Impact of Virtual Reality Navigation on Emotional Response to Virtual Architectural Environments: A Pilot Study

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IST 521: HCI - The User and Technology

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May 02, 2023

Abstract

There is growing evidence that the built environment has direct and indirect psychological impact on its occupants. Immersive Virtual Reality (VR) provides a controlled/experimental setting to study the emotional causal impact of individual architectural design variables (e.g., color, geometry) on people. Because moving around VR is not like real world walking, single/small-scale virtual rooms are predominantly tested in these VR based architectural studies. This study is a usability study comparing two VR locomotion techniques and its influences on users exploring and evaluating architectural designs in virtual reality. The independent variables of interest in this study are VR locomotion techniques, and architectural geometry (design variable). A 2 (teleportation vs continuous locomotion) x 2 (curvilinear geometry vs linear geometry) mixed-factorial design experiment is conducted wherein locomotion technique is a between-subjects factor and architectural geometry is a within-subjects factor. Emotional response (pleasure, arousal, and dominance) to architectural prototypes, user preference of the design options, spatial presence, simulator sickness, system usability scale and task load of using different locomotion techniques were measured. It was observed that participants (N=18) found both locomotion techniques easy to use with non-significant differences in simulator sickness and spatial presence. Participants using the teleportation navigation technique found both the architectural spaces more arousing than those using the continuous navigation technique. Pleasure and dominance response was the same across the two VR locomotion methods. With respect to architectural evaluation, people preferred curvilinear geometry over linear geometry, but the difference was not statistically significant. The study has implications for methods of studying the effects of built space using VR.

Keywords: virtual reality, architecture, emotional response, user experience, VR navigation, architectural geometry, spatial presence, curvilinear spaces, teleportation, continuous movement

Introduction

Architects and designers strive to create spaces that benefit users in their quest to design the built environment. While we are constantly improving our ability to build complex architectural designs using computation, we are less certain of how these forms will affect users emotionally. Humans react cognitively and emotionally to their surroundings and recent advancements in neuroscience and immersive technology make it possible to perform an empirical study on how space impacts occupants' cognition and emotion. Immersive virtual reality can provide a controlled setting to study the psychological impact of architectural design variables on people. However, scientific knowledge is still limited about differences between architectural experience in the real-world physical environment, and the virtual environment.

Room-scale VR is generally used in architecture studies that means it utilizes only the participants' physical walking in the real-world space, and so, the VR scene is small and is restricted around this constraint. Controller-based VR navigation techniques are used to traverse VR spaces that are larger than the physical room. There are 22 different locomotion techniques within VR with various benefits and constraints (Cherni, 2020). Two common virtual locomotion techniques in virtual environments that enables users to travel outside the boundaries of the physically available tracking space are (a) teleportation where users jump from one point to the other by clicking on the point one wishes to move to using a hand-held controller (Bailenson, 2019) and (b) continuous movement where the users move their joystick/controllers to move smoothly over the VR space (Dewez et.al., 2020). To summarize, if the virtual space is a small room, natural walking in the real world helps traverse similar sized rooms in the virtual world. But if the virtual spaces exceed the extent of the physical room, natural walking is not enough to traverse the large space. In such cases, teleportation or other locomotion techniques/interaction methods are necessary and employed to navigate large virtual spaces.

The interactions with the virtual model and the navigation from one room to another in VR is superior to what one can achieve with a desktop interface. Although VR presents obvious advantages over other conventional forms of architectural representations, it is a medium with its own affordances and psychological outcomes. The body does not move through space while large distances are traversed in the virtual environment. VR Teleportation, which is a discrete movement pattern, when compared to continuous walking impacts the visual information one receives and results in the loss of spatial orientation in some cases and hence affects emotional response to the visualized architecture (Cherep et al., 2020).

There is a lack of usability testing of Virtual Reality (VR) in the context of pre-occupancy evaluation of architecture. The purpose of this study is to investigate two types of VR navigation in the context of pre-occupancy evaluation of buildings. In a broader context, this study hopes to suggest efficient use of VR and contribute to robust methodologies to study the psychological impact of architecture. A 2 (teleportation vs continuous locomotion) x 2 (curvilinear geometry vs linear geometry) mixed-factorial design experiment is conducted wherein locomotion technique is a between-subjects factor and architectural geometry is a within-subjects factor. Emotional response (pleasure, arousal, and dominance) to architectural prototypes, user preference of the design options, spatial presence, simulator sickness, system usability scale and task load of using different locomotion techniques were measured. The following sections include related work, the research questions, the experiment method and the results and discussion.

Related Work

This section highlights the use of virtual reality in architecture evaluation studies and its limitations. It also discusses the effect of locomotion technique on emotional response and spatial presence which can be defined as a 'sense of being there' in a mediated environment with an illusion of non-mediation (Hartman et al., 2015). The influence of teleportation and continuous VR movement's simulator sickness is also covered in this section. This section concludes with the research questions that guide our experiment.

Architecture evaluation and Virtual Reality

The importance of a building's ability to shape the human brain, body and mind cannot be overstated. People spend 90 percent of their time indoors, and evidence shows that their behavior, feelings, well-being, and long-term health depend on the characteristics of the space they inhabit (Amatkasmin et al., 2022; Evan, 2003). During the development of design, even when the user is known, their assumed needs and psychological responses to the designed space are difficult to identify. To add to this, there is a growing gap between the designer and the user because often the end-user of a building is not the client of the project (Zeisel, 2006).

In this state, the design problem during the development stage is narrowed down to just the functional requirements of a building. Historically, post-occupancy evaluation of a building has helped the architect learn from his design errors and better address the behavior and experience of users in future projects. Today's architectural practice can now simultaneously evaluate user response to buildings that are yet to be built in parallel to the design development with technological advancements in immersion and visualization. These platforms can be used effectively to aid the process of user-testing in architectural design.

