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The Role of Architectural Boundaries in Shaping Visitors' Aesthetic Experiences in Virtual Exhibition Environments

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Authors	Samah Obeid, Halime Demirkan

Dear Editor and Reviewers,

We sincerely thank you for your thoughtful and constructive feedback on our manuscript, titled "The Role of Architectural Boundaries in Shaping Visitors' Aesthetic Experiences in Virtual Exhibition Environments". We have carefully revised the manuscript in light of your comments. Below, we present a focused point-by-point response that references the relevant manuscript line and page numbers for each requested change.

In the response letter, we have included the editor and reviewers' comments in *italics*, followed by our responses in **bold**. The changes made to the manuscript are indicated with blue fonts.

Sincerely,
Samah Obeid, Prof. Halime Demirkan

Response letter for “The Role of Architectural Boundaries in Shaping Visitors’ Aesthetic Experiences in Virtual Exhibition Environments”.

Dear Dr Samah Obeid:

Your manuscript, "The Role of Architectural Boundaries in Shaping Visitors’ Aesthetic Experiences in Virtual Exhibition Environments" submitted to International Journal of Human-Computer Interaction, has been considered.

We are in general favourable and suggest that, subject to minor revisions, your paper could be suitable for publication. Please consider these suggestions, and I look forward to receiving your revision.

When you revise your manuscript please highlight the changes you make in the manuscript by using the track changes mode or by using bold or coloured text.

To submit a revision, go to:
https://rp.tandfonline.com/submission/flow?submissionId=251556559.R1&step=1.

If you decide to revise the work, please submit a list of changes and a response to each point which is raised when you submit the revised manuscript.

If you have any questions or technical issues, please contact the journal's editorial office at HIHC-peerreview@journals.taylorandfrancis.com

Because we are trying to facilitate timely publication of manuscripts submitted to International Journal of Human-Computer Interaction, your revised manuscript should be uploaded by 21-Nov-2025. If it is not possible for you to submit your revision by this date, please let us know as soon as possible.

Once again, thank you for submitting your manuscript to International Journal of Human-Computer Interaction and I look forward to receiving your revision.

Sincerely,
Dr Constantine Stephanidis
International Journal of Human-Computer Interaction
cs@ics.forth.gr

Reviewer: 1

Comments to the Author
Provide a focused revision that implements the following author actions, with each change traceable in a point-by-point response: report Mauchly's sphericity tests for all repeated-measures factors and interactions; where sphericity is violated, present Greenhouse–Geisser (and, if relevant, Huynh–Feldt) ε, adjusted degrees of freedom, and adjusted p-values, and add 95% confidence intervals for partial η^2 in all ANOVA summary tables;

Response: We thank the reviewer for this valuable suggestion. We have now reported the Mauchly's sphericity tests for all repeated-measures factors and interactions. Additionally, we presented Greenhouse–Geisser ε, adjusted degrees of freedom, and adjusted p-values where the assumption of sphericity was violated. These can be found in the text on pp. 22-23 (lines 456-466), p. 24 (lines 486-489), p. 25 (lines 506-509), pp. 29-30 (lines 585-594), p. 31 (lines 618-621), and pp. 31-32 (lines 634-637). We have also included 95% confidence intervals for partial η^2 in ANOVA summary tables 1 & 3 (p. 26 & p. 33, respectively).

Justify the choice of Golden-Ratio radii as the curvature parameter with a theory-anchored rationale (e.g., perceptual scaling or aesthetic proportion literature) and briefly note alternative parameterizations (constant arc length; curvature κ) to clarify generality;

Response: We have now provided a more detailed justification for our choice of the Golden-Ratio, in relation to aesthetic proportion, referencing previous literature by Kurniawan (2025), Meisner (2018), and Thapa and Thapa (2018) (p. 13, lines 275-280). The references have been revised accordingly (p. 53, lines 1102-1104; p. 54, lines 1123-1124; p. 57, lines 1187-1189, respectively). Additionally, we have included the corresponding constant arc lengths and curvature (κ) values for the radii, as suggested (p. 13, lines 285–286).

In Measurement and Analytic Strategy, specify whether presence was analyzed as a continuous composite score, report item behavior for the motion-sickness indicator, and confirm that no trichotomization was used in inferential models;

Response: We thank the reviewer for pointing out the need for further clarification regarding the treatment of presence level. We have now clarified that in the univariate analysis, the presence level was treated as a continuous variable (p. 33, lines 669–670). Additionally, we confirm that no trichotomization was used in any inferential models (p. 21, lines 426–427). Furthermore, the item related to motion-sickness from the presence questionnaire showed a low mean score (M = 2.45, SD = 1.564) without any extreme outliers. These clarifications have been explicitly stated in the text (pp. 33-34, lines 671–674).

Document order and fatigue checks across the 12 within-subject evaluations (e.g., order covariate screen or trend tests), even if null, and state explicitly whether Greenhouse–Geisser adjustments alter any significance interpretations for curvature main effects on familiarity and excitement;

Response: We thank the reviewer for emphasizing the importance of order and fatigue in the assessment of the 12 VEEs. As previously mentioned, the Python coding software generated 55 randomly ordered 12 VEEs, which means the sequence of the 12 VEEs was unique and randomized for each participant (p. 16, lines 353-355). In the previous literature, a methodological study emphasized that the randomization of the experimental stimuli with a unique sequence for each participant is an effective strategy to minimize the influence of fatigue effects (Keating & Jegerski, 2015). Given the unique randomized stimulus order, the effects of order and fatigue are unlikely to have influenced the outcomes. Additionally, we specify whether the Greenhouse–Geisser corrections affected the significance of the main effects of curvature, as suggested (p. 23, lines 468-469; p. 30, lines 598-600), and we revised the discussion accordingly (p. 39, lines 793-795).

In Covariate and Control Analyses, reaffirm inclusion of floor area and wall length in generalized linear models and provide standardized coefficients to assist interpretation;

Response: We appreciate the reviewer's thoughtful suggestion. We have clarified that our analysis using generalized linear models controlled for both floor area and wall length. Additionally, we have included standardized coefficients (pp. 26-27, lines 530-534; p. 27, lines 538-549).

Consolidate practical implications into a one-page "Design Guidance" box that maps boundary curvature and ceiling height settings to target experiential outcomes (familiarity, excitement, fascination, complexity), with guardrails for unintended effects (e.g., reduced familiarity under high curvature) to support HCI practice;

Response: We thank the reviewer for this valuable suggestion. We have included a design guidance table that summarizes the practical implications of our results (Table 5, p. 42).

Strengthen Limitations with brief notes on ecological validity, potential simulator sickness heterogeneity, and power considerations for between-subject moderators (education type), including a sensitivity analysis;

Response: We sincerely appreciate the reviewer's thoughtful observation. We have now expanded the Limitations and Future Research section to address several important factors: the ecological validity of VR experiments, the potential variability in simulator sickness among participants, and considerations regarding the statistical power between-subject moderators, such as education type. These updates can be found on p. 44, lines 884-889; pp.44-45, lines 903-905; and, p. 45, lines 913-916.

Adjust figures for accessibility by enlarging axis labels, restating N in captions, and defining error bars uniformly as ±1 SD (or 95% CI if revised);

Response: We thank the reviewer for highlighting the need for an editorial refinement on the figures. We have revised the figures by enlarging the axis and legend labels. Additionally, we updated the figure captions to include details about the sample size investigated and clarified the definitions of the error-bars (see Figures 4, 5 and 6).

Add a short Data and Materials Availability note offering stimulus files or parametric generation scripts (preferred) alongside the dataset link;

Response: We acknowledge the reviewer's valuable feedback and now included a note in the Data and Materials Availability section titled 'Modeling Parameters for Stimulus Generation' that outlines the specific parameters used for generating VEE stimuli and explains the generation process step by step (pp. 46-47, lines 945-956).

Run a final terminology consistency pass to align factor names across text, tables, and figures; and supply an editorially clean, numbered response that cites manuscript line numbers for every requested change.

Response: We thank the reviewer for recognizing the importance of a terminology consistency check. We thoroughly reviewed the entire text to ensure consistent terminology across the text, tables, and figures.

Reviewer: 2

Comments to the Author
The revision was responsive to the comments, and I think the revised draft is much improved.

Response: We sincerely appreciate the reviewer's positive feedback on our previous revisions. Thank you for your kind words.

References

Keating, G. D., & Jegerski, J. (2015). Experimental designs in sentence processing research: A methodological review and user's guide. *Studies in Second Language Acquisition*, *37*(1), 1-32. https://doi.org/10.1017/S0272263114000187

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Meisner, G. B. (2018). The golden ratio – The divine beauty of mathematics. Race Point Publishing.

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The Role of Architectural Boundaries in Shaping Visitors' Aesthetic Experiences in Virtual Exhibition Environments

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Other Information

Word count: 10080; Number of Figures: 6; Number of Tables: 6

Abstract

Research into exhibition spaces increasingly focuses on visitors' aesthetic experiences. This study explores how the architectural boundaries of virtual exhibition environments influence visitors' aesthetic experiences. Twelve virtual exhibition environments were developed in which the architectural boundaries defining the exhibition space, such as ceiling height and curvature, were manipulated through virtual reality. Participants assessed their aesthetic experiences based on three dimensions: familiarity, excitement, and fascination. Participants' emotional states, education type, and presence level were also measured. The findings indicated that curvature negatively impacts familiarity, whereas ceiling height and curvature positively correlate with excitement and fascination. This study is a pioneering effort to link aesthetic experience dimensions with architectural boundaries in virtual exhibition environments, enhancing our understanding of how visitors perceive these virtual exhibition environments differently.

Keywords

Aesthetic experience; Architectural boundaries; Ceiling height; Curvature; Virtual exhibition environments

Introduction

Museums or exhibition spaces provide an ideal setting for visitors to engage and experience various art forms and their environments. Since Fechner's (1876) pioneer empirical study of art and aesthetics, research has expanded to include museums and exhibition spaces as important contexts for understanding the meaning of objects classified as art and the significant effects of aesthetic experiences. These experiences are often among the most memorable and personally meaningful ones (Carr, 2003; Pelowski & Akiba, 2011; Smith & Smith, 2001; Smith & Wolf, 1996).

Aesthetic experience is distinct from everyday experience; it represents a unique state of mind that is qualitatively different. Cupchik and Winston (1996) defined aesthetic experience as the psychological process in which attention is focused on a single object while all other objects, events, and daily anxieties are ignored. Later, Locher et al. (2010) and Schubert et al. (2016) expanded on this by describing aesthetic experience as a combination of cognitive and emotional processes evoked by the characteristics of a designed space, which ultimately lead to action-driven behavior.

Currently, museums and exhibition designers aim to create environments that offer high aesthetic experiences. Understanding and mapping the factors within exhibition spaces influencing these experiences is crucial to enhancing visitors' aesthetic experiences. Bitgood and Patterson (1987) categorized the parameters that may affect visitor behavior in exhibition spaces into three factors: the characteristics of visitors, the exhibits, and the exhibition spaces themselves. The interaction of these factors determines the unique patterns of visitors' aesthetic experiences.

The aesthetic experience of users is a key focus of empirical studies in interior architecture. One important reason for studying museums and the architecture of exhibition space is that artifacts and collections can appear, feel, and hold different meanings depending on the context in which they are placed (Becker, 2008; Bourriaud, 2002; Wilson & Hale, 1993). While previous research has looked at how properties of exhibits and visitor characteristics influence visitors' aesthetic experiences, few have looked at the impact of the architectural space itself. This study highlights the importance of this relationship and how it can be improved to enhance visitors' aesthetic experiences. Also, it manipulates various variables in a virtual setting to investigate their direct effects on these experiences. The contribution of our study lies in its focus on architectural space as a factor affecting aesthetic experience.

Factors Influencing Aesthetic Experience in Exhibition Spaces

The design of exhibition spaces has a major influence on shaping the aesthetic experience in visitors, and physical space at a museum or exhibition has long been a focal aspect of the entire visit experience (Falk & Dierking, 2000). To understand how visitors interact with their environment, the field of architecture has evolved to include interdisciplinary research that extends beyond traditional scientific and architectural domains (Lee et al., 2022). By understanding the character of this interaction, the study could inform and enhance the design of future virtual exhibitions and visitors' aesthetic experiences. Based on such insights, this study examines how specific architectural boundaries in exhibition spaces affect visitors' aesthetic experiences.

Spatial features significantly influence visitors' attention, behavior, emotions, and memory (Bitgood, 2010). Various spatial features of a building, such as the locations of exits and entrances, temperature, soundscape, and lighting, can impact visitors' attention, the efficiency of their movement in space, and the time spent there (Bitgood, 2010). While the environmental features such as temperature, soundscape, and lighting in exhibition spaces have defined standard values, other spatial features are open to debate.

In a recent study, Elver Boz et al. (2024) suggested that the physical properties of the interiors affect the aesthetic experience it elicits. Visitors' aesthetic experiences in an exhibition space depend on several properties of interior design. They stated that important properties include the space's boundaries, size, lighting, and layout. Although exhibition spaces are often analyzed in terms of size, lighting, and layout with respect to aesthetic experience, the architectural boundaries that define these spaces are less frequently studied.

