How Virtual Reality Renderings Impact Scale and Distance Perception Compared to Traditional Representation

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Abstract: Spatial scale and distance are essential attributes of physical space in landscape design. Individuals' perceptions of spatial scale and distance reflect how well they understand a space, and decides how they design the space. This research studies how scale and distance perception in landscape design projects using Virtual Reality (VR) renderings can differ from traditional design representations. This study examines perception of space using three design representation methods: VR simple 3D model, VR realistic rendered model, and traditional representation with the illustrative plan. Fifty-four individuals with design education and practice experience participate in this research. Participants were divided into 3 groups, and every group used one design representation method to estimate the spatial scale of selected space and distance to selected objects. Participants' perceptions are investigated through survey and statistically analysed. This research enriches VR-related studies from the perspective of spatial perception and awareness. It inspires diverse possibilities of future design representation in the design industry and education.

Keywords: Virtual Reality (VR), sense of scale and distance, spatial perception, design communication, design representation

1 Introduction

1.1 Design Representation and People's Perception of Space

The design disciplines depend on graphics, drawing, and multi-types of visual experiences as design representation and visualization to demonstrate the work (TWOSE 2017). Design projects involve multi-sectors interests, where design communication is important to design engagement, development, and implementation (AAKHUS 2007). The multisensory communication achieved by design representation extensively affects design development and communication among stakeholders and designers (BROWN 2002). Design representation aims at mediating the relationship between designers and their products; among designers in a group; and between designers and users (BODKER 1998). However, widely-used rendering technology cannot easily realize the same realism as a picture of the actual scene (SKULMOWSKI et al. 2021). Many design representation methods focus more on demonstration than engagement and communication, which makes the visualization less interactive and immersive. These limitations could affect people's spatial perception, including scale and distance (WANG et al. 2022). Therefore, traditional design representation methods may prevent design participants, especially those without professional backgrounds, from efficiently understanding the spatial scale and distance in the designed space.

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1.2 Virtual Reality (VR) Representation and Design Studies

Since the 1990s, digital landscape representation techniques have rapidly increased, with more realistic 3D visualizations and interactive participation capabilities (LOVETT et al. 2015). VR is one of these advanced digital techniques. VR can be defined as a computer-generated environment that people can interact with as if this simulated environment was real (VAN KREVELEN & POELMAN 2010). In other words, VR technology provides a way of transporting someone to a digital environment where they are not physically there but feel as though they are (REBELO et al. 2012). As an advanced visualization technology with interactive and immersive visual experience, VR technology can bring design participants vivid spatial experiences (ALIZADEHSALEHI et al. 2019) and possibly help them have a better sense of scale and distance perception.

The existing research on VR-assisted representation primarily focuses on four aspects: design visualization, design education, design construction, and design collaboration. Regarding design visualization, researchers have investigated the impacts of VR technology on improving people's perception of design by comparing VR with traditional design representation methods. From the perspective of design construction and collaboration, existing studies have explored how VR and mixed reality could help with the installation and development of landscape construction (KIM et al. 2022), and guide engineers' collaboration in structure and electricity construction (CHALHOUB & AYER 2018). In design education, VR technology is researched to discuss its impacts on online learning, students' participation, performance, and cross-disciplinary education (MILOVANOVIC et al. 2017).

Design perception is a core domain closely connected with design visualization, design education, design construction, and design collaboration (CUI et al. 2022, DUPONT et al. 2014). In the product design industry, existing studies have found that immersive VR can reduce the time stakeholders use to comprehend the furniture design options and improve the designers' design perception in teamwork (PRABHAKARAN et al. 2021). In the Architecture, Engineering and Construction (AEC) industry, VR combined with game design engines and Building Information Modelling (BIM) are also found to be helpful to spatial perception. They can provide better perception environments by creating realistic and immersive design representations, which increases communication quality and construction accuracy (CHALHOUB & AYER 2018, WEN & GHEISARI 2020). In the field of urban planning, landscape architecture, and environmental planning, VR integrated with Geographic Information System (GIS), public open access data, new rendering engines, and geo-design theory are regarded as important technologies assisting design perception and communication (PORTMAN et al. 2015).