In addition to pre-occupancy evaluation of architectural prototypes, taking a new turn in this research inquiry, is the coming together of two disparate disciplines namely neuroscience and architecture. This emerging field, called Neuroarchitecture, investigates the intricate relationship between built space and human brain and behavior. The goal is to revamp the building policies to account for the quality of life. However, several neuroarchitecture reviews (Higuera-Trujillo, 2021; Kim & Kim, 2022; Mostafvi, 2022), identified the most common challenge prevalent in this field: lack of a common methodology that unifies research efforts in this field due to the multidisciplinary approach and technology dependence.

The advantage of using immersive technology in neuroarchitecture is touted by many (e.g., Jelic et al., 2016). However, the realness of VR is of concern when trying to understand the psychological impact of real spaces. For instance, one experiment conducted in VR where curved spaces are preferred (Li et al., 2022) and induces stress reduction in observers whereas another employing the same technology found contradictory evidence (Tawil et al., 2021). Can the difference in evidence be due to the technology being used? Moreover, only small virtual reality spaces (single room designs) are tested in these studies (Mostafvi, 2022). Large buildings with multiple areas or cities are not studied because how one navigates virtual reality space is controlled by joystick that is unlike how one walks in a place. Understanding how HCI contributes to the explication of the human-environment and the boundary conditions of this domain needs to be further investigated before confirming that VR is a valid tool in architectural evaluation studies.

VR Locomotion techniques and Spatial Presence

Among the many factors that affect the user experience, VR navigation techniques have been studied for their effect on spatial presence. Two of the most common VR navigation techniques are teleportation (Bailenson, 2019) and continuous movement (Boletsis, 2017). The VR navigation technique employed to traverse spaces that are larger than the physical room one uses to experience IVR is a predictor of presence (Balakrishnan and Sundar, 2011).

Jicol et al. (2021) conducted a study to investigate the effects of emotion and agency on presence in Virtual Reality (VR) environments. They found that the dominant emotion induced by a VR environment positively correlated with presence, and that agency had a significant positive effect on presence while also moderating the effect of emotion on presence. Rantala et al. (2021) compared their newly developed techniques, slider and grab, with the conventional teleport technique in a task involving counting visual targets in a VR environment. Their results indicated that slider and grab were significantly faster to use than teleport and did not cause significantly more simulator sickness, while also providing better spatial awareness.

Balakrishnan and Sundar (2011) explored the impact of navigability affordances and narrative transportation on spatial presence in VR contexts. Their large experiment (N = 240) revealed that narrative transportation detracted from spatial presence, while traversability, in the form of greater degrees of steering motion, enhanced spatial presence even without invoking a mental model of the portrayed environment.

VR Locomotion Techniques and user experience

The success of VR applications largely depends on the quality of the user experience, which can be influenced by different parameters such as navigation techniques. While teleportation has the advantage of reducing motion sickness, many studies have also reported some discomfort issues such as disorientation, nausea, and dizziness (Veličković et al., 2021). Users may feel disconnected from the virtual environment when using teleportation, which can negatively affect their usability experience. However, in the context of continuous movement navigation technique, studies show that this type of navigation technique provides users with a sense of immersion and control, which can enhance the user experience (Habgood et al., March 2018). Moreover, it is associated with some usability issues such as the need for a larger physical space, tripping or colliding with real-world objects, and motion sickness (Schott et al., 2021).

A comparison of the two VR navigation techniques (Langbehn et al., April 2018) has revealed that continuous movement is generally preferred by users, partly due to its ability to create an immersive and realistic experience in the VR environment. However, teleportation is also useful for users who want to explore unreachable areas of the virtual environment without compromising their physical comfort (Ap Cenydd et al., 2018).

VR Locomotion Techniques and Spatial Cognition

Spatial cognition is an essential aspect of architecture, with VR technology providing opportunities for enhanced perception and understanding of spatial configurations. Navigation techniques, such as teleportation and continuous movement, are integral to the user experience, but their influence on spatial cognition is not yet fully understood. Cherep et al (2020) suggested that the teleportation technique can improve the spatial cognition of users by enabling them to explore spaces in a non-linear way and providing them with a different perspective on an object's size, position, and relation to external features.

Several studies have compared the impact of teleportation and continuous movement techniques on spatial cognition in VR. In most cases, continuous movement is found to have a more significant impact on enhancing spatial cognition because it creates a more realistic sense of navigation and movement. However, the impact may vary depending on other factors such as the complexity of the virtual environment and individual cognitive traits (McNamara, T, et al, 2018).

Based on the literature review, the following research questions were addressed:

RQ1: Are both VR navigation techniques easy to learn and use?

RQ2: Will people prefer curvilinear spaces over linear spaces?

RQ3: (a) Do people's emotional responses (pleasure and arousal) to architectural environments presented in VR vary with different locomotion techniques (teleportation and continuous movement)? (b) Will curvilinear spaces be found more pleasurable, arousing, and dominating than linear spaces across both locomotion conditions?

RQ4: (a) Does teleportation navigation elicit more spatial presence experienced in VR? (b) Does teleportation navigation elicit more VR simulator sickness in people?

Method

An experiment was conducted to understand the emotional response to navigation techniques in VR architectural spaces. This study utilizes a pilot research design to largely understand whether people's emotional responses (pleasure, arousal, and dominance) to architectural environments presented in VR vary with different locomotion techniques (teleportation and continuous movement).

Participants

The sample for this study comprised of 18 participants selected via convenience and snowball sampling methods. Participants were required to be aged 18 and over. Prior experience with virtual reality was not essential. Their ages ranged from 21 to 31 years (mean = 25.05 years). 7 identified as males and 11 as females. 17 out of the 18 participants were right-handed. 9 participants wore corrective glasses.

Stimuli

Two large architectural VR scenes: curved (see Figure 1) and linear (see Figure 2) were implemented as the stimuli. Additionally, a tutorial scene (see Figure 3) was rendered for the participants to get used to the controls and the general feeling of the virtual space, before entering the experiment (curved and linear) scenes. The scenes included a spacious room, a tunnel like corridor - one to exterior walkway and one open to exterior space. More views of the architectural environments can be found in Appendix B.