Architectural boundaries are the physical limits that define and enclose a space. Previous research has shown that certain characteristics of architectural boundaries, such as ceiling height, curvature, and the level of enclosure in exhibition spaces, can influence emotional and behavioral responses to the environment (Coburn et al., 2020; Vartanian et al., 2013; Vartanian et al., 2015). In this study, we excluded the aspect of enclosure since openings are typically not included in exhibition spaces to minimize the risk of damage to exhibits from direct sunlight. Instead, we focused on the characteristics of ceiling height and curvature in the architectural boundaries.

Ceiling Heights of Interior Spaces

Past research has continued to emphasize the ceiling height variable as one of the most influential factors in the aesthetic experiences of the built environment. For example, Vartanian et al. (2015) have explored the consequences of ceiling height and perceived enclosure on interior space aesthetic judgments and approach-avoidance decisions. Participants evaluated images of different interior spaces. The results of this study demonstrated that ceiling height and type are some of the most critical factors in interior space design. Rooms with higher ceilings were described as aesthetically pleasing.

Later, Cha et al. (2019) examined the relationship between ceiling height and emotional responses in virtual office environments. To assess emotional responses, the study manipulated ceiling height from 2.6 m to 3.2 m and environment type as open versus closed. Findings showed that higher ceiling height levels in open environments are associated with more positive emotional responses, highlighting the psychological benefits of perceived vertical spaciousness in workspace environments.

Another study by Coburn et al. (2020) investigated the interactions of ceiling height, curvature, and enclosure in physical exhibition spaces regarding their effects on aesthetic experience. Through a slideshow of images, participants experienced different environmental conditions featuring either low or high ceiling height and square or round curvature. The result was that high ceilings, particularly in a curvilinear environment, enhance aesthetic experiences. Their findings indicated how architectural elements can influence visual and emotional engagement. Gath-Morad et al. (2024) explored the impact of typology, contour, and partition height on cognitive and aesthetic appraisal in workspace environments. Participants rated images of a three-dimensional model where ceiling height varied from low to high, and curvature was angular to curved. However, their study revealed that ceiling height did not significantly affect the aesthetic appraisal of the participants.

Also, Chen et al. (2024) explored the effect of size and ceiling height on preference levels in virtual indoor environments. Three ceiling height levels were tested as 2 m, 4 m, and 8 m. According to their results, increasing height did not consistently suggest increasing preference levels. This contradiction emphasizes the need for further research on the influence of ceiling height in shaping the aesthetic experience.

Curvature of Space Boundaries

Earlier research had established that rectilinear shapes and patterns aroused more unfavorable feelings than curvilinear forms (Lundholm, 1921; Poffenberger & Barrows, 1924). These effects are also generalized to interior spaces (Van Oel & van den Berkhof, 2013). A rationale for why individuals favor curved forms over rectilinear ones in interior spaces is because they are more abundant in nature and feel more natural (Coburn et al., 2019; Kellert, 2003; Salingaros, 2015). In support of this hypothesis, for example, the density of curved edges has been positively related to perceptions of naturalness and aesthetic preference for images of outdoor spaces, while that of straight edges has been negatively related to perceptions of naturalness and preference for such spaces (Ibarra et al., 2017; Kardan et al., 2015).

Curvature has raised the interest of aesthetics and architectural scholars since it relates to human perception and emotion. In general, curved boundaries, or curvilinear forms, are characterized by smooth transitions between contours, such as walls, rather than sudden changes within an interior space (Elver, 2018). Hobbs et al. (2015) investigated participant's preferences among four geometries of interior spaces, including curved, rectilinear, angled, and mixed geometries in VR. The participants also preferred curved boundaries and rated the spaces pleasant, relaxing, and friendly. Similarly, several other studies showed that individuals preferred curved shapes over straight ones as more pleasant and safe (Bar & Neta, 2006; Silvia & Barona, 2009). This finding aligns with Pearson (2001), who suggested that curves are more coherent to the human mind and are associated with the body.

Results obtained by Dazkir and Read (2012) indicated that the curvilinear interior space possessed more intense pleasures and a higher degree of approach than was observed for the angular interior space. Individuals who described the forms as curved revealed the environments designed by these forms as more harmonious and emotionally pleasant, thus confirming results from Leder and Carbon's (2005) work where the curvilinear shapes had proven positive effects within various contexts. Individuals have always preferred curved boundaries in architectural spaces over other boundaries (Van Oel & van den Berkhof, 2013). Furthermore, Coburn et al. (2020) investigated the aesthetic responses to ceiling height, curvature, and enclosure in several interior spaces. They found evidence of a higher aesthetic experience with higher curved spaces, though other researchers have encountered that aesthetic experiences are moderated by context (Chuquichambi et al., 2022; Dai et al., 2022). In the study by Gath-Morad et al. (2024), they also showed that curved spaces significantly influenced the aesthetic appraisal of the participants.

Emotional State and Aesthetic Experience

Thompson (1990) stated that subjective choices and personal traits greatly influence an individual's behavior in a free-choice situation. Koran et al. (1988) described these varying personal traits as aptitudes that either support or hinder the desired visitor outcomes. In addition, a visitor's emotional state significantly predicts their engagement in the museum, both physically and intellectually. The physical properties of an environment can evoke emotions related to the environment. Therefore, several studies have assessed the relationship between individuals and the environment regarding emotional responses (Franz et al., 2005; Kaltcheva & Weitz, 2006; Mehrabian & Russell, 1974; Russell & Mehrabian, 1977; Russell & Pratt, 1980).

Mehrabian and Russell (1974) proposed that the physical environment causes users to emotionally elicit reactions in terms of pleasure and arousal that influence their behavioral intentions. Pleasure is the degree to which one feels happy or pleasant, while arousal is the degree to which one feels excited and stimulated (Mehrabian & Russell, 1974). Russell and Pratt (1980) also emphasized that recognizing these emotional responses is essential for understanding an individual's perceptions of a particular space. Therefore, this study aimed to measure visitors' emotional state as a related variable that affects their aesthetic experience in an exhibition space.

There are limited studies in the literature that compare the aesthetic experiences of design-educated and non-design-educated individuals. Diker and Demirkan (2023) examined environments with low (220 cm) and high (260 cm) ceiling height levels in virtual environments, contrasting these with a standard ceiling height of 240 cm. The aesthetic experience scale by Elver Boz et al. (2024) was used while assessing the virtual environments and comparing design-educated and non-design-educated participants on the dimensions of familiarity, excitement, and fascination. Their findings revealed a significant effect of design education only on the fascination dimension in high-ceiling environments.

Pillai and McFall (2015) stated that aesthetics is crucial in shaping engaging and meaningful user experiences by eliciting specific emotions and responses. Also, Catya et al. (2023) emphasized that designers interact with the world through aesthetics, interpreting and transforming it into tangible, meaningful creations. Considering aesthetics enables designers to empathize with the intended audience and comprehend design decisions' emotional and psychological effects. Therefore, this study investigates the relationship between visitors' emotional states and aesthetic experiences in virtual exhibition environments (VEEs).

Virtual Reality as a Tool of Aesthetic Experience

Digital technology is a successful technique for optimizing, integrating, and supporting construction processes in architecture (Eastman et al., 2008; Paes, 2019). Virtual reality (VR) is an important research support tool in many architectural domains that focus on spatial cognition, perception, and behavior (Brade et al., 2017; De Kort et al., 2003; Higuera-Trujillo et al., 2017; Kuliga et al., 2015; Paes et al., 2017, 2021). It has many advantages compared to real environments. First, VR enables systematic environmental modifications that are impractical in real-world settings. As Kuliga et al. (2015) observed, while it would be difficult to significantly alter the spatial configuration of a physical structure, using VR enables the assessment of the effect of multiple designs on user behavior without disrupting actual building use. Importantly, VR enables researchers to focus on the effects of some architectural elements while controlling others. This approach allows for the control of various elements within interior spaces, including layout and size, exhibited arts, light, and materials, while also facilitating the examination of the effects of architectural variables being studied.

VR technologies facilitate virtual immersion in architectural environments. VR simulations have gained popularity in design review owing to their advantages in representing scale, depth, and volume (Paes et al., 2021). The delineation of an architectural immersive environment parallels that of a visual living space. Consequently, it allows an individual to navigate the space as they are in the actual location. Establishing boundaries within that space enhances the viewer's perception of immersion in the environment, enriching the overall experience.

The psychological state of presence is achieved through a strong sense of physical immersion. A digital exhibition, designed as a three-dimensional representation of a physical museum, must effectively convey a strong sense of presence within the virtual environment, which is known as perceived presence (Sylaiou et al., 2010). User responses such as attention and involvement are directly linked to this perceived presence (Lessiter et al., 2001). Moreover, there is a strong correlation between perceived presence and enjoyment (Sylaiou et al., 2010). This sense of presence is measured to assess how deeply visitors are engaged with the VEE (Lee & Youn, 2025).

A recent study by Cheng et al. (2024) explored the influence of augmented reality quality on various aspects of immersion, as well as the implications of these aspects for perceived usefulness and ease of use. The findings demonstrated that higher-quality augmented reality enhances immersion, and an aesthetically pleasing experience can further enhance the immersive experience in an augmented reality setting. Consequently, the presence level in a VEE is examined as a variable that may impact the visitor's aesthetic experience.

VR goes beyond just reproducing originals; it provides access to approaching spaces and experiences that are not accessible, thus facilitating the knowledge of new dimensions formed by the artists, leading to unique, immersive environments that present aesthetic experiences unlike the originals (Shehade & Stylianou-Lambert, 2020). However, most existing research on VR's impact on aesthetic experiences indicates that further investigation is necessary to understand better how these experiences are formed and what factors influence them (Skov & Nadal, 2021).

VEE Design Process

This study is conducted in VR, as this allows for the controlling and manipulation of several variables that are difficult to change in the physical exhibition space. This study has three ceiling height levels (minimum, moderate, and high) and four curvature levels (no-curve, low, moderate, and high). Since guidelines and standards on museums and exhibition spaces do not indicate any definite range for the ceiling height levels in exhibition space, the chosen values reveal the general practice provided in common architectural standards (Smithsonian Institution, 2002). Moreover, this study did not consider the heights of any ceiling lower than the minimum standard of an exhibition space. The lowest ceiling height referred to a minimum standard ceiling height required for exhibition spaces by space regulation of the Ministry of Culture and Tourism of XXX (2005) as 3 m. This investigation expanded to include 3.6 m and 4.6 m to examine the effects of increased ceiling height. This study manipulates ceiling height in three ways: ceilings with a minimum of 3 m height, with a moderate 3.6 m height, and a high level of 4.6 m of ceiling height.

The radius of curvature in this experiment was determined using the Golden Ratio, a mathematical constant frequently used in various design contexts to create aesthetically pleasing and balanced compositions (Kurniawan, 2025). This ratio often appears in nature; a well-known example is the spirals of seashells, as well as in the architecture of historic structures (Thapa & Thapa, 2018). The Golden Ratio has received significant attention in design theories because it is believed to produce beautiful and balanced proportions (Meisner, 2018).

In this study, four curvature levels are defined: no-curve, low curve, moderate curve, and high curve, following the radii of the circles tangent to our space created by the Golden Ratio. The radii for each level are as follows: R= 1.5 m for low curve, R= 2.5 m for moderate curve, and R= 4 m for high curve. These correspond to arc lengths of 2.34 m, 3.93 m, and 6.28 mas well as curvature (κ) of 0.67 m^{-1}, 0.40 m^{-1}, and 0.25 m^{-1}, respectively (Figure 1).

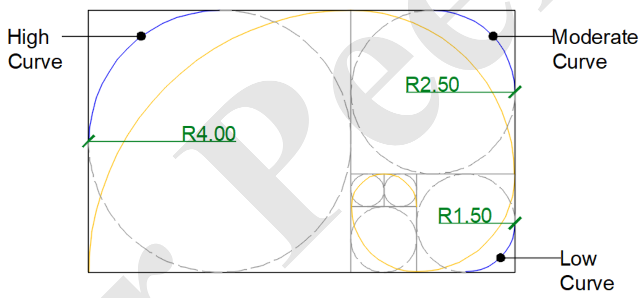

Figure 1. A representation of the curves created by the Golden Ratio of the virtual exhibition space (radii are given in meters).

The created space had a rectangular layout since previous studies demonstrated that people found spaces with rectangular forms larger and more spacious than the ones with square forms, although both spaces were equal in size (Bokharaei & Nasar, 2016; Franz, 2006; Franz et al., 2005;

Garling, 1970a; 1970b; Stamps, 2007; 2009). The minimum area of exhibition space, according to the Ministry of Culture and Tourism of XXX (2005), is 100 m2. Following this and the Golden Ratio, the dimensions of our space were 8 m wide by 13 m long, with an area of 104 square meters. Then, a virtual space was created using Autocad and 3ds Max Software. The studied architectural boundaries were counterbalanced, and the design of 12 VEEs was generated based on the discussed literature.

The exhibits used in this study were abstract paintings. To control the influence of exhibits on visitors, we transformed the original paintings into a black-and-white color scheme, and we designed all the exhibits in square shapes, as the proportion of paintings, individual color tastes, and preferences may act as confounding variables. The scale of the pieces was 100x100 cm. The pieces were mounted to be visible at a comfortable viewing height from the floor, and the midpoint of the exhibit stood at the eye level average height of 155 cm (Smithsonian Institution, 2002). The exhibits were spaced evenly apart, with less space than that left on either side at the ends of a row, as recommended by Read (2013). Also, according to Read (2013), exhibits should usually be uniformly and equally lit without hot spots, reflected glare, or shadows. Thus, the lighting was nondirectional in the VEEs because it evenly illuminated the space in all directions without glare and shadows. For the curved VEEs, the exhibits were placed according to the curvature level of the wall, following the same degree of the corresponding curve, matching the angle of the floor, thus emphasizing the curvature of the space.