1.3 Challenge and Gap

There are many existing studies related to VR technology and design perception. However, they focus more on general design perception and comprehension. Although some studies have investigated VR and spatial perception of design projects particularly, the discussions are still relatively broad. These studies focus more on spatial objects such as buildings, vegetation, streets, water features, and installations. Some studies have involved essential spatial elements of spatial perception, including color, sound, weather, and temperature. However, fundamental elements of spatial perception, such as the sense of scale and distance, still need further and in-depth research.

From the perspective of disciplines, such studies examining the impacts of VR representation on people's scale and distance perception of design projects in the field of landscape architecture are relatively limited. Relevant topics have been involved in architecture, planning, and construction discipline, so similar exploration should be done in the landscape architecture field. Overall, considering the gaps and challenges of current studies about VR technology and spatial perception, exploring the impacts of VR representation on people's scale and distance perception of design projects will be a meaningful research topic in the landscape architecture discipline.

2 Method

2.1 Study Project and Representation Methods

This study uses a 5-acre conceptual park design made by the research team and ZDG group as the study project. The project includes diverse types, scales, and functions of space which are common in landscape projects. The illustrative plan, simple 3D model, and realistic rendered model of this project are prepared for the following spatial perception study. How these design representations are generated and how they will be viewed are explained in Table 1. The VR headsets adopted in this study are two sets of HP windows mixed reality. They are connected to a ThinkPad P1workstation and are used to view the simple 3D and realistic rendered models.

Table 1: Design representation methods and the way to use them

Design representation methods	Software	Viewing method
Illustrative plan	Adobe Illustrator	Using iPad to view the digital version
Simple 3D model	Rhino	VR headsets
Realistic rendered model	Rhino and Twinmotion	VR headsets

For illustrative plan, design elements are visualized with the correct color and basic texture (Figure 1). For simple 3D model, the fundamental shape and geometry of design elements are modeled, and abstract plants are included. No material or texture is added to the simple 3D model, and different materials are represented with different colors (Fig. 2). For realistic rendered model, the correct material, texture, and realistic plants are included. At the same time, the environmental context, such as skylight, shadow, and wind, are involved (Fig. 3).

Fig. 1: The illustrative plan of the study project

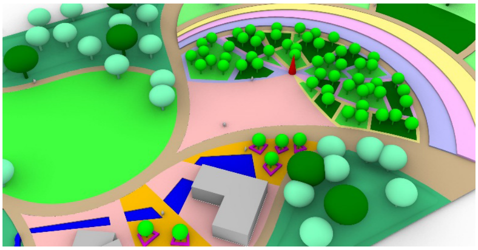


Fig. 2: The VR simple rendered model

Fig. 3: The VR realistic rendered model

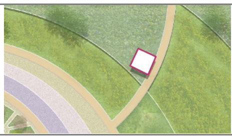
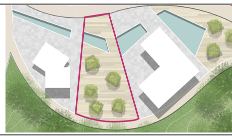
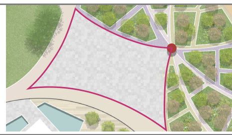
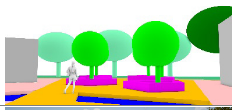
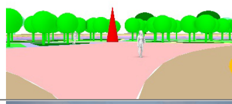
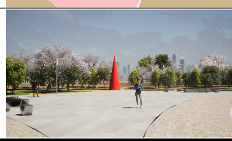
2.2 Study Participants

This study recruits 54 participants with design study or practice experience (in landscape architecture, architecture, urban design, urban planning, and environmental design) from Virginia Tech and several design firms in the U.S. and China. The participants are between 18 and 50 years old, 28 of whom are females and 26 of whom are males. Considering that the familiarity and expertise with spatial scale and distance estimation might vary greatly between people with and without design-related backgrounds. In the research, the comparison between VR renderings and traditional design representation methods is the focus, so the impacts of design experience should be controlled. Therefore, the final selected study participants have 2 to 30 years of experience in design education and practice.

