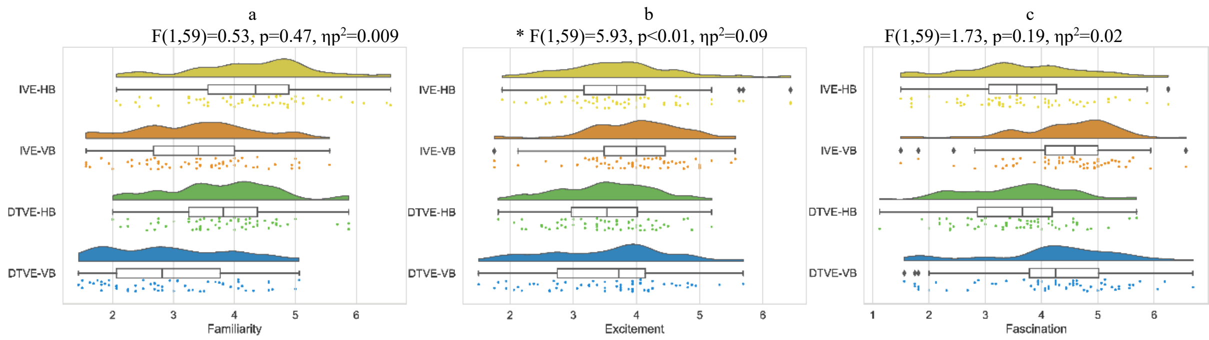
HB: Horizontal boundaries

VB: Vertical boundaries

Figure 5. Raincloud plots of aesthetic experience dimensions (a: Familiarity, b: Excitement, and c: Fascination) and curvilinear boundaries

4.3. Curvilinear boundaries and VEs interactions in aesthetic experience dimensions

In Figure 6, 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 boundaries and VEs. The excitement dimension showed a significant interaction between boundaries and VEs ($F(1,59)=5.93$, $p<0.01$, $\eta_p^2=0.09$). The horizontal curvilinear boundaries were more exciting than those for the IVE ($t(59)=-1.86$, $p=0.07$). In contrast, the two boundary types 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

DTVE-VB: Desktop-based virtual environment-Vertical boundaries

Figure 6. Raincloud plots of curvilinear boundaries and VEs interactions in each aesthetic experience dimension (a: Familiarity, b: Excitement, and c: Fascination)

4.4. Presence of VEs in aesthetic experience dimensions

In Figure 7, 10 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.

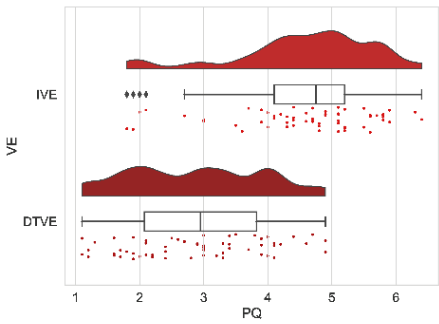


Figure 7. Raincloud plots of presence scores and VEs

4.5. 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 (Table 2). 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 2. All the aesthetic dimensions were checked for collinearity, and all the predictors had tolerance levels greater than 0.1.

Table 2. 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.

5. Discussion

5.1. Effects of VEs on aesthetic experiences

The present study examines users' aesthetic experience and presence results within the related VEs. As a result of the study, the familiarity and excitement components are highly significant factors in both VEs. The aesthetic experience dimension of familiarity covers elements that Elver Boz et al. (2022) categorized as 'pleased, happy, satisfied, pleasant, relaxed, like to spend time, prefer to live, enjoy exploring, and others.' The familiarity dimension may also be conceptually related to the 'hominess' factor named in Coburn et al.'s (2020) study, where the human aesthetic experience was explored by operating different architectural variables. The familiarity dimension may represent belonging to a space like home.