The VEEs in this study were made out of obstacle-free exhibition space to maintain constant visibility and proximity among all exhibits using the same initial size, having a ground-floor area of 104 m². As curvature level increased across environments, the ground floor area correspondingly decreased. The investigated architectural boundaries varied interchangeably between the environments (ceiling height and curvature), as seen in Figure 2.

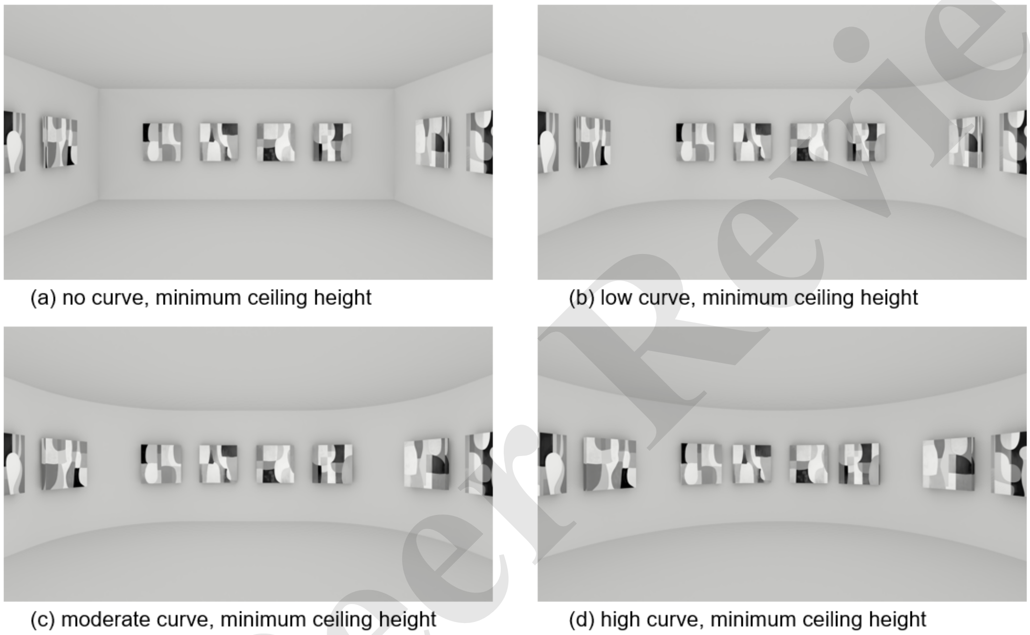

Figure 2. Visualizations of the VEEs under the category minimum ceiling height with four different curvature levels.
Note. VEE= Virtual exhibition environment

Method

Hypotheses

Four hypotheses were developed for this study based on the previous literature review:

- $H1_a$: Exhibition spaces with higher ceiling height levels will positively stimulate familiarity.

- $H1_b$: Exhibition spaces with higher curvature levels will positively stimulate familiarity.
- $H1_c$: Exhibition spaces with higher ceiling height levels will positively stimulate excitement.
- $H1_d$: Exhibition spaces with higher curvature levels will positively stimulate excitement.
- $H1_e$: Exhibition spaces with higher ceiling height levels will positively stimulate fascination.
- $H1_f$: Exhibition spaces with higher curvature levels will positively stimulate fascination.
- H2: Participants' emotional state will influence the aesthetic experience.
- H3: The education type of the participants will influence the aesthetic experience.
- H4: Participants' presence level will influence the aesthetic experience.

Participants

The experiment took place in the VR lab room at XXX University, dedicated to VR research purposes. The students were informed about the experiment by university mailing list and department announcements and signed up for participation of their own free will. Based on a priori G* Power F-test analysis for ANOVA: Repeated measures, within factors, were conducted using computed effect size (f) 0.25, alpha=0.05, and a power level of 0.95 (Cohen, 1988), indicating that a total sample size of 43 participants would be required. In this study, a total of 55 students at XXX University were recruited using convenience sampling method. Later, two participants were excluded from the study because of an unsuccessful VR experience; as they reported low levels of presence. Each participant experienced all 12 VEEs. However, the order sequence of the 12 VEEs was unique and randomized to each participant; this was made possible by Python coding software that generated 55 randomly ordered 12 VEEs. Of the participants, 37 were females, 15 were males, and one identified as other. Participants ranged from 19 to 35 years (M= 23.36 years; SD= 4.69 years). Most participants came from undergraduate programs, 44 in total, while only nine were from graduate programs. Also, 28 participants were design-educated, and 25 were non-design-educated. Regarding interest in visual art, most participants (39 out of 53) were highly interested in the visual arts. Most participants visited exhibition spaces at a low to medium rate, and most were unfamiliar with VR tools.

The Procedure and Instruments

The experiment procedure is described step-by-step, showing the relative instruments, as seen in Figure 3. For this study, we received approval from the ethics committee at XXX University (No: 2024_03_12_01). Each participant distributed and signed a consent form covering information about the purpose, procedure, benefits, and all confidentiality issues related to this experiment (Step 1). Before the experiment, all participants were asked to complete a demographic questionnaire covering gender, age, degree, and education (Step 2). It also included measures on the interest level in visual art, how often the respondent visited any art exhibitions, and previous experiences with VR (anchored by 4 levels, see Appendix A). These variables only were measured once, before the experiment. Afterward, in order to measure participants' emotional state before the experiment, participants were asked to complete the Mehrabian and Russell's (1974) model, adapted from Bradley and Lang's (1994) covering pleasure and arousal, each comprising six bipolar adjective pairs (Step 3). The adjectives were rated on a five-point semantic differential scale (-2, -1, 0= neutral, 1, 2). The emotional state was measured once more after experiencing all 12 VEEs.

In preparation for the VEEs, a training phase in which participants could familiarize themselves with the VR tool PICO Neo 3 Pro took place (Step 4). The VR tool used for this experiment was a high-tech visual represented by a wireless head-mounted display and two wireless controllers. It is an immersive VR tool that allows participants to feel present in the VR space and move around in virtual spaces freely. Twelve 360-degree VEEs were designed using the software 3ds Max. Each participant went through all 12 VEEs in a different order. After the training phase, the participants began the experiment, and they could move from one environment to another using the thumbstick on the controllers; a black screen appeared before each new VEE, serving as a visual separator (Step 5). Participants viewed the VEEs through 360-degree panoramas, which provided full rotational freedom but no translational movement.

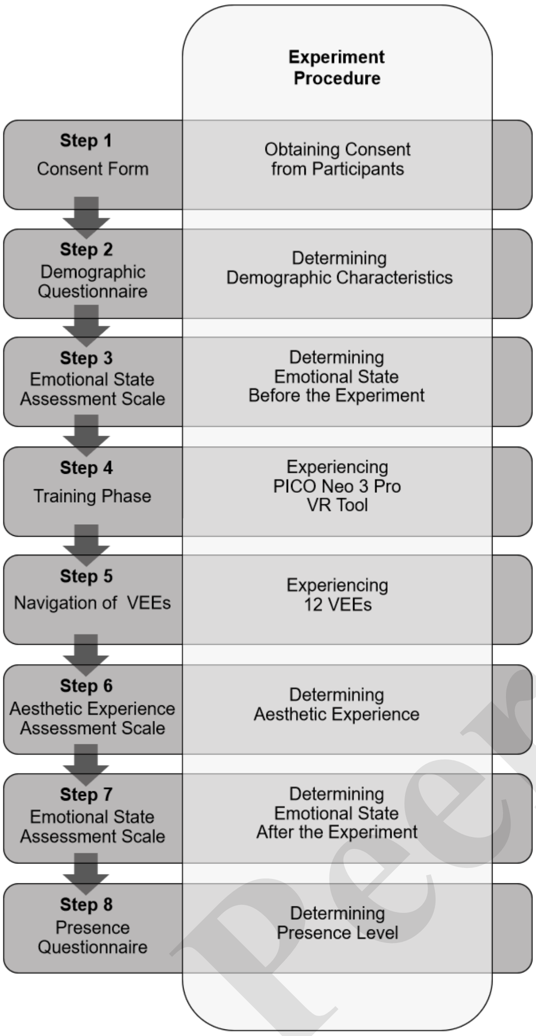

Figure 3. The procedure and instruments of the experiment.
Note: VEE= virtual exhibition environment, VR= Virtual Reality

After navigating through each environment, participants were asked to assess their aesthetic experience using the aesthetic experience scale by Elver Boz et al. (2024) on a 7-point Likert scale (1= 'not familiar/not excited/not fascinated', 4= 'neutral', 7= 'familiar/excited/fascinated'), which determines three key dimensions related to aesthetic experience: familiarity, excitement, and fascination (Step 6). Familiarity was defined 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" (p. 1052); excitement is "how excited, frenzied, jittery or contended one feels in an environment" (p. 1052); fascination is "how mysterious or complex an environment looks or how stimulated one feels in that environment" (p. 1052). All participants were equally informed about what aesthetic experience means and the definitions for the measured dimensions. Also, all participants evaluated aesthetic experience within the virtual setting. VR testing has a distinct advantage over immersion-level testing in removing interrupts within the simulation. At the end of the experiment, participants were asked to re-evaluate their emotional state (Step 7). The investigator provided definitions of each item to the participants. The rating was given orally while the participants were still in the VEE, and the investigator took notes. Each aesthetic experience dimension was assessed in the VEE, resulting in a total of 12 evaluations for each participant.

After that, the participants were asked to fill out the presence questionnaire to assess the presence level they experienced in the VEEs (Step 8). This was measured once at the end of the 12 VEEs. The presence questionnaire used in this study is adapted from the study of Paes (2019), which consisted of 11 items in total. Items of the presence questionnaire were evaluated on a 7-point Likert scale (see Appendix A for the items and corresponding anchors). The items aimed at assessing the extent to which participants felt present and engaged in the VEEs. It included questions about the extent of their involvement, the time factor during the experiment, the control they felt over their actions, awareness of their physical body in the experienced space, and whether they had any motion sickness during the experiment. The details of the items, response options, and scale anchors utilized in the instruments are provided in Appendix A.

Results

All quantitative data were analyzed using the Statistical Package for Social Sciences (SPSS, version 21) software. The analyses were conducted using the original scale of the variables, with no trichotomization or categorical recoding applied in any of the analyses.

Architectural Boundaries and Aesthetic Experience Analysis

For Cronbach's alpha of the overall aesthetic experience scale, 0.886 represents high reliability. Also, regarding each dimension: 0.857 for the familiarity dimension, 0.820 for the excitement dimension, and 0.779 for the fascination dimension.

We calculated the mean scores given to each dimension across all 12 VEEs. The results demonstrated that the highest familiarity level was perceived repeatedly in no-curve VEEs with different ceiling height levels. The highest familiarity ratings were observed in no-curve VEEs with the following ceiling height levels: Moderate height-no-curve VEE (M=4.68, SD=1.85), minimum height-no-curve VEE (M=4.60, SD=1.85), and high height-no-curve VEE (M=4.30, SD=1.46), respectively. On the excitement dimension, the mean scores demonstrated that the highest excitement levels were persistent and perceived in high ceiling height VEEs for all curvature levels; high height-high curve VEE (M=4.96, SD=1.63), high height-no-curve VEE (M=4.23, SD=1.58), high height-low curve VEE (M=4.21, SD=1.53), and high height-moderate curve VEE (M=4.13, SD=1.33). On the fascination dimension, the results of mean scores showed that the highest fascination level was perceived in high ceiling height VEEs for all curvature levels: high height-high curve VEE (M=4.79, SD=1.51), high height-low curve VEE (M=4.42, SD=1.55), high height-no-curve VEE (M=4.30, SD=1.56), and high height-moderate curve VEE (M=4.28, SD=1.36) (Figure 4).

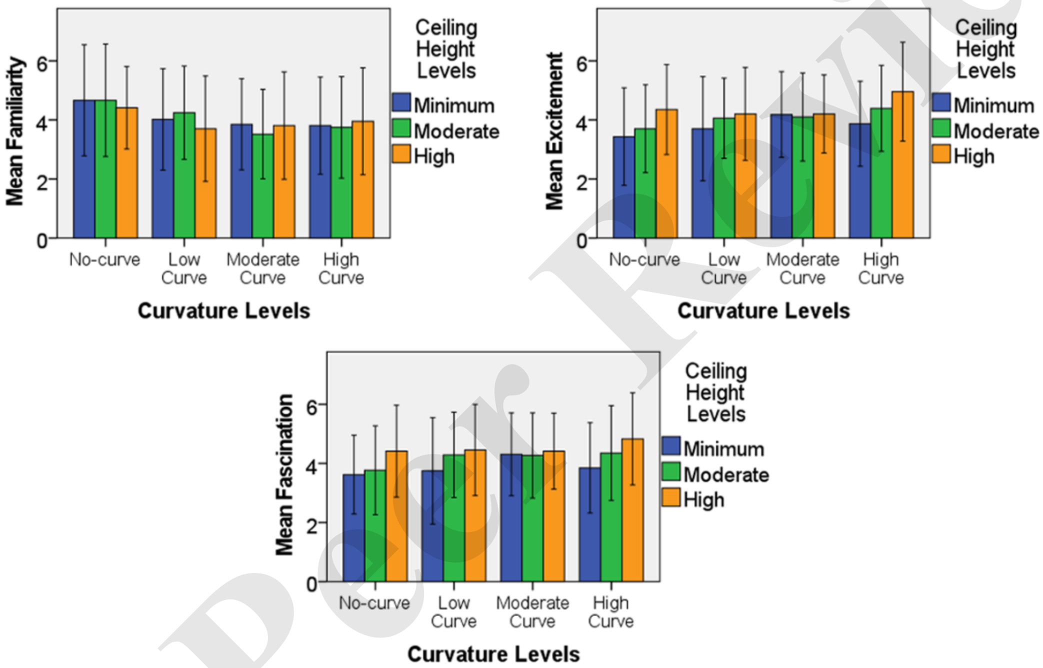

Figure 4. Mean familiarity, excitement, and fascination scores by ceiling height levels (minimum, moderate, high) and curvature levels (no-curve, low curve, moderate curve, high curve) (clustered by curvature). Error bars represent ±1 standard deviation from the mean. *Note.* N= 53

Furthermore, a repeated measures ANOVA was conducted, along with the Mauchly's sphericity tests for all repeated-measures factors and interactions. Greenhouse–Geisser corrections were applied where the assumption of sphericity was violated; adjusted degrees of freedom and p-values were reported accordingly.