2.3 Study Design

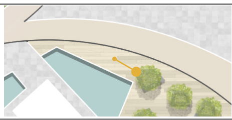
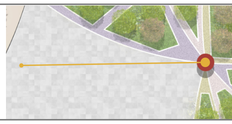
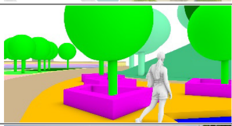
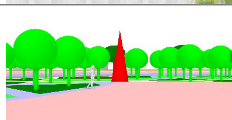
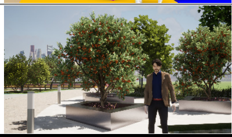
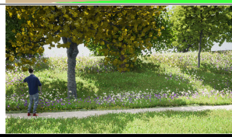
To examine participants' spatial scale perception, 3 types of landscape space are selected in the study project (S-test A, S-test B, and S-test C). The areas of these 3 spaces are from large to small, representing small-scale, medium-scale, and relatively large-scale space, respectively (Table 2).

Table 2: Spatial scale perception study

	S-test A	**S-test B**	**S-test C**
Type	Small-scale space	Medium-scale space	Large-scale space
True scale	25m^2	270m^2	520m^2
Illustrative plan			
Simple 3D model			
Realistic rendered model			

To investigate participants' spatial distance perception, 3 different landscape objects are chosen in the study project (D-test A, D-test B, and D-test C), and their distances to the participants' viewpoint are different (from near to far) (Table 3).

Table 3: Spatial distance perception study

	D-test A	D-test B	D-test C
Selected object	Planter A	Tree B	Sculpture C
True distance	3m	10m	25m
Illustrative plan			
Simple 3D model			
Realistic rendered model			

This study divides participants into 3 groups according to their preference and availability to use different design representation methods. Every group uses one design representation method to estimate the spatial scale of selected space and distance to selected objects. For different groups, participants are asked to either check the illustrative plan or move around the space using VR headsets and controllers to estimate the approximate area of 3 selected spaces. Meanwhile, they are required to either look at the illustrative plan or around the space from a fixed viewpoint to guess the distance between the 3 chosen objects and themselves. To avoid difficulty in judging scale or distance due to the lack of understanding of the project, participants are allowed to know the approximate canopy diameter of the nearest trees. For groups using VR techniques, people models are added as a reference, too. During the experiment, every participant has up to 5 minutes to check the plan or 10 minutes to view the space using VR. After the experiment, participants' answers are investigated through the survey. Table 4 summarizes the study design explained above.

Table 4: Study design summary

	Number of participants	Representation method	Viewing method	Viewing Time	Survey time
Group 1	20	Illustrative plan	iPad	Up to 5 minutes	5 minutes
Group 2	20	Simple 3D model	VR headsets	Up to 10 minutes	5 minutes
Group 3	14	Realistic rendered model	VR headsets	Up to 10 minutes	5 minutes

3 Results

The participants' answers are collected through survey and statistically analyzed with SPSS. The overall descriptive statistics show that people's perceptions of small-scale, medium-scale, and large-scale landscape spaces are different. Participants make fewer errors in estimating the area for smaller spaces than for larger spaces. However, for spatial distance perception, participants make fewer mistakes in estimating the medium distance. Compared to the long distance, more errors are made in short-distance estimation (Table 5).

Table 5: Overall descriptive statistics of the experiment results

	Minimum	Maximum	Mean	Percentage	Std. Deviation
Age	21	49	30.98		7.429
Years of experience	2	30	11.31		7.526
S-test A*	0	20	6.07	24.28%	5.400
S-test B*	0	210	67.72	25.08%	48.544
S-test C*	0	420	138.96	26.72%	101.117
D-test A*	0	5	1.17	39%	1.112
D-test B*	0	5	1.93	19.3%	1.588
D-test C*	0	25	5.78	23.12%	5.012

S-test A* =|S-test A - 25|; S-test B* =|S-test B - 270|; S-test C* =|S-test C - 520|; D-test A* =|D-test A - 3|; D-test B* =|D-test B - 10|; D-test C* =|D-test C - 25|