Figure 1 VR Curved scene

Figure 2 VR Linear scene

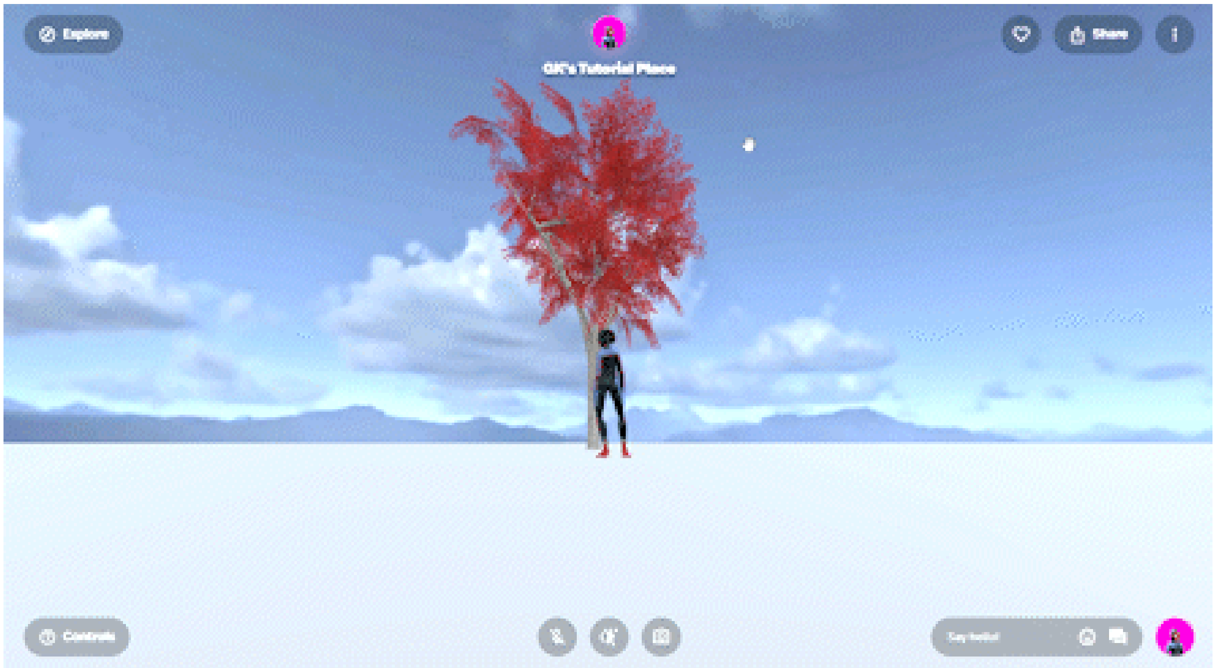

Figure 3 Tutorial scene

Materials

The Oculus Quest (see *Figure 4*) was used to present the VR scenes to the participants and spatial.io (https://www.spatial.io/) was used to display the 3D model of the architectural spaces. The 3D model of the VR scenes was designed using Rhino 3D. Rhino 3D is a commercial 3D computer graphics and computer-aided design application software. The 3D models were then exported as .fbx format to spatial.io. And Spatial is a platform that allows you to create your own virtual avatar and spaces to organize live events and interact with other people in a metaverse environment. The scale and position of the imported 3D models were adjusted and set as the VR environment. Finally, a point in the VR space was set as the spawn point of the scene.

There were two avatars involved in the three VR scenes: (a) Participant avatar (first-person's view) and (b) Observer/Experimenter avatar (third-person's view). It is important to note here that the participants will not be able to see their avatar from their first-person's view. The participant avatar was placed within the VR environment at a fixed origin/starting point in each of the three environments. This was done to maintain consistency across all participants, as participants were all exposed to the same VR environments with the same avatar placement. This consistent placement also allowed for more precise measurements of the impact of navigation type on emotional response, reducing variability across participants.

Additionally, the observer avatar's placement within the VR environment was also chosen deliberately to minimize its impact on participants' emotions. It was positioned in such a way that it did not obstruct the participant's VR field of view or interfere with the virtual environment's design.

Figure 4 shows the Oculus Quest headset with its two touch controllers. The headset offersh six degrees of freedom, full room motion sensing, head tracking, and high-resolution screens, 1440x1600 per-eye, refresh rate 72Hz, and 2 x OLED binoculars. It also has a finger tracking feature with partial finger and thumb tracking via capacitive sensors. Input methods include capacitive face buttons, capacitive joystick, capacitive touch pad, capacitive index trigger, and middle finger trigger.

Built-in video capture feature (in Oculus Quest) was used to cast the participants' point of view on the experimenter's smartphone, and the screen was recorded on the phone. Further, two laptops and a PC were used to record audio and survey respectively. One of the laptops was used to record the third-persons perspective on the spatial.io website.

Figure 4 Oculus Quest

Measures

The following variables were measured in the survey in Table 1. The complete questionnaire is given in Appendix C. The measured variables are pleasure, arousal, dominance, spatial presence, virtual reality simulator sickness, NASA-tlx task load and system usuability. All measures were adapted from well-established scales to ensure reliability.

Table 1 Measures and scales used in the questionnaire.