In the familiarity dimension, the results of Mauchly's sphericity test indicated that the assumption of sphericity was met for ceiling height (χ^2 (2) = 1.60, p = 0.45). However, the assumption was violated for curvature (χ^2 (5) = 29.83, $p < 0.001$) and for the interaction between ceiling height and curvature (χ^2 (20) = 37.05, p = 0.012); Therefore, Greenhouse–Geisser corrections were applied to the curvature analyses ($\varepsilon = 0.73$) and interaction effects ($\varepsilon = 0.80$). Huynh–Feldt corrections yielded comparable results. The results demonstrated a significant effect of curvature on the familiarity dimension ($F_{(2.17,113.05)}$ =7.435, p= 0.001, η_p^2=0.125), with a large effect size, while no significant effect was demonstrated for the ceiling height and on the interaction of ceiling height and curvature (Figure 5). The Greenhouse–Geisser corrections did not change the significance of the main effects of curvature on familiarity.

Furthermore, trend analysis revealed a significant linear trend for the effect of curvature on familiarity (p = 0.001, η_p^2=0.206) with a large effect size and a significant quadratic trend for the effect of curvature on familiarity (p = 0.024, η_p^2=0.095) with a medium effect size. The linear trend indicated that familiarity decreased with increasing curvature. However, the quadratic trend suggested that the decrease in familiarity is not uniform. In addition, pairwise comparisons demonstrated a significant difference in familiarity scores between the curvature levels with no-curve and moderate curve with p= 0.004 and no-curve and high curve with p= 0.011, with Bonferroni correction applied.

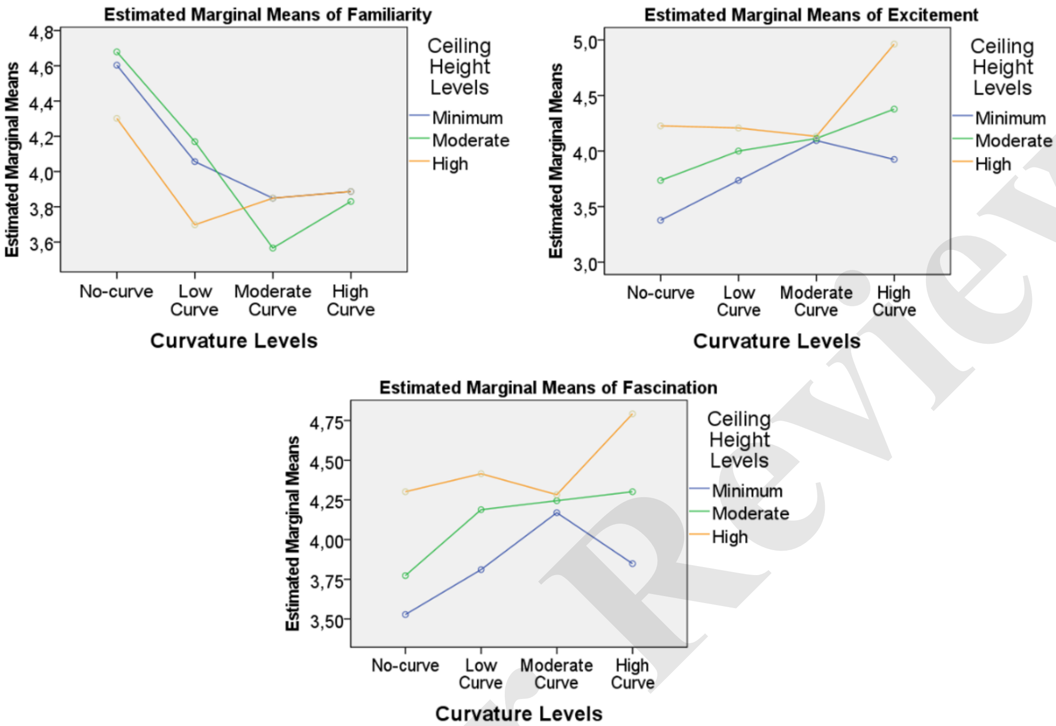

Figure 5. The relationship between ceiling height levels (minimum, moderate, high), curvature levels (no-curve, low curve, moderate curve, high curve), familiarity, excitement, and fascination.
Note. N= 53

In the excitement dimension, the Mauchly's sphericity test indicated that the assumption of sphericity was met in the following cases: ceiling height (χ^2 (2) = 5.31, p = 0.07), curvature (χ^2 (5) = 10.86, p = 0.054), and the interaction between ceiling height and curvature (χ^2 (20) = 26.17, p = 0.16). As a result, no corrections were necessary. Furthermore, repeated measures ANOVA results demonstrated a significant effect of ceiling height on excitement (F (2,104) =8.709, p=0.001, η_p^2=0.143) with a large effect size. In addition, a significant effect of curvature on the excitement dimension was also shown (F (3,156) =7.079, p<0.001, η_p^2=0.120) with a large effect size. The results of the interaction of ceiling height and curvature demonstrated no significant effect on the excitement dimension (see Figure 5).

Trend analysis revealed a significant linear trend for the effect of ceiling height on excitement ($p = 0.001$, $\eta_p^2 = 0.208$) with a large effect size and a significant linear trend for the effect of curvature on excitement ($p < 0.001$, $\eta_p^2 = 0.232$) with a large effect size indicating that excitement increased with increasing ceiling height and curvature. Pairwise comparisons demonstrated a significant difference in excitement scores between ceiling height levels, minimum and high, with $p = 0.002$. In contrast, no significant difference was demonstrated between minimum and moderate levels and moderate and high levels. Pairwise comparisons demonstrated a significant difference in excitement scores between curvature levels, no- and high curves with $p = 0.001$, and low and high curves with $p = 0.021$, with Bonferroni correction applied.

In the fascination dimension, the Mauchly's sphericity test indicated that the assumption of sphericity was met for ceiling height (χ^2 (2) = 4.72, $p = 0.09$), curvature (χ^2 (5) = 8.54, $p = 0.13$), and the interaction between ceiling height and curvature (χ^2 (20) = 26.29, $p = 0.16$). As a result, no corrections were necessary. Moreover, repeated measures ANOVA results demonstrated a significant effect of ceiling height on fascination (F (2,104) =9.057, $p < 0.001$, $\eta_p^2 = 0.148$) with a large effect size. In addition, a significant effect was found for the curvature (F (3,156) =2.885 $p = 0.043$, $\eta_p^2 = 0.053$) with a small effect size. However, the results of the interaction of ceiling height and curvature demonstrated no significant effect on fascination (see Figure 5). Trend analysis revealed a significant linear trend for the effect of ceiling height on fascination ($p < 0.001$, $\eta_p^2 = 0.224$) and a significant linear trend for the effect of curvature on fascination

(p=0.015, η_p^2=0.108), indicating that fascination increased with increasing ceiling height and curvature. Pairwise comparisons demonstrated a significant difference in fascination scores between minimum and high ceiling height levels with p= 0.001 simultaneously, with Bonferroni correction applied. Table 1 provides details on the repeated-measures ANOVA results for the effect of architectural boundaries on aesthetic experience dimensions.

Table 1. Repeated-measures ANOVA results for aesthetic experience dimensions.

		(df1, df2)	**F**	**p**	η_p^2	**95% CI for** η_p^2
Familiarity	Main effect of ceiling height	(2, 104)	0.960	0.386	0.018	[0.000, 0.066]
	Main effect of curvature	(3, 156)	7.435	*0.001	0.125	[0.027, 0.238]
	Interaction of ceiling height & curvature	(6, 312)	0.965	0.438	0.018	[0.000, 0.052]
Excitement	Main effect of ceiling height	(2, 104)	8.709	*0.001	0.143	[0.049, 0.245]
	Main effect of curvature	(3, 156)	7.079	*<0.001	0.120	[0.040, 0.203]
	Interaction of ceiling height & curvature	(6, 312)	1.757	0.108	0.033	[0.000, 0.075]
Fascination	Main effect of ceiling height	(2, 104)	9.057	*<0.001	0.148	[0.052, 0.252]
	Main effect of curvature	(3, 156)	2.885	*0.043	0.053	[0.001, 0.113]
	Interaction of ceiling height & curvature	(6, 312)	1.250	0.281	0.023	[0.000, 0.062]

Note. η_p^2 = partial eta squared, CI= confidence intervals, 95% confidence intervals are provided for η_p^2, $^*p< 0.05$

In the design of the VEE, we observed that as the curvature level increased, both the floor area and wall length of the exhibition space decreased. To further explore whether these spatial factors influence the effect of curvature, we conducted a generalized linear model analysis, using floor area and wall length as covariates. The results showed that when floor area was included as a covariate, curvature had a significant effect on familiarity (χ^2 (2) = 11.09, p= 0.004). However, when wall length was included as a covariate, the effect of curvature was reduced. Notably, the parameter estimates indicated a significant difference for the no-curve VEE compared to the other curvature levels (B= 0.704, β= 0.17, p< 0.001). These results indicated that the effect on familiarity arises from curvature, rather than from variations in floor area or wall length.

Although controlling for floor area and wall length reduced the overall effect of curvature on excitement and fascination (χ^2 (2) = 0.63, p= 0.73; χ^2 (2) = 0.18, p= 0.91, respectively), the parameter estimates indicated a significant difference among curvature levels for no-curve and low curve VEEs (B= -0.629, β= -0.18, p< 0.001; B= -0.428, β= -0.12, p= 0.012, respectively). Similarly, the effect of curvature on the fascination dimension was also reduced (χ^2 (2) = 2.50, p= 0.29; χ^2 (2) = 0.60, p= 0.74, respectively). However, the parameter estimates indicated a significant difference for the no-curve VEE compared to the other curvature levels (B= -0.459, β= -0.13, p= 0.007). This suggests that curvature has distinct effects on excitement and fascination ratings, independent of changes in spaciousness. While including spatial covariates decreased the overall significance of curvature in some cases, important parameter estimates (specifically between no-curve and low curve) remained significant across familiarity, excitement, and fascination dimensions. These findings indicate that curvature influences aesthetic experience beyond merely affecting spaciousness.

Emotional State and Aesthetic Experience Analysis

The Cronbach's alpha for the overall scale was 0.698 for items before the experiment and 0.852 for items after the experiment, which showed a strong reliability of the emotional state scale. Furthermore, the pleasure and arousal mean scores of the participants, recorded before (B) and after (A) the experiment, demonstrated an increase in the pleasure and arousal scores after the experiment (Pleasure; M_B= 3.47, SD_B= 0.66; M_A= 3.74, SD_A= 0.82 and Arousal; M_B= 3.07, SD_B= 0.57; M_A= 3.29, SD_A= 0.66), as seen in Figure 6. Furthermore, a paired samples t-test was conducted to investigate the pleasure and arousal mean scores before and after the experiment. The results demonstrated a significant difference in the pleasure mean scores (t=3.44; df= 52; p=0.001) with Cohen's d= 0.374 for pleasure, which indicates a small to medium effect size, and a significant difference in the arousal mean scores (t=2.34; df=52; p=0.023) with Cohen's d= 0.360 for arousal, indicating a small to medium effect size.

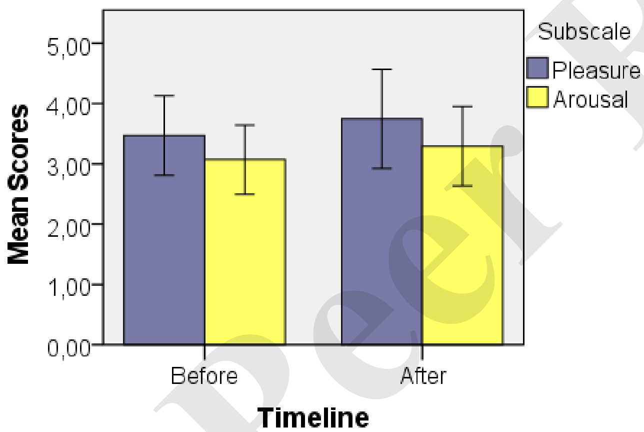

Figure 6. Mean scores for pleasure and arousal subscales before and after the experiment. The purple bars represent pleasure and yellow bars represent arousal. Error bars correspond to ±1 standard deviation.
Note. N= 53

Furthermore, the Pearson correlation coefficient (r) was calculated to determine the relationship between before and after pleasure and arousal subscales and aesthetic experience dimensions (Table 2). Results demonstrated no correlation between the previous variables. Moreover, repeated measures ANOVA results demonstrated that familiarity, excitement, and fascination did not affect the relationship between before and after pleasure and arousal subscales.