3.1 Spatial Scale Perception

Table 6.1 and 6.2 shows the ANOVA and Post Hoc analysis of participants' spatial scale perception and 3 different design representation methods. The results indicate the significant impacts of design representation methods on people's spatial scale perception, including small-scale, medium-scale, and large-scale landscape space. It shows that traditional illustrative plan, VR simple rendered model, and VR realistic rendered model can affect people's scale perception differently. Table 6.2 shows that, for S-test A (small-scale space), VR-based rendering does not show a significant difference from the illustrative plan. However, VR simple rendered model and VR realistic rendered model have significantly different impacts

Table 6.1: Over all ANOVA analysis of participants' spatial scale perception and design representation methods

		Sum of Squares	df	Mean Square	F	Sig.
S-test A*	Between Groups	223.939	2	111.970	4.320	.018
	Within Groups	1321.764	51	25.917		
	Total	1545.704	53			
S-test B*	Between Groups	47254.569	2	23627.285	15.520	.000
	Within Groups	77640.264	51	1522.358		
	Total	124894.833	53			
S-test C*	Between Groups	264276.012	2	132138.006	24.273	.000
	Within Groups	277633.914	51	5443.802		
	Total	541909.926	53			

Table 6.2: Post Hoc Tests of participants' spatial scale perception and design representation methods

Dependent Variable	(I) Deign representation method	(J) Deign representation method	Mean Difference (I-J)	Std. Error	Sig.
S-test A*	plan	simple 3D model	-3.350	1.610	.104
		realistic rendered model	1.607	1.774	.639
	simple 3D model	plan	3.350	1.610	.104
		realistic rendered model	4.957*	1.774	.020
	realistic rendered model	plan	-1.607	1.774	.639
		simple 3D model	-4.957*	1.774	.020
S-test B*	plan	simple 3D model	-62.650*	12.338	.000
		realistic rendered model	-3.543	13.596	.963
	simple 3D model	plan	62.650*	12.338	.000
		realistic rendered model	59.107*	13.596	.000
	realistic rendered model	plan	3.543	13.596	.963
		simple 3D model	-59.107*	13.596	.000
S-test C*	plan	simple 3D model	-118.300*	23.332	.000
		realistic rendered model	50.343	25.711	.133
	simple 3D model	plan	118.300*	23.332	.000
		realistic rendered model	168.643*	25.711	.000
	realistic rendered model	plan	-50.343	25.711	.133
		simple 3D model	-168.643*	25.711	.000

on people's spatial scale perception. For S-test B (medium-scale space) and S-test C (large-scale space), there is no apparent difference between the traditional illustrative plan and VR realistic rendered model, but VR simple rendered model shows a significant difference from the other two methods.

3.2 Spatial Distance Perception

Table 7 shows the ANOVA analysis of participants' spatial distance perception and 3 different design representation methods. The results do not indicate any significant difference between the traditional illustrative plan, VR simple rendered model, and VR realistic rendered model. However, for VR simple rendered model and VR realistic rendered model, the accuracy of distance estimation is significantly higher than that of scale estimation according to the survey data.

Table 7: Overall ANOVA analysis of participants' spatial distance perception and design representation methods

		Sum of Squares	df	Mean Square	F	Sig.
D-test A*	Between Groups	1.471	2	.736	.586	.560
	Within Groups	64.029	51	1.255		
	Total	65.500	53			
D-test B*	Between Groups	2.739	2	1.370	.533	.590
	Within Groups	130.964	51	2.568		
	Total	133.704	53			
D-test C*	Between Groups	61.333	2	30.667	1.231	.300
	Within Groups	1270.000	51	24.902		
	Total	1331.333	53			