Measure	Definition	Number of items	Cronbach's alpha
Pleasure. Adapted from Self-Assessment Manikin (SAM), a pictorial assessment that measures pleasure, arousal, and dominance of a person's affective reaction to stimulus. (Bradley and Lang, 1994).	The Pleasure-Displeasure Scale measures how pleasant or unpleasant one feels about something.	1 item (On a scale of 1-9. A higher score indicates a stronger feeling in that dimension).	N/A
Arousal (Adapted from Bradley and Lang, 1994)	The Arousal-Non arousal Scale measures how intensely one feels.	1 item (On a scale of 1-9. A higher score indicates a stronger feeling in that dimension).	N/A
Dominance (Adapted from Bradley and Lang, 1994)	The Dominance-Submissiveness Scale represents the controlling and dominant versus controlled or submissive one feels.	1 item (On a scale of 1-9. A higher score indicates a stronger feeling in that dimension).	N/A
Spatial Presence (Adapted from Hartman et al., 2015)	Spatial presence can be defined as a 'sense of being there' in a mediated environment with an illusion of non-mediation	6 items (On a scale of 1-6, 1 = strongly disagree, 6 = strongly agree)	0.82
Virtual Reality Simulator sickness (Adapted from Kim et al., 2018)	Motion sickness experienced in VR. Symptoms can include general eye strain, dizziness, etc.	8 items (On a scale of 0-3, 0 = none and 3 = severe)	0.89
NASA-TLX (Adapted from Hart and Staveland, 1988)	Measures the task load experienced when performing a task	6 items (scale 1-100)	<0.6
SUS (Adapted from Brooke, 1996)	Measured ease of use of a system	7 items (On a scale of 1-5, 1 = strongly disagree and 5 = strongly agree)	<0.6

Design and Procedure

Participants were given a brief orientation and introduced to the VR system. They were then instructed to navigate three virtual architectural environments: tutorial scene, curved scene, and linear scene. The experiment was conducted over several days starting 12th April 2023 to 24th April 2023 at the Stuckeman Family Building located at The Pennsylvania State University. The participants were randomly assigned to 2 conditions of navigation techniques (namely teleportation and continuous movement), and each participant navigated both curved and linear scenes in a counterbalanced order.

A demographic survey was conducted before the experiment began. After which the participants were asked to wear the Oculus Quest - Head Mounted Display (HMD) and enter the VR tutorial scene to get comfortable with the controls. The tutorial scene was designed in such a way that it mimicked the main VR scenes. The participants were then asked to enter both curved and linear VR scenes in a counterbalanced order. They were simply asked to move around the VR scenes using either of the navigation techniques and were asked to observe the architectural space. The right controller was assigned to teleportation and the left controller to continuous movement. After each VR scene, participants were asked to take a survey (based on Pleasure, Arousal and Dominance). Participants' evaluation of the architectural space, sense of presence, and perceived workload were also measured.

Additionally, Participant 1 pointed out some amendments in the survey as well as the virtual scenes (such as color of the floor and the walls) which were then implemented for the rest of the participants. Besides, we also added a window in the VR scenes for more light.

The time required for each step and the total time required to conduct the study is given in Table 2.

Table 2 Experiment time breakdown

Estimated Completion Time	51 minutes
Introduction and consent	~ 5 minutes
Demographic questions	~ 5 minutes
Training and demo of VR experience	5 to 10 minutes
First VR experience (design variable 1)	~5 minutes
Survey	5 to 11 minutes
Second VR experience (design variable 2)	~5 minutes
Survey	5 to 10 minutes

Ethical Considerations

All participants provided informed consent prior to participation, and the study was approved by the Institutional Review Board of Pennsylvania State University. Participants were informed of their right to withdraw from the study at any time and were assured that their participation was voluntary and confidential. They were also informed about the general side effects of using head-mounted displays (HMD).

Results

A split-plot ANOVA with standard least square method was used to analyze the mixed-factorial experiment design in JMP. *Subjects'* variable was included as random effects to analyze the relationship between (a) the navigation techniques (factor 1) and emotional response (pleasure, arousal, and dominance), (b) architectural geometry (factor 2) and emotional response and (c) the interaction effect between architectural (factor 2) and technological (factor 1) variable. A second test namely t-test was used to find the relationship between the locomotion techniques (teleportation and continuous movement) and (a) spatial presence and (b) virtual reality simulator sickness.

A total of 19 participants were recruited. But the study conducted with participant 1 was considered as a pre-test study. This participant was excluded from the analysis leaving N = 18 for the statistical tests. Participant 1 provided feedback on the legibility of the VR scene, the comprehensiveness of the questionnaire and the instructions provided to teach the VR locomotion methods. Relevant changes were made to the stimuli, questionnaire and the experiment protocol.

Observations from the experiments

The observer avatar changed for some of the participants due to technical difficulties during the experiment, but that has no bearing on the research based on participant's one-on-one feedback at the end of the experiment. It was observed that most participants were not aware of what the avatar looked like at the end of the experiment.

Descriptive statistics

The means and standard errors of the measured variables (emotion response (pleasure, arousal, and dominance) and spatial presence after scene 1 and 2, SUS and VRSQ) are given in Table 2. It should be noted that these scores were not distributed normally due to the small sample size and the analysis should be treated as exploratory.

Table 3 Means and standard errors of the measured variables.

Dependent Variables	Mean	Standard error
Pleasure – Curved space	7.06	0.38
Arousal – Curved space	4.5	0.58
Dominance – Curved space	7.89	0.28
Pleasure – Linear space	7.11	0.38
Arousal – Linear space	4.72	0.58
Dominance – Linear space	7.83	0.28
Spatial presence – Teleportation method	3.62	0.23
Spatial presence – Continuous method	2.26	0.23
Virtual reality simulator sickness (VRSQ) - Teleportation method	0.61	1.24
Virtual reality simulator sickness (VRSQ) - Continuous method	0.29	0.06
System Usability Scale (SUS) – Teleportation method	3.63	0.56
System Usability Scale (SUS) – Continuous method	3.56	0.06

On average, participants spent 3.63 minutes in scene 1 (mean = 218 seconds, SD = 88.8 seconds) and 3.92 minutes in scene 2 (mean = 235.28 seconds, SD = 112.21 seconds) with the curved and linear spatial conditions counterbalanced. In the VR scenes, participants spent 3.46 minutes (mean = 207.94 seconds) with continuous navigation and 4.08 minutes (mean = 245.33 seconds) with teleportation method. As shown in Figure 5, it was observed that participants using continuous navigation method spent similar amount of time in both curved and linear space whereas the time spent in a VR scene for teleportation method varied based on the architectural space they were in (more time in curved spaces). This could be because they found both curved and linear spaces equally engaging but the teleportation method required more actions (push trigger, point, release trigger) to move from one place to another when compared to the continuous movement method (push trigger to propel forward). However, differences in time spent across conditions and methods were not statistically significant.