Table 2. Correlation among participants' pleasure and arousal subscales before and after the experiment and aesthetic experience dimensions.

	Pleasure Before	Pleasure After	Arousal Before	Arousal After	Familiarity	Excitement	Fascination
Pleasure Before	–						
Pleasure After	0.707**	–					
Arousal Before	0.219	0.135	–				
Arousal After	0.201	0.460**	0.390**	–			
Familiarity	0.040	-0.062	-0.111	-0.102	–		
Excitement	0.065	0.119	0.165	0.215	0.218	–	
Fascination	0.093	0.074	0.023	0.127	0.197	0.892**	–

** Correlation is significant at the 0.01 level (2-tailed)

Education type with exhibition-oriented activities and aesthetic experience analysis

To examine how different education types influence various dimensions of aesthetic experience, repeated-measures ANOVAs were conducted using education type as a between-subjects factor. The Mauchly's sphericity tests were also conducted for all repeated-measures factors and their interactions. Greenhouse–Geisser corrections were applied where the assumption of sphericity was violated; adjusted degrees of freedom and p-values were then reported.

In the familiarity dimension, the Mauchly's sphericity test indicated that the assumption of sphericity was met for ceiling height, (χ^2 (2) = 3.48, p = 0.176). However, the assumption was violated for curvature (χ^2 (5) = 27.49, $p < 0.001$) and for the interaction between ceiling height and curvature (χ^2 (20) = 36.08, $p = 0.015$). Consequently, Greenhouse–Geisser corrections were applied to the curvature analyses ($\varepsilon = 0.74$) and the interaction effects ($\varepsilon = 0.80$). Huynh–Feldt corrections yielded comparable results. The results indicated a significant interaction between ceiling height and education type for familiarity scores (F (2,102) =3.607, p= 0.031, η_p^2= 0.066). However, there was no significant interactions found between curvature and education type nor between ceiling height, curvature, and education type for the familiarity dimension (Table 3). The Greenhouse–Geisser corrections affected the significance of the interaction between curvature and education type for the familiarity dimension (uncorrected p= 0.045, adjusted p= 0.06). Additionally, the analysis of estimated marginal means indicated that design-educated participants reported similar familiarity scores across different ceiling height levels (M_{Low}= 4.09, SE_{Low}= 0.24; M_{Medium}= 3.94, SE_{Medium}= 0.23; M_{High}= 4.12, SE_{High}= 0.22). In contrast, non-design-educated participants reported lower familiarity scores for high ceiling height levels (M_{High}= 3.73, SE_{High}= 0.24) compared to low and medium ceiling height levels (M_{Low}= 4.11, SE_{Low}= 0.25; M_{Medium}= 4.20, SE_{Medium}= 0.24). This indicates that a significant difference in familiarity scores between design- and non-design-educated participants is based on ceiling height. Furthermore, the analysis of estimated marginal means indicated that design-educated participants reported the highest familiarity score at the no-curve level ($M_{no\text{-}curve}$= 4.81, $SE_{no\text{-}curve}$= 0.23), compared to other levels (M_{Low}= 3.79, SE_{Low}= 0.25; $M_{Moderate}$= 3.74, $SE_{Moderate}$= 0.26; M_{High}= 3.85, SE_{High}= 0.28). However, non-design-educated participants reported the highest familiarity scores at the no-curve and low curvature levels ($M_{no\text{-}curve}$= 4.21, $SE_{no\text{-}curve}$= 0.25; M_{Low}= 4.18, SE_{Low}= 0.26), with lower and similar scores for moderate and high curvature levels ($M_{Moderate}$= 3.77, $SE_{Moderate}$= 0.27; M_{High}= 3.88, SE_{High}= 0.29). This indicates that design-educated participants were more sensitive to the introduction of curvature, while non-design-educated participants' familiarity only decreased after the introduction of moderate and high curvature levels.

In the excitement dimension, the results of Mauchly's sphericity test indicated that the assumption of sphericity was met for ceiling height (χ^2 (2) = 5.13, p = 0.08), curvature (χ^2 (5) = 10.65, p = 0.06), and the interaction between ceiling height and curvature (χ^2 (20) = 29.45, p = 0.08). Consequently, no corrections were necessary. Moreover, ANOVA results demonstrated a significant interaction between curvature and education type for excitement scores (F (3,153) =2.721, p= 0.046, η_p^2= 0.051). However, there was no significant interaction between ceiling height and education type, nor between ceiling height, curvature, and education type for the excitement dimension (Table 3). Further analysis of the estimated marginal means indicated that design-educated participants reported progressively higher excitement scores as curvature levels increased ($M_{No\text{-}curve}$= 3.58, $SE_{No\text{-}curve}$= 0.21; M_{Low}= 4.09, SE_{Low}= 0.21; $M_{Moderate}$= 4.21, $SE_{Moderate}$= 0.18; M_{High}= 4.31, SE_{High}= 0.20). However, non-design-educated participants reported the highest excitement scores only at the high curvature level (M_{High}= 4.55, SE_{High}= 0.21), compared to other levels ($M_{No\text{-}curve}$= 4.00, $SE_{No\text{-}curve}$= 0.22; M_{Low}= 3.85, SE_{Low}= 0.22; $M_{Moderate}$= 4.00, $SE_{Moderate}$= 0.19). These results suggest that design-educated participants experienced a gradual increase in excitement with higher curvature levels. In contrast, only the highest curvature level influenced the excitement scores of non-design-educated participants.

In the fascination dimension, the Mauchly's sphericity test indicated that the assumption of sphericity was met for ceiling height (χ^2 (2) = 4.38, p = 0.11), curvature (χ^2 (5) = 9.68, p = 0.08), and for the interaction between ceiling height and curvature (χ^2 (20) = 28.29, p = 0.10., Therefore, no corrections were necessary. Furthermore, ANOVA results revealed a significant interaction between curvature and education type ($F(3,153) = 3.742$, $p = 0.012$, $\eta_p^2 = 0.068$). However, there was no significant interaction observed between ceiling height and education type, nor between ceiling height, curvature, and education type (Table 3). Estimated marginal means indicated that design-educated participants reported higher fascination scores for low and moderate curvature levels compared to no-curve and high curvature levels ($M_{No\text{-}curve} = 3.65$, $SE_{No\text{-}curve} = 0.20$; $M_{Low} = 4.33$, $SE_{Low} = 0.20$; $M_{Moderate} = 4.39$, $SE_{Moderate} = 0.18$; $M_{High} = 4.19$, $SE_{High} = 0.20$). However, non-design-educated participants reported higher fascination scores for the high curvature level ($M_{High} = 4.45$, $SE_{High} = 0.21$) compared to similar and lower fascination scores at the other levels ($M_{No\text{-}curve} = 4.10$, $SE_{No\text{-}curve} = 0.21$; $M_{Low} = 3.92$, $SE_{Low} = 0.22$; $M_{Moderate} = 4.05$, $SE_{Moderate} = 0.19$). These results indicate that slight changes in curvature level influenced design-educated participants' fascination scores. In contrast, the fascination scores of non-design-educated participants were only influenced by the highest level of curvature increase. Because of their expertise, design-educated participants are more sensitive to slight changes in architectural boundaries compared to non-design-educated participants.

Table 3. Repeated-measures ANOVA results for aesthetic experience dimensions by education type.

	Familiarity	**Excitement**	**Fascination**
Ceiling Height, curvature & education type			
Main effect of ceiling height	F (2,102) =1.195, p= 0.307, η_p^2=0.023, 95% CI [0.000, 0.093]	*F (2,102) =8.803, p< 0.001, η_p^2=0.147, 95% CI [0.049, 0.244]	*F (2,102) =9.363, p< 0.001, η_p^2=0.155, 95% CI [0.056, 0.252]
Main effect of curvature	*F (3,153) =7.266, p< 0.001, η_p^2=0.125, 95% CI [0.046, 0.194]	*F (3,153) =7.249, p< 0.001, η_p^2=0.124, 95% CI [0.045, 0.193]	*F (3,153) =2.875, p= 0.038, η_p^2=0.053, 95% CI [0.002, 0.106]
Interaction of ceiling height & curvature	F (6,306) =0.942, p= 0.452, η_p^2=0.018, 95% CI [0.000, 0.049]	F (6,306) =1.772, p= 0.104, η_p^2=0.034, 95% CI [0.000, 0.069]	F (6,306) =1.262, p= 0.275, η_p^2=0.024, 95% CI [0.000, 0.055]
Interaction of ceiling height & education type	*F (2,102) =3.607, p= 0.031, η_p^2=0.066, 95% CI [0.005, 0.142]	F (2,102) =0.444, p= 0.643, η_p^2=0.009, 95% CI [0.000, 0.047]	F (2,102) =0.076, p= 0.380, η_p^2=0.019, 95% CI [0.000, 0.046]
Interaction of curvature & education type	F (2.22,113.43) =2.783, p= 0.060, η_p^2=0.052, 95% CI [0.000, 0.107]	*F (3,153) =2.721, p= 0.046, η_p^2=0.051, 95% CI [0.001, 0.103]	*F (3,153) =3.742, p= 0.012, η_p^2=0.068, 95% CI [0.011, 0.127]
Interaction of ceiling, curvature & education type	F (6,306) =1.784, p= 0.120, η_p^2=0.034, 95% CI [0.000, 0.070]	F (6,306) =1.259, p= 0.276, η_p^2=0.024, 95% CI [0.000, 0.055]	F (6,306) =1.179, p= 0.317, η_p^2=0.023, 95% CI [0.000, 0.053]

Note. η_p^2 = partial eta squared, CI= confidence intervals, 95% confidence intervals are provided for η_p^2, *p< 0.05

Presence Level and Aesthetic Experience Analysis

Cronbach's alpha was calculated to be 0.797, indicating strong reliability of the presence questionnaire. We calculated the mean scores for the presence scale, as well as for the dimensions of familiarity, excitement, and fascination. The presence level was analyzed as a continuous variable. The results of the univariate analysis indicated that presence level did not significantly predict familiarity, excitement, or fascination (Table 4). The presence questionnaire item regarding motion-sickness, rated on a 7-point Likert scale (1= not at all, 7= a great deal), showed low variance (M = 2.45, SD = 1.564). Notably, 43% of participants reported experiencing no motion-sickness at all, while 96% had scores of 5 or lower.

Table 4. Univariate models of presence level as a predictor of aesthetic experience dimensions.

	F	**(df1, df2)**	**p**	η_p^2
Familiarity	2.810	(1, 51)	0.10	0.052
Excitement	0.036	(1, 51)	0.850	0.001
Fascination	1.344	(1, 51)	0.252	0.026

Note. Presence level (mean of 11 items) entered as covariate.

Discussion

The results are discussed in light of the hypotheses on the architectural boundaries and aesthetic experience dimensions. We expected that higher ceiling height and curvature levels in exhibition spaces will positively lead to familiarity ($H1_a$ and $H1_b$). The results indicated a significant negative effect of curvature on familiarity; no curved walls led to higher familiarity; however, there was no significant effect of ceiling height on familiarity. The highest familiarity level was repeatedly perceived in no-curve VEEs with minimum, moderate, and high ceiling height levels, implying that environments with no curvature were found to be more familiar. Thus, our hypothesis was rejected.

Nevertheless, this observation is inconsistent with the literature claiming that in the built environment, people would favor curved forms over the rectilinear, as they appear more frequently in nature and provide one with a natural feeling (Coburn et al., 2019; Kellert, 2003;

Salingaros, 2015). Individuals interacting frequently with rectilinear forms in everyday life may reflect biased preferences for familiarity. This suggests that more work can be done to explore the association between curvature and familiarity. One idea could be that rectilinear interior space is ubiquitous in everyday living and work settings. Theories of habituation, such as those proposed by Zajonc (1968), suggest that repeated exposure to an environment increases individual attitudes toward it.

Additionally, pairwise comparisons have shown that small progressive curvature changes- low to moderate or moderate to high- would not lead to significant differences in the familiarity scores. These data suggest that differences between intermediate curvature levels are less relevant when exploring familiarity. The results suggest a thresholding effect: Only significant changes in curvature produce changes in perceived familiarity. More analysis and consideration must be given before convincing claims can be made. The main reason for incorporating intermediate ceiling height and curvature levels was to test for possible nuanced differences in aesthetic experience that binary conditions may miss. These findings, however, suggested that slight variations in curvature do not substantially affect familiarity because they showed no significant differences in familiarity scores between gradual curvature levels (low vs. moderate or moderate vs. high). In the context of VEEs, if high curvature implementation is not feasible due to spatial or technical constraints, moderate curvature may be adequate to elicit a similar familiarity response. In contrast, low and no curvature appear to generate similar impressions of familiarity. This finding allows designers to prioritize significant interventions over unnecessary or ineffective modifications.