4 Discussion

Some arguments are worthy of further discussion based on the study results and related data analysis. The results show that participants make fewer errors in estimating the area for smaller spaces than larger spaces. Compared to the traditional illustrative plan, this difference is more evident for both VR simple rendered model and VR realistic rendered model (Table 8.1). This finding implies that, when dealing with the scale estimation of large-scale landscape design or planning, adopting VR rendering might not be very useful, and illustrative plan could be a better choice. On the contrary, VR rendering works better for the area estimation of small-scale landscape designs such as garden, plaza, playground, and small park. In terms of spatial distance perception, the ANOVA analysis fails to find any significant difference between the 3 design representation methods' impacts on distance estimation but the descriptive statistics shown in Table 8.2 might indicate more information. All design representation methods studied in this research show limitations in estimating short distances. However, for short distances, both VR simple rendered model and VR realistic rendered model give a more correct answer than the traditional plan, while realistic rendering works slightly better. This also indicates the advantages that VR rendering has in small-scale landscape projects.

Table 8.1: Descriptive statistics of the spatial scale perception

	S-test A*/ Mean	S-test B*/ Mean	S-test C*/ Mean	Total
Illustrative plan	5.52	43.60	108.20	52.44
Simple 3D model	8.60	106.25	226.50	113.78
Realistic rendered model	3.64	47.14	57.86	36.21

Table 8.2: Descriptive statistics of the spatial distance perception

	D-test A*/ Mean	D-test B*/ Mean	D-test C*/ Mean	Total
Illustrative plan	1.35	2.20	6.60	3.38
Simple 3D model	1.15	1.85	6.20	3.06
Realistic rendered model	0.93	1.64	4.00	2.19

Existing research has found that VR technology can achieve more immersive and realistic visual experiences. Nevertheless, for people with experience in design, using VR rendering to estimate distance and area is not significantly more accurate than using the traditional illustrative plan in this research. The reason might be that estimating the spatial scale and distance from the plan is an important skill of professional designers. For people without design backgrounds, the different performance between traditional illustrative plan and VR rendering might be more obvious. Therefore, "with or without design experience" as another research variable should be considered in future relevant research.

Meanwhile, when comparing VR simple rendered model with VR realistic rendered model, the realistic model tends to work better than the simple model in spatial scale perception while the distance perception keeps approximately the same. It indicates that realistic material, vegetation, people, and environmental context could help people develop a better sense of scale. Moreover, if VR rendering is required for designers in the design process, using it for distance estimation is more helpful than area estimation. In addition, compared with the illustrative plan, the area estimations using VR renderings are relatively smaller than the proper answers, especially for medium-scale and large-scale landscape space. The current experiment done in this study cannot thoroughly answer this question. This might be related to the difference between the VR perspective and the human eye perspective, which requires more research in the future.

5 Conclusion and Outlook

This research examines the role of VR technology in establishing a sense of scale and distance for design participants in landscape projects. It also explores the differences between VR technology and traditional design representation in design perceptions. This research finds that participants make fewer errors in estimating the area for smaller spaces than larger spaces, especially using VR rendering. Among all 3 design representation methods, VR realistic rendered model is most suitable for scale and distance perception in small-scale landscape projects. Among participants with design experience, using VR rendering to estimate distance and area is not significantly more accurate than using traditional illustrative plan. However, the realistic rendered model works better than simple 3D model in spatial scale perception, while the distance perception keeps approximately the same. Therefore, VR realistic rendered model is more suggested for the area estimation in the design process. Overall, this research enriches VR-related studies from the perspectives of spatial perception and awareness. It inspires the diverse possibilities of future design representation in the design industry and education.

This study has only explored a limited scope of VR rendering and spatial scale or distance perception. Future research needs to consider more factors such as participants' background, view perspective or angle, and rendering accuracy. Meanwhile, other design representation methods and VR techniques, such as VR with mobile devices, could be adopted for the next step. In addition, the rapid development of gaming design software and associated technologies is potential to visualize more realistic and immersive 3D scenes. Compared with landscape design modelling and rendering tools, how these gaming design techniques can enhance and affect the spatial perception of design work is worth of further exploration. In terms of investigating and evaluating participants' spatial perception, this study only uses survey with statistical analysis, and the sample size is not large enough. On the other hand, qualitative approaches like in-depth interview and experiment-based approach like visual impact assessment, eye tracking, and vision research could be involved to extensively understand participants' thoughts and obtain more comprehensive findings.

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