In the Coburn et al. (2020) study, the fascination component was described with explorability, complexity, interest, and stimulation scales, and the present study is described as the feeling of how mysterious or complex an environment is or how stimulated one feels in that environment (Elver Boz et al., 2022). Complexity and stimulation are common adjectives in both studies, and interest could correspond to mysterious feelings in the environment. The fascination dimension was only active in the presence of IVE in the present study. The coherence and excitement dimensions have different describing adjectives. In Coburn et al.'s (2020) study, they are related to the ease with which one organizes and comprehends a scene; in the present study, the excitement dimension is related to how excited, frenzied, jittery, or contended one feels in an environment.

Specifically, in the IVE, familiarity aesthetic components have higher results than in DTVE in the current study. The reason may be that IVE makes the participant feel closer and 'like home' than the DTVE. It may be because the participants can experience the places without any external factors or interruption. Another reason may be that while in the IVE, participants were allowed to move their heads around in the VE. They can turn their heads whenever needed, like in real-world actions.

Participants were seated and not allowed to walk during the experiment. For that reason, DTVE is a less familiar way to explore and visualize a room than moving around. Participants may feel in a familiar space because of the focus vision in the IVE. In addition, excitement aesthetic components show the same result as familiarity. Elver Boz et al. (2022) emphasized excitement as 'contended (satisfied).'This finding is consistent with Imamoglu (2000), suggesting that more familiar stimuli may appear relatively more predictable, satisfying, and less complex. However, fascination with aesthetic components is expressed as 'complex' by Elver Boz et al. (2022). The fascination with aesthetic experience differs from the other two aesthetic scales, and no significant factors (mysterious, complex, and stimulated) exist.

Imamoglu's (2000) previous study supports this study's findings that as participants feel more familiar with a particular stimulus, the environment may appear more predictable and, hence, less complex and mysterious.

The previous studies using simulated built environments have shown different perceptions of IVE and DTVE (Higuera-Trujillo et al., 2017; Paes et al., 2017; Paes et al., 2021; Paes et al., 2023; Shu et al., 2019). However, these studies have measured the differences in users' sense of presence and immersion between the two VEs. Besides perception and preference, the aesthetic experience of the VEs needs to be investigated more extensively in the literature. Hepperle and Wölfel (2023) conducted a systematic scoping review of human behavioral studies that analyzed VR settings in three categories: perception, interaction, and sensing and reconstruction of reality. However, they recorded only one study in their literature review on the sensing and reconstruction of reality category related to aesthetic experience in VE facade design (Verwulgen et al., 2019).

5.2. Effects of curvilinear boundaries on aesthetic experiences

Chuquichambi et al. (2022) stated that while human curvature preference is common, it is not universally constant or invariant. Furthermore, Djebbara and Kalantari (2023) demonstrated a negative relationship between curvature preference and possible interactions with an object. Elver Boz et al. (2022) controlled curvilinear boundary types and space properties in their research one by one in the built environment. However, one of the aesthetic components, the fascination dimension, was affected by none of the architectural variables controlled in their studies. Also, Elver Boz et al. (2022) proposed that combining the boundary types and space properties, which means a holistic approach, allows 'fascination' with aesthetic components that interact with the perception of the built environment.

Consequently, instead of studying architectural variables in isolation, our study examines architectural variables in a combined way. This result is consistent with real-life architectural properties such as curvilinear boundaries, size, light, texture, and color in our living environment. This study investigates the impacts of curvilinear boundaries with various architectural properties. The study found that the three aesthetic components, familiarity, excitement, and fascination, were modulated by the environment one experiences.

Familiarity and complexity are consistently perceived as independent dimensions of the physical environment (Alexander, 2002; Kaplan & Kaplan, 1989; Salingaros, 2007). As a result of this study, horizontal boundaries with various space properties were more familiar than vertical boundaries, and vertical boundaries were found more exciting and fascinating than horizontal boundaries. Elver Boz et al. (2022) previous study supports this finding that studies of horizontal boundaries were more familiar and exciting than studies of vertical boundaries. Elver Boz (2022) suggests that familiar things and unexpected different ones are perceptually salient qualities of the built environment that can be manipulated independently in architectural design strategies parallel with the study of Coburn et al. (2020).

