Effects of Visual Cues on Depth Perception in Virtual Landscapes

Rümeysa Merve Öksüz[1], Ikhwan Kim[2]

[1]Istanbul Technical University, Istanbul/Turkey· rumeysamrvoksuz@gmail.com
[2]Istanbul Technical University, Istanbul/Turkey

Abstract: With computer technology development, the volume and quality of virtual landscapes developed dynamically. This subject has the potential to be a new field for landscape architecture. This paper focused on the perception of space in a virtual landscape because the concept of perception will underlie every future research related to this topic. Researchers indicated that when the presence of visual cues is restricted, the deterioration in perception increases (LOYOLA 2016). Although research revealed the effect of visual cues on perception, no study could be conducted on developing their application rates. This study aims to show the impact of visual cues on depth perception in virtual landscapes. Articles published on visual cues that affect depth perception were studied. The effect of each visual cue in the experiment shows with spheres created within a room visualized in Unreal Engine 5. 40 Participants are asked to estimate the distance of the displayed sphere from the back wall at each stage. Participants' answers are compiled through a semi-structured interview. Comparative analysis is made between the true distance and the estimation. The absolute error is found and presented with comparison graphics. The results reveal visual cues 'effects on depth perception in virtual landscapes. This study presents the effects of visual cues for virtual landscape designers to use by revealing data that will strengthen the perception of depth in virtual landscape designs. The result of this research will be a robust future reference for landscape architects who will investigate the new domain of landscape architecture.

Keywords: Virtual landscape, visual cue, depth perception, landscape architecture, VR

1 Introduction

1.1 Background

The essence of landscape architecture as a design discipline is defined as constructing and articulating three-dimensional outdoor space (NIJHUIS 2011). As KIM (2019) points out, this definition is changing with developing technologies, opening up new design spaces for landscape architects. Virtual Reality, one of these technologies, plays an important role in the design, evaluation, and training processes (BERG & VANCE 2016), such as Product Design and Prototyping, education, health, entertainment, Industrial Simulation applications, and Driving Simulations (HAMAD & JIA 2022). The Gaming sector, in particular, has great potential for Virtual Landscapes to emerge, with an expected growth rate of 13.4% from 2023 to 2030 (VIDEO GAME MARKET SIZE & SHARE GROWTH REPORT 2022). For this reason, related industries are looking for professionals who can design Virtual Landscapes (VL) (KIM 2019). The design and development of VL is the new threshold for landscape architects. Designers must understand the "place" to design VL (KIM et al. 2017). However, researchers have observed inaccurate perceptions of place in the VL when we look at VL. The most common fallacy researchers encounter is to perceive spatial dimensions as smaller (LOOMIS & KNAPP 2003, MESSING & DURGIN 2005, RENNER et al. 2013a, b). These distortions threaten designers' ability to represent VL accurately and reliably. For this reason, researchers discuss underestimating spatial dimensions in VL in their research. RENNER et al. (2013)

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mentioned that the estimated dimensions in VL are about 74% of the actual modeled dimensions. Previous research on depth perception shows that distance estimation can be estimated with a margin of error of 6% in the physical environment. In contrast, in VL, the margin of error is 20% (NG et al. 2016). One of the methods used by designers to solve such problems in physical environments is to create illusions by using visual cues in spaces. Researchers suggest that size perception in physical environments is based on visual cues provided by the spatial context, among other factors (HOWARD 2012, CUTTING & VISHTON, 1995). Accordingly, the availability of visual cues is a factor in explaining inaccuracies in size estimation in VL. Understanding the concept of visual cues is essential for Virtual Landscape designers to enhance spatial perception in VL, as it forms a fundamental aspect of VL's framework. Therefore, we should research visual cues to enhance the perception of space in VL design, which is the aim of this research. Researchers have not yet investigated how visual cues affect depth perception. Therefore, the effects of visual cues should be re-evaluated relative to each other in an experimental setup. Misuse of visual cues in VL negatively affects depth perception. This research will fill the gap in the sector as it provides data that will bring the depth perception of the environments projected in VL closer to the actual value.

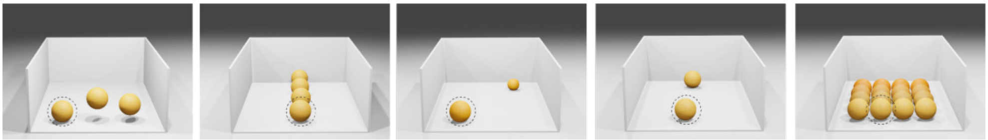
2 Data Collection and Methodology

2.1 Selection of Visual Cues for Experiment

Articles on visual cues affecting depth perception in VL reviewed. The keywords "Virtual Reality, Dept perception, VL, Visual cue" were used in the selection. Seven articles evaluating depth perception through visual cues in the virtual environment were identified among those found using the keywords. The most frequently cited visual cues that affect depth perception in VL are binocular inequality, motion parallax, linear perspective, texture gradient, occlusion, relative size, lighting, and shading (LOYOLA 2016, JAMIY & MARSH, 2019, HURTER et al. 2021, GERIG et al. 2018, HUANG 2022). This study did not use binocular disparity and motion parallax as the display data would have provided them. The other five visual cues (linear perspective, texture gradient, occlusion, relative size, lighting, and shading) are the subject of this research.