We also hypothesized that exhibition spaces with higher ceiling height and curvature levels evoke excitement ($H1_c$ and $H1_d$). ANOVA results showed that the ceiling height and curvature levels had a significant positive effect on excitement with a large effect size (η_p^2= 0.143 for ceiling height; η_p^2= 0.120 for curvature); thus, the hypothesis was not rejected. In this experiment, ceiling height accounts for a somewhat more significant percentage of the variance in excitement ratings than curvature. VEEs with higher ceiling height and curvature levels were rated more exciting than the other VEEs. The mean scores show that the highest level of excitement was persistent and perceived in high ceiling height VEEs for all curvature levels. Ceiling height demonstrated a slightly higher η_p^2, possibly indicating a more significant influence on excitement than curvature. However, the difference is minimal, and cautious interpretation is necessary. The interaction between the ceiling height and curvature was insignificant. Although ceiling height and curvature independently affected excitement, their combined effects did not exceed the significant effect of their influence; hence, their combined effects on excitement were independent and did not augment each other. In this regard, the significant difference in excitement scores concerning the minimum and high ceiling height levels indicated that the meaningful increases considerably enhanced excitement. In contrast, the nonsignificant differences between minimum and moderate and moderate and high ceiling height levels would indicate that more minor manipulations of ceiling height are insufficient to alter states of excitement significantly. While significant differences in excitement score are found between no-curve and high curves and low and high curves, supporting the idea that highly curved space is perceived as more exciting than either its low or no curvature comparison, a lack of significant differences within other comparisons, for example, no-curves or moderate or high curvature levels would suggest that this increase in excitement with curvature rapidly reaches a ceiling at a moderate level.

We thus hypothesized that the higher the ceiling height and curvature level, the more fascination stimulation in the exhibition space would be elicited ($H1_e$ and $H1_f$). ANOVA results have shown that the ceiling height and curvature significantly affected the fascination with the large effect size of ceiling height (η_p^2=0.148) and a small one of curvature (η_p^2=0.053). So, high ceiling height and curvature levels elicited more fascinating environments, hence not rejecting hypotheses $H1_e$ and $H1_f$. VEEs with a high ceiling height for all curvature levels perceived the highest fascination level. The effect sizes further suggest that ceiling height explains a more considerable variance in fascination than curvature in this study. This finding indicates that ceiling height is crucial in designing virtual exhibition spaces that elicit fascination. The small effect size of curvature on fascination indicates that curvature is the subordinate design feature to affect fascination. Furthermore, no significant interaction was found between ceiling height and curvature; thus, their interaction did not lead to fascination.

Our findings partly coincided with some studies and contradicted others. Consistently with Coburn et al. (2020), our results showed that higher ceiling height levels positively affected aesthetic experience, precisely excitement and fascination dimensions. Similarly, Cha et al. (2019) found that higher ceiling height could provoke positive emotional responses and support the psychological benefits of vertical spaciousness. The results underlined the role of ceiling height in enhancing engagement and emotional responses in both physical and virtual contexts. Nevertheless, our results contradict those of Gath-Morad et al. (2024), who found no significant impact of ceiling height on aesthetic appraisal in workplace settings. Contextual differences between work and exhibition settings could explain the inconsistency of results. Furthermore, no consistent relationship between increased ceiling height and preference levels was found by Chen et al. (2024), which indicates that the influence of height may be moderated by other contextual or design factors. The differences identified suggest that ceiling height should be considered within a variety of spatial contexts in order to understand its impact on aesthetic experience better.

Our findings showed that higher curvature levels positively influenced excitement and fascination while negatively influencing familiarity. This finding agrees with the findings by Hobbs et al. (2015), which indicated that curved boundaries are perceived as more pleasant and relaxing, and with Dazkir and Read (2012), who observed significant feelings of pleasure and approachability associated with curvilinear designs. Our results showed that ceiling height and curvature significantly influenced excitement and fascination, while only curvature significantly influenced familiarity. These results contributed to the previous literature by relating architectural boundaries to aesthetic experience dimensions.

Thus, we expected the aesthetic experience to vary with the participants' emotional state (H2). Emotional state aesthetic experience results show rising means in all pleasure and arousal subscales scores both before and after the aesthetic experience, with small-to-medium overall effect sizes after the exhibition. This evidence indicates that it had an added positive influence on the participants. These findings support Mehrabian and Russell's (1974) model of emotional response to environments where physical space influences emotional states of pleasure and arousal. However, Pearson correlation results showed no significance for the participants' emotional state and aesthetic experiences before and after. Even though exploring the virtual exhibition spaces made participants more pleased and aroused afterward, this increase in their emotional state did not influence how they evaluated their aesthetic experience of the environment. Thus, our hypothesis was rejected. This finding would suggest that emotional reactions do not directly represent how people value their aesthetic experiences or that other variables intervene in this relationship.

We also hypothesized that education type will affect the aesthetic experience of participants (H3). The results demonstrated a significant interaction between ceiling height and education type for the familiarity dimension, and between curvature and education type for the excitement and fascination dimensions. These findings support some assumptions in the literature, arguing that individuals with design education might have more aesthetic experiences due to increased exposure to aesthetic concepts. The results suggest that aesthetic experience is affected by education type, where design-educated participants were more sensitive to graduate increases in curvature due to their expertise. In contrast, non-design-educated participants were only affected by greater increases in ceiling height and curvature levels. While for familiarity, design-educated participants reported close familiarity scores across different ceiling height levels, non-design-educated participants reported lower familiarity scores for high ceiling height levels compared to low and medium levels. Suggesting that non-design-educated participants may experience greater difficulty constructing spatial familiarity for higher ceiling height levels. In addition, the results indicated that design-educated participants reported the highest familiarity score at the no-curve level, compared to the other levels. In contrast, non-design-educated participants reported the highest familiarity scores at the no-curve and low curvature levels, with lower and similar scores for moderate and high curvature levels. Suggesting that design-educated participants were more sensitive to introducing curvature. However, non-design-educated participants' familiarity decreased after introducing moderate and high curvature levels. Moreover, the results indicated that design-educated participants reported gradually higher excitement scores for progressively increasing curvature levels. However, non-design-educated participants reported higher excitement scores only at the highest curvature level. These results suggest that the slight increases in curvature levels influenced design-educated participants' excitement, as they are more sensitive to design concepts and architectural forms, and thus are affected by the levels that created almost similar scores for non-design-educated participants.

Furthermore, the results indicated that slight changes in curvature level influenced design-educated participants' fascination scores. In contrast, the fascination scores of non-design-educated participants were only influenced by the highest increase in curvature level. This pattern implies that, whereas design-educated participants engage in progressive architectural variation, non-design-educated participants require more radical variations to experience greater fascination. Due to their expertise, design-educated participants were more sensitive to slight changes in architectural variations than non-design-educated participants, who required more substantial variations to report a significant score among the levels.

We also hypothesized that participants' presence level would affect aesthetic experience (H4). A univariate analysis was conducted to test this hypothesis, and the results indicated that the presence level did not significantly predict aesthetic experience dimensions. The results suggest that presence did not influence the aesthetic experience dimensions in VEEs. This could be explained by our approach to measuring presence level at the end of all 12 VEEs sessions, which produced a broad generalization of presence scores. Such an approach could have obscured specific variations in presence scores, thereby limiting the sensitivity of the analysis. Finally, to promote the application of the findings in interior design, we present design guidance that focuses on aesthetic dimensions (see Table 5). This guidance summarizes how architectural boundaries interact with aesthetic dimensions of familiarity, excitement, and fascination.

Table 5. Design guidance linking architectural boundaries to aesthetic dimensions.

Architectural Boundaries	Aesthetic Dimensions	Design Guidance
Ceiling Height	*Familiarity* Similar outcomes across all ceiling height levels.	Higher ceiling height levels lead to similar levels of familiarity, enhancing excitement and fascination.
	Excitement Increases with higher ceiling height levels.	
	Fascination Increases with higher ceiling height levels.	
Curvature	*Familiarity* Decreases with higher curvature levels.	None and low curvature levels can increase familiarity but reduce excitement and fascination. High curvature levels reduce familiarity, while moderate curvature levels achieve a more balanced outcome.
	Excitement Increases with higher curvature levels.	
	Fascination Increases with higher curvature levels.	
Ceiling Height and Curvature	Moderate curvature with high ceiling height levels, can result in high excitement and fascination while maintaining moderate to low familiarity. High curvature with high ceiling height levels, result in greater excitement and fascination but with lower familiarity.	Avoid high curvature with low ceiling height levels, as this may reduce familiarity. Low curvature with low ceiling height levels, may reduce excitement and fascination.

Conclusion

This study explored how the variance of architectural boundaries influenced aesthetic experiences within VEEs. Our findings identified that curvature is associated with familiarity dimension; ceiling height and curvature are strongly associated with excitement and fascination dimensions in reviewing the architectural boundary-aesthetic experience relationships. Besides linking architectural boundary elements to aesthetic experience dimensions in a virtual exhibition space, our study quantifies the influence of emotional state, education type, and presence level on the evaluation of aesthetic experience.

These findings supplement the literature review on empirical aesthetics and present practical implications for design approaches in virtual exhibition spaces. The result of this study could guide designers working on virtual exhibitions and researchers who shall direct their concentration on the aspect of architecture's influence on aesthetic experience in virtual contexts. This study emphasizes the use of VR, which offers several advantages in the methodology and design process of the experimental environments. The results will contribute to the field of digital exhibitions. Further research will be able to build from these findings and further develop the effectiveness of VR as a tool for creating engaging and significant virtual exhibition spaces.

Limitations and future research

This study has several limitations and suggests some avenues for further research. Further studies might investigate the relationship between curvature and familiarity, given cultural background and environmental exposure associating the use of curved shapes with familiarity. It could give more relevant arguments for the determined inconsistencies. These findings can also be further reproduced on an extended sample size to investigate the relationship between emotional state and aesthetic experience. The sample size in this study is 53, which might be considered a small sample size, perhaps limiting the generalization of the results. While the sample size was determined based on a previous G*Power analysis for within-subject effects, it may have masked smaller between-subject effects related to education type. Using G*Power analysis for between-subject effects, with alpha= 0.05, a power level of 0.80, and a sample of 53, the sensitivity analysis indicated a minimum effect size of η_p^2 =0.15. Future research should explore this effect further. In addition, the variations in the ceiling height examined in this study were restricted to between 3 m and 4.6 m. Future research could test a wider range of ceiling height levels to more accurately represent the variations found in real-world museum spaces.

Future studies can use multiple physiological emotion indices such as heart rate and skin conductance to perform more specific analyses on emotional states. Thus, this study only compared design and non-design-educated participants; therefore, knowledge about how different educational backgrounds influence aesthetic experiences remains limited. The follow-up research might compare subjects from various fields to establish whether design education acts exclusively on aesthetic experience. A mixed-method approach, using qualitative interviews and quantitative measures, may further elucidate how participants express their aesthetic experiences and how the education type will affect their perception. In addition, presence was measured once at the end of the session to avoid repeated assessments that might bias or interrupt the VR experience. Future research could assess presence during each VEE and explore the relationship between presence and architectural boundaries. Although the reported motion-sickness scores were low, individual differences in tolerance to VR exposure may have influenced the participants' subjective experiences.

Furthermore, our findings, which statistically controlled for potential impacts of floor area and wall length, indicated that curvature has distinct effects beyond changes in spaciousness. Since curvature, floor area, and wall length are mathematically interconnected in our stimuli, it is challenging to isolate the influence of curvature from the sense of spaciousness; thus, curvature manipulations cannot be entirely separated from spaciousness. Future research could further isolate these factors using VR to provide new insights into the role of floor area and wall length in shaping aesthetic experiences. Finally, the results of this study serve as a reference for designing exhibitions in virtual environments. However, it is essential to consider that VR experiments have limitations in ecological validity, as they cannot fully replicate the multisensory and contextual richness of real-life experiences.

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CRediT authorship contribution statement

Samah Obeid: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft.

Halime Demirkan: Conceptualization, Formal analysis, Methodology, Project administration, Supervision, Validation, Writing – review and editing.

Data and Materials Availability

The manuscript includes an open-source dataset https://data.mendeley.com/datasets/v38jtwkfn5/1

Modeling Parameters for Stimulus Generation:

The stimulus layout, which corresponds to four curvature levels, was initially drawn in AutoCAD and then modeled in 3d Max. We developed three different ceiling height levels, resulting in a total of 12 VEE stimuli. These three-dimensional models were rendered in 3ds Max as 360-degree images and subsequently uploaded into the VR tool, PICO Neo 3 Pro, to provide a fully immersive experience. The corresponding ceiling height and curvature parameters are detailed in Table 6.

Table 6. Relative ceiling height and curvature parameters for experiment stimuli.

	Ceiling Height		
Curvature (Floor area/Wall length)	**3 m**	**3.6 m**	**4.6 m**
0.0 m (90.26 m^2/35.13 m)	VEE 1	VEE 5	VEE 9
1.5 m (98.63 m^2/37.70 m)	VEE 2	VEE 6	VEE 10
2.5 m (102.06 m^2/39.42 m)	VEE 3	VEE 7	VEE 11
4.0 m (104.00 m^2/42.00 m)	VEE 4	VEE 8	VEE 12

Note. Curvature is determined by radius. Please refer to the text for alternative parameterization (constant arc length and curvature κ).