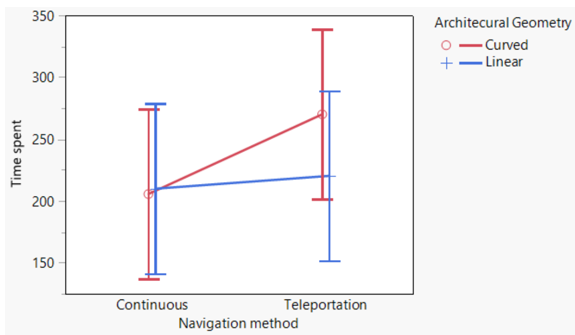

Figure 5 Interaction plot showing the interaction effect of navigation technique and architectural geometry condition on time spent in VR scene.

The number of clicks for participants in the teleportation navigation condition is given in Table 3. On average, people clicked more in curved architectural space than linear space. However, the people who used less clicks did not mean they did not spend a lot of time in the scene. They simply clicked far from their position and spent time looking around from each vantage point. The people who clicked more clicked on a point close to themselves and were gradually jumping as they explored the virtual space.

Table 4 The number of clicks the participants executed in the teleportation navigation condition across both architectural spaces.

Participant	2	4	6	8	10	12	14	16	18
Curved space (mean clicks = 146.66)	281	180	265	166	35	40	40	207	105
Linear space (mean clicks = 105.33)	365	110	110	128	46	28	73	38	50

Inferential statistics

Research question 1 sought to find out which of the two VR navigation techniques were easier to learn and use. On a scale of 1-100, the mental demand (mean = 12.8, SD = 14.17), physical demand (mean = 10.5, SD = 15.69) and temporal demand (mean = 7.39, SD = 11.86) of using both the navigation techniques were rated low. The effort needed to perform the navigation tasks with the VR hand-held controller was less (mean = 19.39, SD = 24.53) and the resulting frustration was also low (mean = 2.22, SD = 3.34). The performance success was considered to be high by the participants (mean = 89, SD = 16.81). Moreover, the scores on SUS were not statistically significant between the two locomotion techniques (continuous method, mean = 3.56, Sd = .167; teleportation method, mean = 3.63, SD = .56) showing that the participants found both teleportation and continuous methods easy to use.

Research question 2 sought to find out which architectural geometry the participants preferred. 8 out of 18 participants preferred linear spaces whereas 10 participants preferred curvilinear spaces. The difference between these numbers is not statistically significant. Analyzing the reasons given by the participants in response to an open-ended survey question, it was observed that people who preferred the curved scene over the linear scene provided sound reasons for liking the curved architecture. They mention that they found the wavy patterns more relaxing. Whereas people liked the linear because they experienced it better and were excited to explore a new space. Words like cool (novel), dynamic, relaxing, smooth, smooth edges, flowing, aligned with nature, calming, peaceful and elegant were used to describe curvilinear architecture. Whereas, words intimidating, normal, blocky, square-shaped were mentioned for not-liking linear spaces. Only 1 participant mentioned that they found the curved space weird.

Research question 3 sought to find out if people's emotional responses (pleasure, arousal, and dominance) to architectural environments presented in VR vary with different locomotion techniques (teleportation and continuous movement). The main effect and interaction effects of the two independent factors were analyzed. There were no main or interaction effects of architectural geometry and navigation techniques on pleasure and dominance.

With respect to arousal, the locomotion method had a main effect ($F(1,32) = 7.91$, $p = .0083$) on the level of arousal experienced by participants in both architectural spaces. Participants using teleportation method (mean = 5.67, SE = .53) experienced more arousal towards the architectural spaces when compared to the continuous movement (mean = 3.56, SE = .53) technique (see Figure 6).

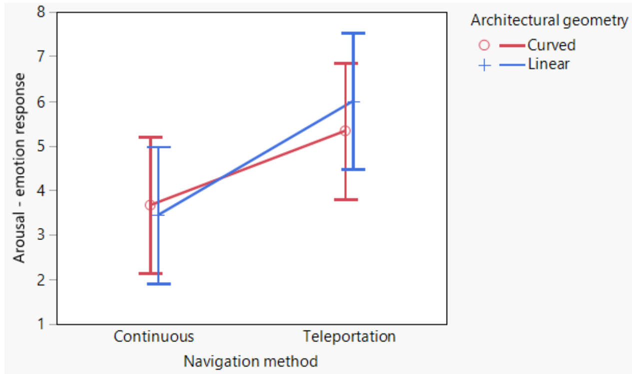

Figure 6 Least squares means plot showing the interaction of navigation technique and architectural geometry condition on arousal emotional response.

Research question 4 sought to find the effect of locomotion techniques (teleportation and continuous movement) on spatial presence and virtual reality simulator sickness. Although, spatial presence was higher in continuous navigation (mean = 3.63, SD = 1.01) than in teleportation method (mean = 3.26, SD = .94), this difference was not statistically significant, at two-tailed t(34) = - 1.1, p = .27. Similarly, VR simulator sickness was lower in continuous navigation (mean = 0.29, SD = .16) than in teleportation method (mean = 0.61, SD = .79), this difference was not statistically significant, at two-tailed t(34)=1.66, p=.1. It was found that the higher the simulator sickness, the lower the spatial presence (r = -.11, p = .53, non-significant finding). However, it must be noted that 6 out of the 9 people in the teleportation condition wore glasses and rated the general discomfort of using VR as high.

Discussion

This study shed light on how technological variables play a role when it comes to evaluating architectural designs in VR. Overall, it was found that both teleportation and continuous navigation methods were easy to learn and use for all the participants. Although both navigation methods seem conducive to be used in architectural evaluation studies with large VR spaces, teleportation methods performed better in the context of measuring arousal impact of architectural prototypes. This difference in emotion response in the two navigation methods shows that technological features have an effect on how people respond to architecture in VR. Further investigation is needed to understand how to use VR effectively in architecture evaluation studies.