2.2 Design of the Experiment

We designed the experiment to find the effect of different visual cues on depth perception in VL. The VL was visualized with Unreal Engine 5, Blender, and Sketch-up. Visual depth sensitivity decreases for some cues at distances up to five meters, while others have the highest effect above five meters (ARMBRÜSTER et al. 2008). Five rooms of 6 x 8 meters were designed to preserve the effects of visual cues. 0.5m spheres and a 0.25m radius sphere were placed inside them. The placement of the spheres was determined to reflect the effect of visual cues. A fixed sphere was placed in the five rooms (Fig. 1) at the same distance from the back wall of the designed room. Placing the sphere at the same distance in each room revealed the margin of delusion as the visual cues changed.



V1 *V2* *V3* *V4* *V5*

Fig. 1: Visual cue representations in the VL

Lighting and Shading (V1)

Room number one represents the visual cue of Lighting and shading. Three spheres stand at the same distance in the room to measure the effect of light and shadow. Two of the spheres stand at different heights to create shadows. The spheres are at three different heights and exposed to the same light, creating different shadows. In this way, the shadow condition determined the comparison of the center sphere with the other spheres to estimate the distance. This setup represented the Lighting and Shading visual cue.

Linear perspective (V2)

Room number two represents the Linear perspective. Four spheres are arranged in a row in the same direction, not exceeding the size of the room, with a distance of one meter between them. Linear perspective is created by making parallel lines in 3D appear to converge towards one or more vanishing points in a projected image as they recede into the distance (HÖHNE & BERNSTEIN 1986). Therefore, the position of the spheres is in a linear succession with the same intervals.

Relative size (V3)

Room three represents the Relative Size visual cue. For this, two spheres are placed in the room, one with a radius of 0.5 m and one with a radius of 0.35 m. Relative size: If two objects are equal, the distant object occupies less field of view than the nearer one (GREGORY 1968). To create this effect, the sphere in front has a radius of 0.5m, and the sphere behind has a radius of 0.25m. In this way, the Relative size visual cue was created.

Occlusion (V4)

Room four represents the visual cue Occlusion. When an object is completely or partially hidden, it is the hidden (occluded) object. The object covering it (the occluding object) is considered to be further away, behind it (GREGORY 1968). According to this definition, There are two spheres with a radius of 0.5 m inside the room. The one behind the spheres is 0.25 m further to the right than the one in front.

Texture gradient (V5)

Room number five represents the Texture Gradient visual cue. The gradual change in the texture surface provides additional clues about the depth of the scenes (GREGORY 1968). The gradual color change creates the visual cue of Texture Gradient. 16 spheres with a radius of 0.5m are placed in the room in four rows. The color change in the spheres is such that the color used in each row gets progressively darker.

The research consisted of two stages. In the first stage, the questionnaire was determined as the second stage, the experiment. Participants were recruited through public spaces on undergraduate and graduate university campuses and public social networks in university groups. It took five weeks to complete the experimental phase of the research. The researchers briefly explained to the participants the purpose and procedure of the survey. In the experiment's first phase, this research created a Google Form questionnaire to collect control variables, including vital socio-demographic variables such as gender, age, and education (Fig. 2). In addition, participants were asked about their familiarity with VL design to assess their VL expertise (Fig. 2). In addition, the qualities of the designed rooms were evaluated as the dependent variable. During the recruitment process, we told the participants that they would be shown virtual landscapes with the monitor and that they would make a distance estimation. We explained that the study investigated visual cues' effect on measuring depth perception in virtual landscapes. For the experiment, 40 people aged 19-34 attending universities volunteered. In the second phase of the experiment, the participants observed the designed VL environment with a standard-sized portable computer (15.6 inches). REMPEL et al. (2007) recommend 52–73cm for eye distance to a computer monitor based on an experiment manipulating viewing distance. Based on this, participants looked at the monitor from an average distance of 52 – 73cm. Participants made their predictions in meters. Participants of the created VL estimated the distance of the sphere indicated (Fig. 1) from the room's back wall to the front in each VL environment. The research team recorded his estimates. An essential methodological issue is the difficulty of measuring distance perception. Since spatial cognition is a psychological process that cannot be directly observed, researchers can resort to indirect methods that may be biased (LOYOLA 2017). Direct verbal estimation is the most common method. In this study, both direct and indirect verbal estimation techniques were used. To improve data quality and avoid problems with time, 40 participants were included in the experiment. The researcher collected data by recording participants' distance estimates. Participants verbally estimated the distance between the sphere and the room's back wall in meters in the interviews. Participants repeated their estimates for five rooms.