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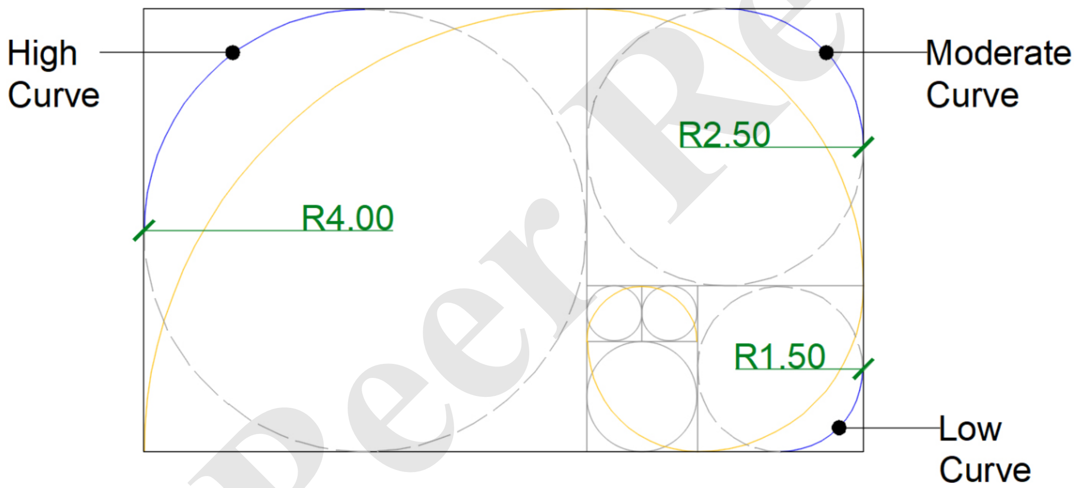
Appendix A: Instruments of the Study

Table 1. List of Measured Scales by Items and Correspondent Anchors

Scale **Item(s)**	**Anchors**
Art Exhibition Visit Frequency On average, how often do you visit art exhibitions in a year?	1= Never, 2= Rarely to A few times, 3= Often, 4= Very Frequently
Visual Art Interest How would you rate your interest in visual arts?	1= Not at all interested, 2= Slightly interested, 3= Moderately interested, 4= Very interested
Previous VR Experience *How familiar are you with VR?*	1= Not at all familiar, 2= Slightly familiar, 3= Moderately familiar, 4= Very familiar
Emotional State Pleasure Unhappy-Happy, Annoyed-Pleased, Unsatisfied-Satisfied, Melancholic-Contented, Despairing-Hopeful, Bored-Relaxed Arousal Relaxed-Stimulated, Calm-Excited, Sluggish-Frenzied, Dull-Jittery, Sleepy-Wide-awake, Unaroused-Aroused	5-point Likert scale (-2, -1, 0= neutral, 1, 2)
Aesthetic Experience *Please rate the following three items related to your aesthetic experience on a 7-point Likert scale. You will be provided with the definition of each item and the rating will be done orally while you are still in the VEE and the investigator will be taking notes.*	
1. Familiarity 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.”	7-point Likert scale (1= not familiar, 4= neutral, 7= familiar)
2. Excitement as “How excited, frenzied, jittery or contended one feels in an environment.”	7-point Likert scale (1= not excited, 4= neutral, 7= excited)
3. Fascination is “How mysterious or complex an environment looks or how stimulated one feels in that environment.”	7-point Likert scale (1= not fascinated, 4= neutral, 7= fascinated)
Presence Level *Please have in mind the following definition of presence when responding to this questionnaire: ‘Presence is the sense of being in the place depicted.’ Paes (2019, pp. 129-130).*	
1. To what extent did you feel present in the VEE considering your presence experiences in the real world?	1= Not at All, 7= A Great Deal
2. When you think back about your experience, to what extent do you think of the VEE as a place in a way similar to when you remember of other places that you have been today?	1= Not at All, 7= A Great Deal
3. When you think back about your experience, to what extent do you think of the VEE as somewhere you were at?	1= Not at All, 7= A Great Deal

4.	During the time of the experience, how strong was your sense of being in the VEE rather than being in the experiment room?	1= Not at All, 7= Very Strong
5.	To what extent did your visual experiences in the VEEs seem consistent with your visual experiences in the real world?	1= Not at All, 7= A Great Deal
6.	To what extent did you feel you could grasp an object in the VEEs?	1= Not at All, 7= A Great Deal
7.	If the VEE ceiling had started to collapse, what would have been the probability of you dodging in an attempt to not getting hit by falling parts?	1= Not at All, 7= Very Likely
8.	To what extent did you feel like exploring the rest of the VEE?	1= Not at All, 7= A Great Deal
9.	Were there times during the experience when the VEE was the reality for you?	1= Not at All, 7= Almost All Times
10.	Were you involved in the experience to the extent that you lost track of time?	1= Not at All, 7= A Great Deal
11.	To what extent have you experienced motion sickness (nausea, dizziness)?	1= Not at All, 7= A Great Deal

List of Figures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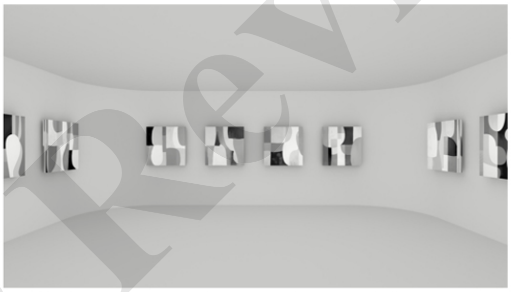
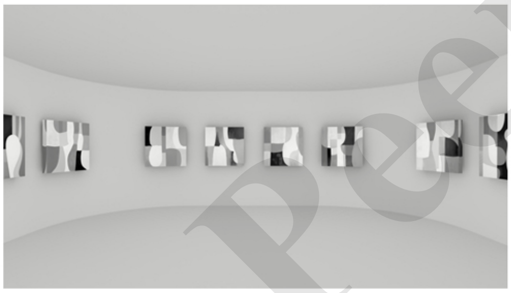
Moderate Curve
R2.50
R4.00
R1.50
Low Curve

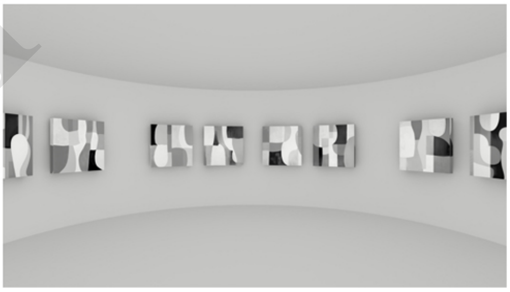
(a) no curve, minimum ceiling height



(b) low curve, minimum ceiling height



(c) moderate curve, minimum ceiling height



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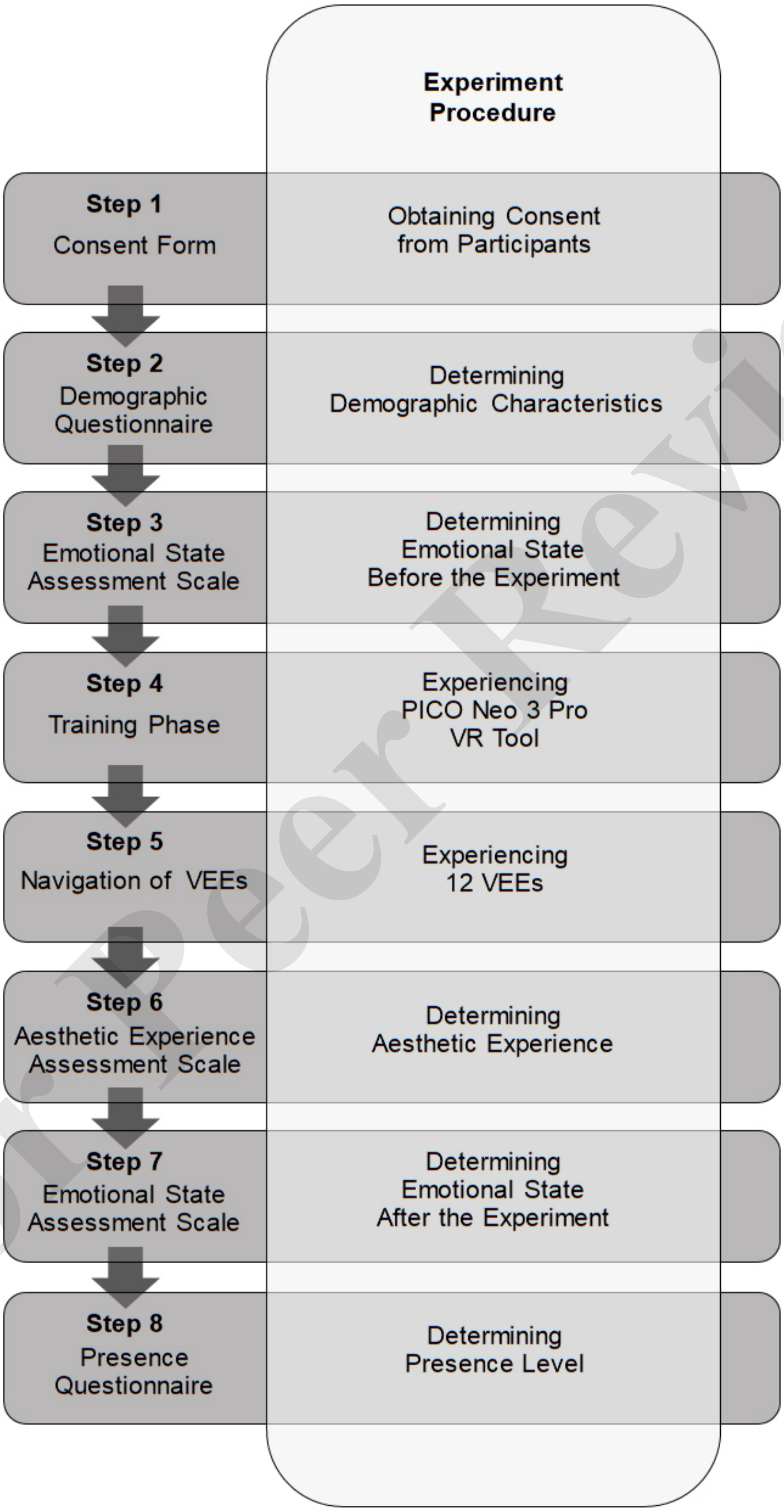
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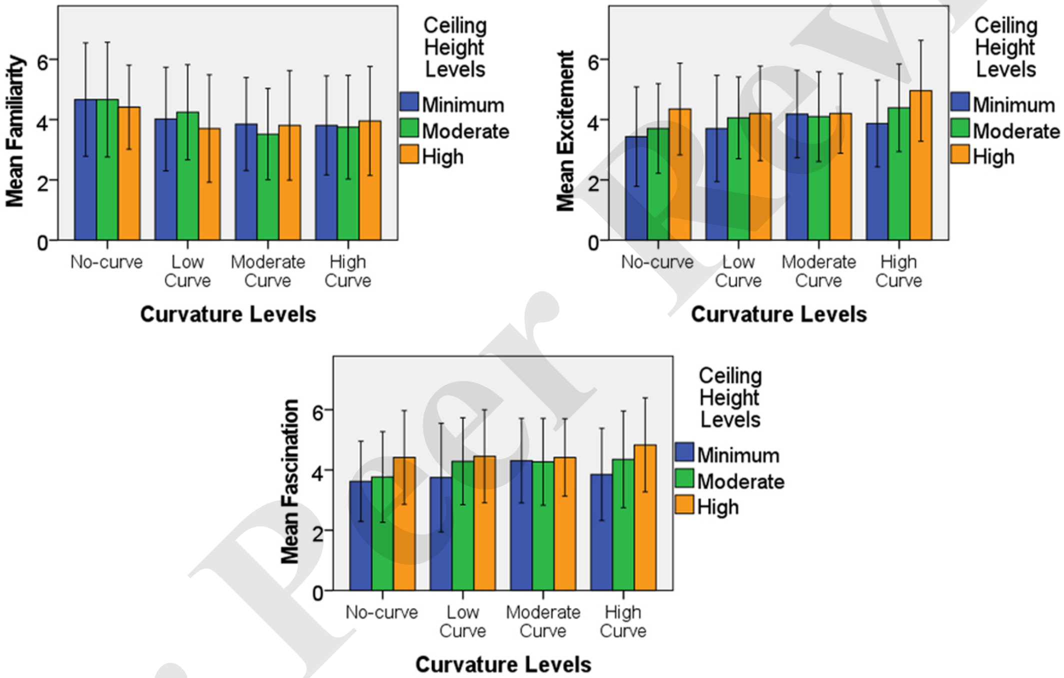
Determining Presence Level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Moderate Curve
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Curvature Levels
Ceiling Height Levels
Minimum
Moderate
High
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2
4
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Moderate Curve
High Curve
Curvature Levels
Ceiling Height Levels
Minimum
Moderate
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Mean Fascination
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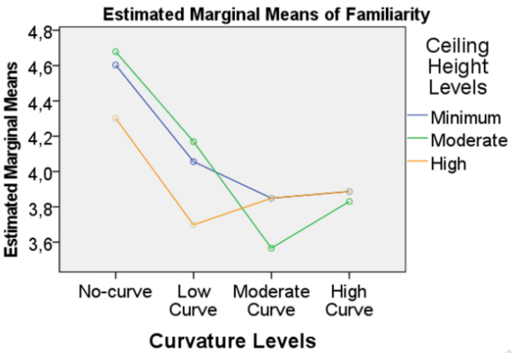
Curvature Levels
Ceiling Height Levels
Minimum
Moderate
High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Estimated Marginal Means
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4,4
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3,6
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High Curve
Curvature Levels
Ceiling Height Levels
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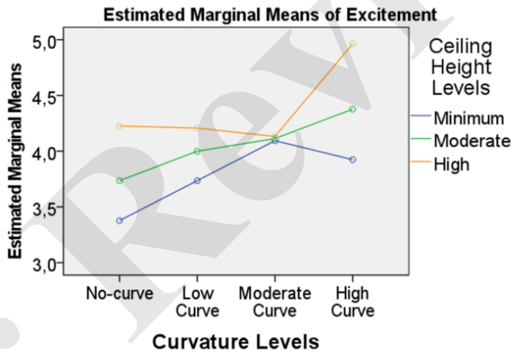
Moderate
High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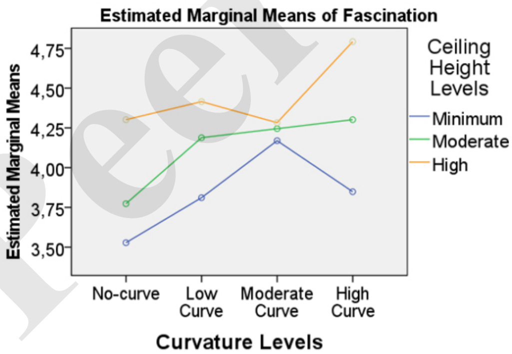
Moderate
High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Estimated Marginal Means
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3,50
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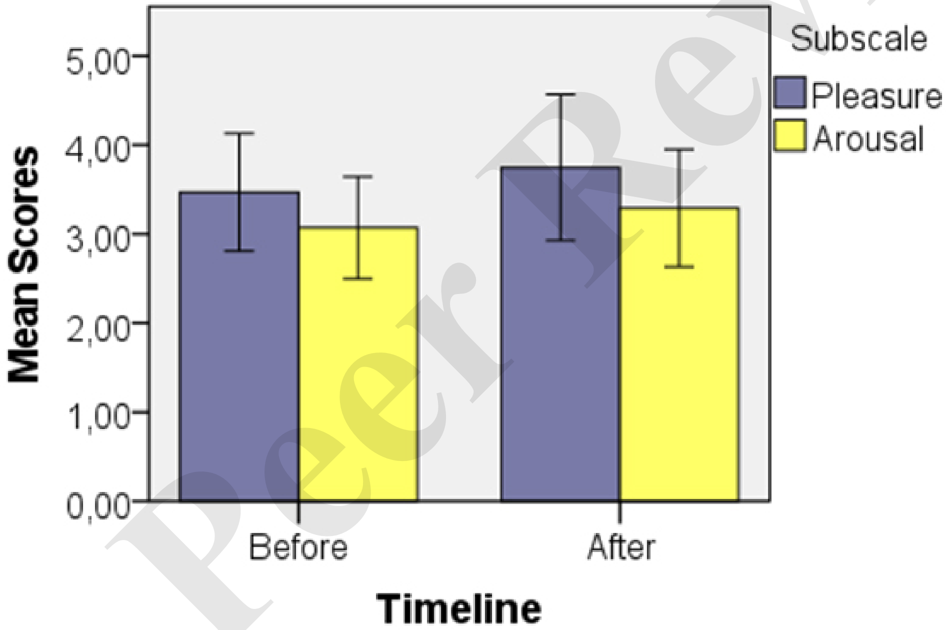
High Curve
Curvature Levels
Ceiling Height Levels
Minimum
Moderate
High