Theoretical implications

Built environment affects the mental well-being of its occupants both directly and indirectly (Evans, 2003). There is converging evidence that high rise housing buildings result in psychological distress that can be due to a range of factors including floor level and housing quality to design features. Depression, anxiety, and stress were found to be positively correlated with the lack of windows, exposure to daylight and the amount of space available for quiet contemplation (see this review Rive et al., 2022). However, the methodology adopted to determine the housing-mental-health relationship is not conducive to establishing true and causal relationships. Establishing a robust human-computer interaction method to study human-environment interaction will help shape a better environment in the future. It can help shape building policies and our built environment to enhance the overall well-being and mental health of dwellers who spend 90 percent of their time indoors.

Practical implications

This study can help inform the design of VR oriented products that are entering the market to help architects receive user-feedback in the design process by enriching the VR experience incorporated in these digital products. Additionally, the study has implications for future research that understands the intricate relationship between humans and the built environment using immersive virtual reality.

This study offers valuable insights for the design of VR-based products emerging in the market, aimed at assisting architects in obtaining user feedback during the design process. By enhancing the VR experience integrated into these digital tools, architects can better understand users' preferences and emotional responses. Moreover, the study holds significant implications for future research focused on the complex interplay between humans and the built environment using immersive virtual reality. The findings contribute to the growing body of literature on how architectural spaces can influence individuals providing a deeper understanding of the psychological impact of architectural experiences.

These insights can inform the design of spaces that encourage physical activity, healthy eating habits, and other behaviors contributing to overall well-being. Recognizing the connection between mental well-being and architectural spaces is crucial for responsibly shaping future building policies and promoting healthier living environments.

Future research may explore the long-term effects of architectural design on mental health, the integration of biophilic design elements, and the impact of changing technological variables in VR settings.

The findings of this study can add to the growing literature on how spaces can shape the moods and emotions of people by shedding light on the psychological effects of places. This in turn can help design spaces that promote physical activity, healthy eating or other good habits that contribute to overall well-being. Understanding the relationship between mental well-being and architectural spaces is important to responsibly shape future building policies.

Limitations and future directions

There are several limitations to this study. The study focused on a particular type of architectural geometry and hence the findings of this study may not be generalizable to other designs. Moreover, this study measures the cross-sectional impact of an architectural space on people and hence the emotional impact observed in this study cannot be translated to the real-world settings where architectural spaces are inhabited and experienced longitudinally. Future studies should test a wide range of design variables longitudinally.

This study focused on the navigation affordance of VR technology. Other technological variables/affordances like user agency and interactivity should also be tested in future studies.

The virtual reality (VR) scenes/stimuli were designed in a way that they were suspended in the air. It is hypothesized that this unique feature of the VR environments may potentially elicit a distinct emotional response from participants as compared to typical ground-level designs. This confounding variable needs to be addressed in future studies.

In future studies the mediating effects of spatial presence and simulator sickness on the emotional response can be analyzed. Additionally, objective measures of emotional response like heart rate sensors and galvanic skin conductance measures can be used.

The sample size in this study is also relatively small and may not accurately represent the general population. Therefore, a larger and more diverse sample may be needed to confirm the results.

Conclusion

In conclusion, this study provides valuable insights into the effects of VR locomotion techniques on users' emotional responses and preferences when evaluating architectural designs. The findings suggest that both teleportation and continuous navigation methods can be effectively used in architectural evaluation studies, with teleportation methods performing better in the context of measuring arousal impact of architectural prototypes.

Further research is needed to explore the long-term effects of architectural design on mental health, integration of biophilic design elements, and the impact of changing technological variables in VR settings.

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Appendix A

Study Protocol

Hello and thank you for your participation in our pilot study of emotional response to VR navigation techniques. Before the study begins, you will take a short survey, after which you will be asked to wear a VR headset and enter a tutorial VR scene. This scene is for you to get comfortable with the controls and the virtual space in general. After this, you will navigate two Virtual Reality architectural scenes. And you will take a survey after navigating each scene. Please answer the survey as honestly as possible. The maximum time spent on the VR experience will be 15-20 minutes, including the surveys. Please be informed that you will be seated throughout the VR experience. Feel free to let us know if you want to stop the experiment or if you have any concerns at any point in the experiment.

For the purpose of this research, we request your permission to record the audio of the session. Additionally, one of the researchers will be recording what you see in the VR environment, on the web VR space. And we will also run a screen recording inside the Oculus Headset. Before we begin, I want to ensure that you have given your informed consent to participate in this study. If you have any questions at any point during the study, please do not hesitate to ask. Also, please be informed that due to the scope of the study, we will not be able to provide compensation.

Thank you again for your participation in this study. Please let us know if you have any questions or concerns, and we will be happy to address them before beginning the experiment.

Appendix B

VR stimuli

Views of the VR scenes

More views of the architectural spaces are given in this section.