3 Results

3.1 Descriptive Statistics of Survey Results

The research consisted of a statistical analysis of 280 records for the experiment with one group in the semi-structured interview. The statistics of the control variables were evaluated. The experiment assessed the participant's familiarity with the virtual environment based on the answers to the questionnaire. 72.5% of the participants stated that they had never experienced Metaverse or similar VR technologies before, while 27.5% had. Participants were asked how often they played PC or console games. 77.5% of the participants stated that they never play digital games. On the other hand, 15.5% of the participants said they play once a month, 5% once a week, and 5% every day.

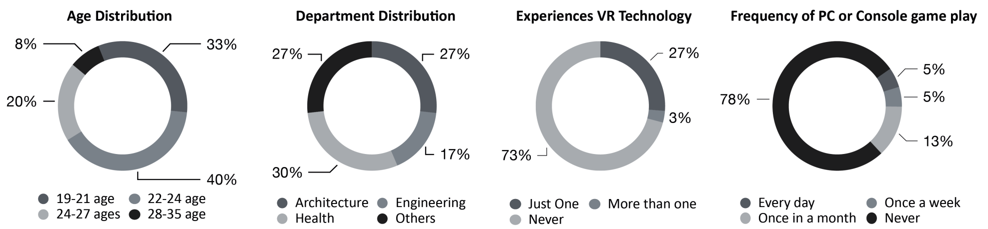


Fig. 2: Socio-demographic variables, their familiarity with VL, and Participants 'familiarity with VL

The collected participant data provided valuable insights into participants' virtual environment experience and gaming habits, enhancing our understanding of their engagement with the experiment.

3.2 Descriptive Statistics of Experiment

The experiment results were presented using descriptive statistics. The mean value of 40 participants was found for each visual cue separately. These values are shown in Table 2. Table 2 shows the sum of the distance estimates for the five visual cues, divided by the number of participants to show the averages. The total distance estimate for the visual cue Lighting and Shading was 272.88, for Linear Perspective 318.93, for Relative Size 312.48, for Occulusion 309.38, for Texture gradient 329.98.

Table 1: Sum and arithmetic mean of the estimated distances

Visual Cues	Estimation Totals	Arithmetic Mean of Estimates
Lighting and Shading	272.88	6.8
Linear Perspective	318.93	7.9
Relative Size	312.48	7.8
Occlusion	309.38	7.7
Texture Gradient	329.98	8.2

Dividing each by the number of participants (40) yielded Lighting and Shading 6.8, Linear Perspective 7.9, Relative Size 7.8, Occulusion 7.7, Texture gradient 8.2. The actual distance is 6.5m. The comparison with the accurate distance is shown in Diagram 1 As a result of the experiment, the Lighting and shading data perceived the distance to be closer to the VL. In contrast, the Texture gradient data perceived it to be farther away.

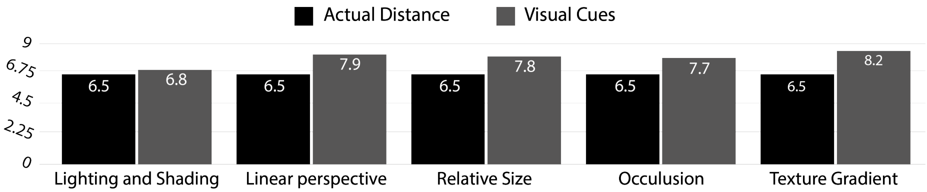


Diagram 1: The comparison between the accurate distance and estimation distance arithmetics

Linear perspective and Relative size data gave an average value with close deviations. Occlusion data provided the closest estimate to the actual distance.

4 Discussion and Conclusion

When Virtual Landscapes (VL) are designed without accurately reflecting the influence of visual cues, it will lead to perceptual issues. Therefore, visual cues that affect depth perception have been the subject of research. The information obtained about visual cues plays a guiding role for landscape architects designing VL. The research was conducted on five visual cues, and as a result, it was found that the Lighting and Shading visual cue was near to the true value, while the Texture Gradient cue was far. Based on this information, manipulations can be made in space designs according to designer decisions, and it is also one of the information to be used in creating the space composition. The expected academic value of the research is to suggest more efficient and effective design techniques for VL for landscape architects by utilizing disciplines such as architecture, cinema, digital games, etc., that are interested in VL design. Also, on an industrial level, landscape architects can focus on using Visual Cues in a VL to produce environments that enhance user-space interaction and reduce perceptual distortions. This research differs from previous research in that it gives the effect of each visual cue on depth perception. In this respect, the results provide detailed information to landscape architects and other researchers. This research shows that the difference in using Visual Cues can initiate a series of studies. As the research shows, we can easily predict that landscape-related virtual content, such as digital games and virtual museums, will aim to increase users' spatial and visual perception. At the same time, this research has limits. We examined only the conditions of visual cues relative to each other. We have not measured the effect of each visual cue when applied in different degrees. Therefore, in future research, we will examine the effect of each visual cue on depth perception in depth to create a research series. This study was made possible with the help of a monitor. However, it's equally crucial to assess whether the utilization of various technologies, such as the head-mounted display, will yield varying impacts or not. There is also a risk of obtaining different results depending on the screen size, which is why more research should be done in the future. However, this study still has potential as a reference study for landscape architects to improve depth perception in virtual landscapes.

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