Mean Scores
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4,00
3,00
2,00
1,00
0,00
Before
After
Timeline
Subscale
Pleasure
Arousal

Tables

Table 1. Repeated-measures ANOVA results for aesthetic experience dimensions.

		(df1, df2)	**F**	**p**	**η_p^2**	**95% CI for η_p^2**
Familiarity	Main effect of ceiling height	(2, 104)	0.960	0.386	0.018	[0.000, 0.066]
	Main effect of curvature	(3, 156)	7.435	*0.001	0.125	[0.027, 0.238]
	Interaction of ceiling height & curvature	(6, 312)	0.965	0.438	0.018	[0.000, 0.052]
Excitement	Main effect of ceiling height	(2, 104)	8.709	*0.001	0.143	[0.049, 0.245]
	Main effect of curvature	(3, 156)	7.079	*<0.001	0.120	[0.040, 0.203]
	Interaction of ceiling height & curvature	(6, 312)	1.757	0.108	0.033	[0.000, 0.075]
Fascination	Main effect of ceiling height	(2, 104)	9.057	*<0.001	0.148	[0.052, 0.252]
	Main effect of curvature	(3, 156)	2.885	*0.043	0.053	[0.001, 0.113]
	Interaction of ceiling height & curvature	(6, 312)	1.250	0.281	0.023	[0.000, 0.062]

Note. η_p^2 = partial eta squared, CI= confidence intervals, 95% confidence intervals are provided for η_p^2, *$p< 0.05$

Table 2. Correlation among participants' pleasure and arousal subscales before and after the experiment and aesthetic experience dimensions.

	Pleasure Before	Pleasure After	Arousal Before	Arousal After	Familiarity	Excitement	Fascination
Pleasure Before	–						
Pleasure After	0.707**	–					
Arousal Before	0.219	0.135	–				
Arousal After	0.201	0.460**	0.390**	–			
Familiarity	0.040	-0.062	-0.111	-0.102	–		
Excitement	0.065	0.119	0.165	0.215	0.218	–	
Fascination	0.093	0.074	0.023	0.127	0.197	0.892**	–

** Correlation is significant at the 0.01 level (2-tailed)

Table 3. Repeated-measures ANOVA results for aesthetic experience dimensions by education type.

	Familiarity	**Excitement**	**Fascination**
Ceiling Height, curvature & education type			
Main effect of ceiling height	F (2,102) =1.195, p= 0.307, η_p^2=0.023, 95% CI [0.000, 0.093]	*F (2,102) =8.803, p< 0.001, η_p^2=0.147, 95% CI [0.049, 0.244]	*F (2,102) =9.363, p< 0.001, η_p^2=0.155, 95% CI [0.056, 0.252]
Main effect of curvature	*F (3,153) =7.266, p< 0.001, η_p^2=0.125, 95% CI [0.046, 0.194]	*F (3,153) =7.249, p< 0.001, η_p^2=0.124, 95% CI [0.045, 0.193]	*F (3,153) =2.875, p= 0.038, η_p^2=0.053, 95% CI [0.002, 0.106]
Interaction of ceiling height & curvature	F (6,306) =0.942, p= 0.452, η_p^2=0.018, 95% CI [0.000, 0.049]	F (6,306) =1.772, p= 0.104, η_p^2=0.034, 95% CI [0.000, 0.069]	F (6,306) =1.262, p= 0.275, η_p^2=0.024, 95% CI [0.000, 0.055]
Interaction of ceiling height & education type	*F (2,102) =3.607, p= 0.031, η_p^2=0.066, 95% CI [0.005, 0.142]	F (2,102) =0.444, p= 0.643, η_p^2=0.009, 95% CI [0.000, 0.047]	F (2,102) =0.076, p= 0.380, η_p^2=0.019, 95% CI [0.000, 0.046]
Interaction of curvature & education type	F (2.22,113.43) =2.783, p= 0.060, η_p^2=0.052, 95% CI [0.000, 0.107]	*F (3,153) =2.721, p= 0.046, η_p^2=0.051, 95% CI [0.001, 0.103]	*F (3,153) =3.742, p= 0.012, η_p^2=0.068, 95% CI [0.011, 0.127]
Interaction of ceiling, curvature & education type	F (6,306) =1.784, p= 0.120, η_p^2=0.034, 95% CI [0.000, 0.070]	F (6,306) =1.259, p= 0.276, η_p^2=0.024, 95% CI [0.000, 0.055]	F (6,306) =1.179, p= 0.317, η_p^2=0.023, 95% CI [0.000, 0.053]

Note. η_p^2 = partial eta squared, CI= confidence intervals, 95% confidence intervals are provided for η_p^2, *p< 0.05

Table 4. Univariate models of presence level as a predictor of aesthetic experience dimensions.

	F	**(df1, df2)**	**p**	**η_p^2**
Familiarity	2.810	(1, 51)	0.10	0.052
Excitement	0.036	(1, 51)	0.850	0.001
Fascination	1.344	(1, 51)	0.252	0.026

Note. Presence level (mean of 11 items) entered as covariate.

Table 5. Design guidance linking architectural boundaries to aesthetic dimensions.

Architectural Boundaries	Aesthetic Dimensions	Design Guidance
Ceiling Height	*Familiarity* Similar outcomes across all ceiling height levels. *Excitement* Increases with higher ceiling height levels. *Fascination* Increases with higher ceiling height levels.	Higher ceiling height levels lead to similar levels of familiarity, enhancing excitement and fascination.
Curvature	*Familiarity* Decreases with higher curvature levels. *Excitement* Increases with higher curvature levels. *Fascination* Increases with higher curvature levels.	None and low curvature levels can increase familiarity but reduce excitement and fascination. High curvature levels reduce familiarity, while moderate curvature levels achieve a more balanced outcome.
Ceiling Height and Curvature	Moderate curvature with high ceiling height levels, can result in high excitement and fascination while maintaining moderate to low familiarity. High curvature with high ceiling height levels, result in greater excitement and fascination but with lower familiarity.	Avoid high curvature with low ceiling height levels, as this may reduce familiarity. Low curvature with low ceiling height levels, may reduce excitement and fascination.

Table 6. Relative ceiling height and curvature parameters for experiment stimuli.

	Ceiling Height		
Curvature (Floor area/Wall length)	**3 m**	**3.6 m**	**4.6 m**
0.0 m (90.26 m^2/35.13 m)	VEE 1	VEE 5	VEE 9
1.5 m (98.63 m^2/37.70 m)	VEE 2	VEE 6	VEE 10
2.5 m (102.06 m^2/39.42 m)	VEE 3	VEE 7	VEE 11
4.0 m (104.00 m^2/42.00 m)	VEE 4	VEE 8	VEE 12

Note. Curvature is determined by radius. Please refer to the text for alternative parameterization (constant arc length and curvature κ).

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Table 1. List of Measured Scales by Items and Correspondent Anchors

Scale **Item(s)**	**Anchors**
Art Exhibition Visit Frequency On average, how often do you visit art exhibitions in a year?	1= Never, 2= Rarely to A few times, 3= Often, 4= Very Frequently
Visual Art Interest How would you rate your interest in visual arts?	1= Not at all interested, 2= Slightly interested, 3= Moderately interested, 4= Very interested
Previous VR Experience *How familiar are you with VR?*	1= Not at all familiar, 2= Slightly familiar, 3= Moderately familiar, 4= Very familiar
Emotional State Pleasure Unhappy-Happy, Annoyed-Pleased, Unsatisfied-Satisfied, Melancholic-Contented, Despairing-Hopeful, Bored-Relaxed Arousal Relaxed-Stimulated, Calm-Excited, Sluggish-Frenzied, Dull-Jittery, Sleepy-Wide-awake, Unaroused-Aroused	5-point Likert scale (-2, -1, 0= neutral, 1, 2)
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Presence Level *Please have in mind the following definition of presence when responding to this questionnaire: 'Presence is the sense of being in the place depicted.' Paes (2019, pp. 129-130).*	
1. To what extent did you feel present in the VEE considering your presence experiences in the real world?	1= Not at All, 7= A Great Deal
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3. When you think back about your experience, to what extent do you think of the VEE as somewhere you were at?	1= Not at All, 7= A Great Deal

4.	During the time of the experience, how strong was your sense of being in the VEE rather than being in the experiment room?	1= Not at All, 7= Very Strong
5.	To what extent did your visual experiences in the VEEs seem consistent with your visual experiences in the real world?	1= Not at All, 7= A Great Deal
6.	To what extent did you feel you could grasp an object in the VEEs?	1= Not at All, 7= A Great Deal
7.	If the VEE ceiling had started to collapse, what would have been the probability of you dodging in an attempt to not getting hit by falling parts?	1= Not at All, 7= Very Likely
8.	To what extent did you feel like exploring the rest of the VEE?	1= Not at All, 7= A Great Deal
9.	Were there times during the experience when the VEE was the reality for you?	1= Not at All, 7= Almost All Times
10.	Were you involved in the experience to the extent that you lost track of time?	1= Not at All, 7= A Great Deal
11.	To what extent have you experienced motion sickness (nausea, dizziness)?	1= Not at All, 7= A Great Deal

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2. When you think back about your experience, to what extent do you think of the VEE as a place in a way similar to when you remember of other places that you have been today?	1= Not at All, 7= A Great Deal
3. When you think back about your experience, to what extent do you think of the VEE as somewhere you were at?	1= Not at All, 7= A Great Deal

4.	During the time of the experience, how strong was your sense of being in the VEE rather than being in the experiment room?	1= Not at All, 7= Very Strong
5.	To what extent did your visual experiences in the VEEs seem consistent with your visual experiences in the real world?	1= Not at All, 7= A Great Deal
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7.	If the VEE ceiling had started to collapse, what would have been the probability of you dodging in an attempt to not getting hit by falling parts?	1= Not at All, 7= Very Likely
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11.	To what extent have you experienced motion sickness (nausea, dizziness)?	1= Not at All, 7= A Great Deal