5.3. Interactions of curvilinear boundaries with aesthetic experiences

Elver Boz et al. (2022) emphasized interactions between boundary types and space properties such as size, light, texture, and color one by one. Elver Boz et al. (2022) found 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.

Furthermore, this study explores the curvilinear boundaries with various architectural properties and VEs interactions in each aesthetic experience dimension. Only the excitement dimension showed the main effect of interactions between VE and boundary. This finding is a main contribution to the present literature since, to our knowledge, no other research has examined aesthetic experiences in VEs with various architectural variables.

5.4. Effects of presence in VEs on aesthetic experiences

In the Gregorians et al. (2022) study, the participants were asked to rate the built environments filmed in the videos for the valence, arousal, spatial layout complexity, fascination, coherence, hominess, and unusualness qualities. They found that fascination, coherence, and hominess are all strongly correlated with valence (intrinsic appeal or repulsion), which is in line with the previous work of Coburn et al. (2020). In the Gregorians et al. (2022) study, neither the appearance of green/blue space nor the presence of people significantly affected video ratings.

This study mainly investigates the effects of the aesthetic experience of participants in the presence of VEs. As a result of the study, the data showed that IVE has more presence feelings than DTVE. In the related literature, Elver Boz et al. (2022) only focus on IVE in their studies, and research needs to be conducted in the literature concentrating on space with curvilinear boundaries with various architectural properties in VEs presence comparison. This study expands the VE's presence feelings with the human psychology of aesthetic assessments. This research provides a deeper analysis of what happens when a user reports VEs about presence. The excitement dimension is the main predictor of presence in both environments (IVE and DTVE).

6. Conclusion

This study makes significant contributions by analyzing the current state of VE literature. The study findings mainly contribute to three areas: (1) the relationship between the VEs and the three main aesthetic experience dimensions. (2) the relationship between the curvilinear boundaries with various architectural properties and the three main aesthetic experience dimensions. (3) the interaction between VEs and curvilinear boundaries with various architectural properties and the dimensions of the three main aesthetic experiences.

The acquired knowledge of this research has many implications for the built environment. The familiarity and excitement experiences increase in IVE. Also, the familiarity experience increases in horizontal curved boundaries, and excitement and fascination dimensions increase in vertical curved boundaries. In line with this result, designers can manipulate this idea in the existing spaces that include different architectural variables. These results can be substantial for renovating the built environment.

The study provided immersive and non-immersive virtual environments relations regarding curvilinear boundaries with various architectural properties. As a result, virtual worlds presented in an IVE are more comparable 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 may be useful information for designers and researchers looking to create more immersive and realistic virtual experiences.

Nevertheless, there were limitations in this study, such as the use of a head-mounted display (HTC Vive Pro). Technological devices have been developing each passing day, and using new versions of technological devices was not included in this research. Further research could be conducted with more immersive display equipment like augmented reality to investigate three aesthetic dimensions. In addition, in real interior space stimuli experiments, participants may be affected by other factors (e.g., furniture, openings, murals) in the environment. In this study, 32 interior images were designed as stimuli to limit participants' focus in the designed space. However, since it does not resemble the space we see in real life, this may cause limitations in our perception.

As potential guidelines for future research, proposals for studies in the application of virtual environments and space properties of interior spaces to understand aesthetic experiences are encouraged. Moreover, future works may include new space properties to differentiate the various visualizations of interior spaces. For instance, in this study, the surrounding surfaces' space properties (size, light, texture, and color) are composed of two intensity levels. However, different space properties with many levels of intensity may be explored in further investigation. Also, a future study could determine if some semantic inconsistencies provide differences in evaluating interior spaces. Since the experiments are conducted in different cultural backgrounds, a cross-cultural study could be valuable to identify these differences.

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