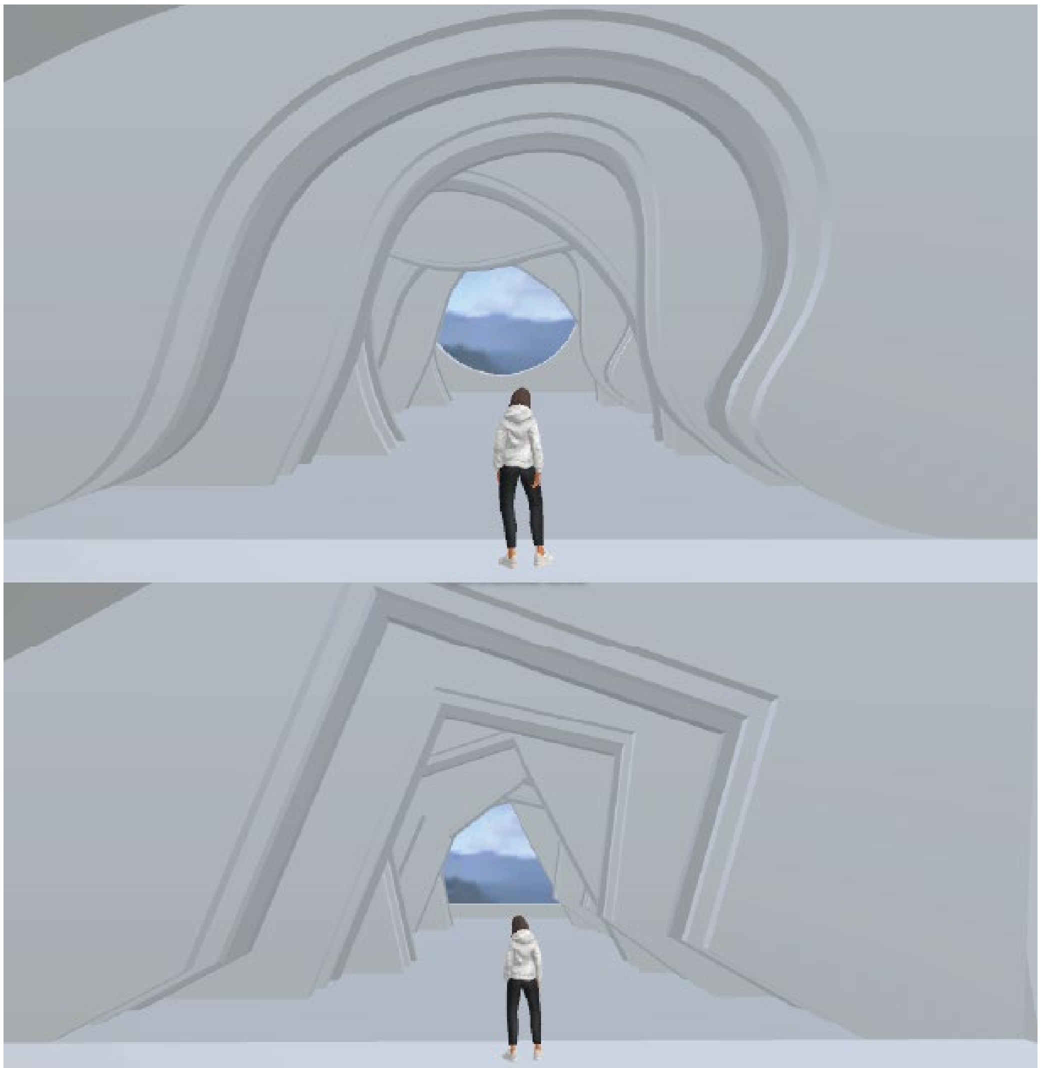


Figure 7 View of tunnel in curvilinear space (top) and linear space (bottom)

Figure 8 View of open space in curvilinear space (bottom) and linear space (top)

Appendix C

Survey Questions

Preview link to Qualtrics Survey

https://pennstate.yul1.qualtrics.com/jfe/preview/SV_42XMA6Bhg3osUnk?Q_CHL=preview

Full Questionnaire

Thank you for participating in our IRB-approved experiment.

Consent

Do you consent to take part in this study about virtual reality for architecture? Yes or No

Inclusion Criteria

Are you 18 years of age or older? Yes or No

Did you sleep well last night? Yes or No

Would you say you are well-rested and relaxed? Yes or No

Demographics

What is the highest level of school you have completed or the highest degree you have received?

- Less than high school degree
- High school graduate (high school diploma or equivalent including GED)
- Some college but no degree
- Associate’s degree in college (2-year)
- Bachelor's degree in college (4-year)
- Master's degree
- Doctoral degree
- Professional degree (JD, MD)
- Prefer not to answer

What is your ethnicity? Please choose all categories that apply

- American Indian or Alaska Native

- Asian
- Black or African American
- Hispanic or Latino
- Native Hawaiian or Pacific Islander
- White
- Other (open-ended)
- Prefer not to answer

What is your gender?

- Male
- Female
- Non-binary / third gender
- Prefer not to say

What is your age?

Are you left-handed or right-handed? Left-handed or Right-handed

Are you afraid of heights in buildings? Yes or No

Do you wear glasses? Yes or No

On a scale of 1-6, please indicate how much you agree with the following statements about video gaming experience.

1 = Strongly Disagree

6 = Strongly Agree

- I am a video game player.
- I spend a lot of time playing video games.
- I would call myself a good video game player.

On a scale of 1-10, please answer the following questions on your immersive VR experience with a headset.

- How much experience would you say you have with immersive VR? (10 = lot of experience and 1 = less experience)
- How much would you say you enjoyed your previous experience with immersive VR? (10 = enjoyed a lot and 1 = did not enjoy)
- How much would you say you felt comfortable in your previous experience with immersive VR? (10 = very comfortable and 1 = not comfortable at all)

Training Session

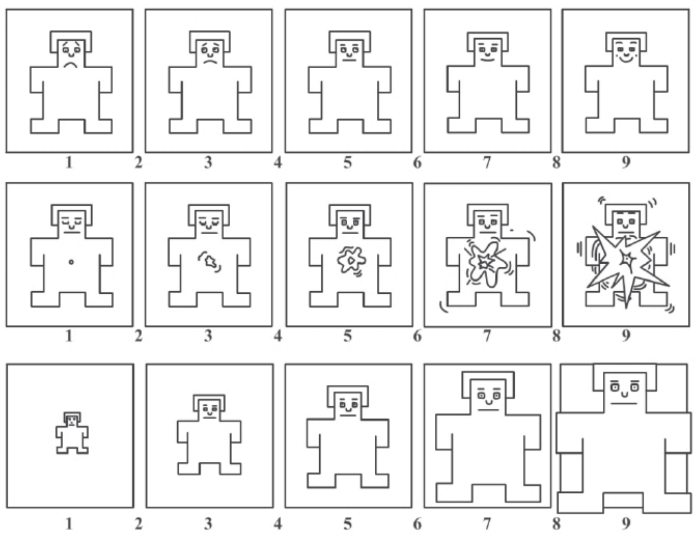
Training Session will now start.

Please feel free to stop the experiment anytime if you feel uncomfortable or dizzy in any way.

VR scene 1

Please answer the following questions based on your experience in the 1st VR scene.

How long did you spend exploring the first VR scene? (Ask the experimenter)



Please choose the manikin (shown above) that best represents your feelings on a scale of 1-9. A higher score indicates a stronger feeling in that dimension.

- How would you rate your current level of pleasure?
- How would you rate your current level of arousal (a state of excitement linked to an emotion)?
- How would you rate the extent to which the emotion makes you feel you are in control of the situation?

Viewing this VR scene #1,

On a scale of 1-5, please rate your emotional response to the architectural space you viewed.

- How interested did you feel during the VR scene?
- How anxious did you feel during the VR scene?
- How happy did you feel during the VR scene?
- How sad did you feel during the VR scene?

- How scared did you feel during the VR scene?
- How relaxed did you feel during the VR scene?
- How engaged did you feel during the VR scene?
- How overwhelmed did you feel during the VR scene?
- How bored did you feel during the VR scene?
- How uncomfortable did you feel during the VR scene?
- How beautiful did you find the VR scene you just experienced?

Please indicate how much you agree with the following statements.

1 = Strongly disagree

5 = Strongly agree

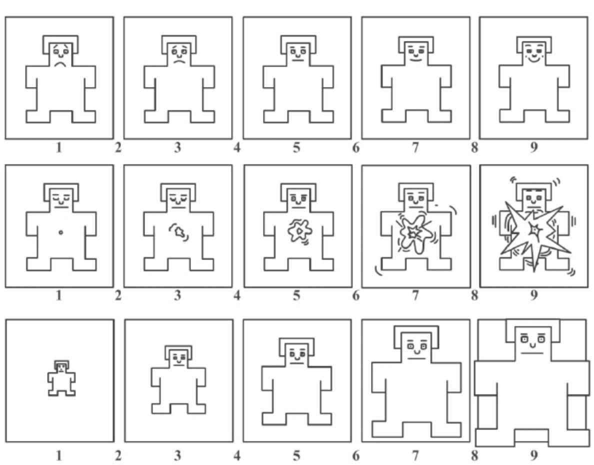
- I felt like I was actually there in a virtual environment.
- I felt like I could move around among the objects in the virtual environment.
- The objects in the environment gave me the feeling that I could actually touch them.
- It seemed to me that I could have some effect on things in the virtual environment, as I do in real life.
- I felt that I could move freely in the virtual environment.
- I had the impression that I could reach for the objects in the virtual environment.

VR scene 2

Please answer the following questions based on your experience in the 2nd VR scene.

How long did you spend exploring the second VR scene? (Ask the experimenter)

How was the architectural space in the second VR scene different from the first one? (Manipulation check)



Please choose the manikin (shown above) that best represents your feelings on a scale of 1-9. A higher score indicates a stronger feeling in that dimension.

- How would you rate your current level of pleasure?
- How would you rate your current level of arousal (a state of excitement linked to an emotion)?
- How would you rate the extent to which the emotion makes you feel you are in control of the situation?

Viewing this VR scene #2,

On a scale of 1-5, please rate your emotional response to the architectural space you viewed.

- How interested did you feel during the VR scene?
- How anxious did you feel during the VR scene?
- How happy did you feel during the VR scene?
- How sad did you feel during the VR scene?
- How scared did you feel during the VR scene?
- How relaxed did you feel during the VR scene?
- How engaged did you feel during the VR scene?
- How overwhelmed did you feel during the VR scene?
- How bored did you feel during the VR scene?
- How uncomfortable did you feel during the VR scene?
- How beautiful did you find the VR scene you just experienced?

Please indicate how much you agree with the following statements.

1 = Strongly disagree

5 = Strongly agree

- I felt like I was actually there in a virtual environment.
- I felt like I could move around among the objects in the virtual environment.
- The objects in the environment gave me the feeling that I could actually touch them.
- It seemed to me that I could have some effect on things in the virtual environment, as I do in real life.
- I felt that I could move freely in the virtual environment.
- I had the impression that I could reach for the objects in the virtual environment.

NASA-TLX

On a scale of 0-100, rate how difficult it was to navigate in the VR space.

- How mentally demanding was the navigation task? (Slider: very low to very high)
- How physically demanding was the navigation task?
- How hurried or rushed was the pace of the navigation task?
- How successful were you in accomplishing in navigating VR space?
- How hard did you have to work to accomplish your level of performance?
- How insecure, discouraged, irritated, stressed, and annoyed were you?

VRSQ

On a scale of 0-3, please indicate the severity of the following symptoms related to simulator sickness.

- General discomfort
- Fatigue
- Eyestrain
- Difficulty focusing
- Headache
- Blurred vision
- Dizzy
- Vertigo (the sensation that you, or the environment around you, is moving or spinning)

Usability of locomotion technique

Which hand-held VR controller did you use? Right or Left

VR NAVIGATION METHOD is the locomotion technique that enables movement from one place to another within a virtual reality environment.

Please indicate how much you agree with the following statements about the VR navigation method.

1 = Strongly disagree

5 = Strongly agree

- I found the navigation method unnecessarily complex
- I thought the navigation method was easy to use
- I think that I would need the support of a technical person to be able to use this navigation method.
- I would imagine that most people would learn to use this navigation method very quickly
- I found the navigation method very cumbersome to use
- I felt very confident using the navigation method

- I needed to learn a lot of things before I could get going with this navigation method

Preference of design scenes

If you have to choose, which VR scene do you prefer/like better?

- VR scene 1
- VR scene 2

Why do you prefer this scene? Please explain as best as you can. (open-ended)

End of survey