Which Tangible or Intangible Elements of Streetscape are More Critical for Pedestrian Comfort? – Focus on Immersive Virtual Reality Simulation

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Abstract: In this study, we present an immersive simulation technique for tangible and intangible elements in a streetscape using virtual reality. We used a simulation production method based on 3D modelling to produce a virtual reality (VR) simulation and created the VR contents using Unreal Engine 4. We conducted an immersive VR experiment and evaluated the influence of the tangible and intangible elements of the streetscape on pedestrian comfort using the analytic hierarchy process evaluation method. Through this evaluation, it was possible to recognize the importance of the intangible elements of the streetscape and confirm that the street planting elements are relatively important. We confirmed the possibility of using VR to integrate and evaluate the tangible and intangible elements of a streetscape on a single platform.

Keywords: Digital twin, landscape simulation, Unreal Engine 4, analytic hierarchy process

1 Introduction

The streetscape is an important urban landscape element forming the image of a city. Among the five elements that make up such an image of a city, the "path" is the street connecting urban areas and allowing mobility (LYNCH 1960). To create a pleasant streetscape reflecting the needs of the citizens, it is necessary for such citizens to participate in the planning and design (HAN et al. 2011). Various countries have provided guidelines for creating pleasant street environments, and South Korea has created guidelines for pedestrian-oriented streetscapes. To plan a pleasant streetscape, it is necessary to actively reflect the opinions of pedestrians. In this process, a streetscape simulation approach is needed, allowing people to intuitively immerse themselves in the planning scenario and reflect their opinions.

Landscape simulations have gradually evolved from 2D into 3D through technological development. The existing general landscape simulation method predicts a landscape using photographs and CG images and evaluates the user preference for a particular landscape (BETAKOVA et al. 2015). With the development of computer technology, it has become increasingly common to build 3D models when simulating landscapes. And with the development of virtual reality (VR) technology, users can experience 3D models not only through 2D media such as displays, images, and videos, but also use VR devices such as head-mounted displays (HMD) to experience an immersive landscape (ATWA et al. 2019). We can also simulate both visual and auditory landscapes using VR (YU 2018).

VR technology is typically used in landscape design and planning fields for a planned and designed reality with components that do not yet exist (PORTMAN et al. 2015). The digital

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twin is a technology for creating a virtual model identical to reality, synchronizing real data to a virtual environment, and simulating it in a virtual world (LEE et al. 2020). VR presents new possibilities in landscape architecture based on various simulations and digital twins. Disappeared landscapes can be re-implemented in VR to preserve them as virtual heritage (WU & CHEN 2020). For a dangerous and difficult-to-access ecological space, we can use a VR simulation to create a management plan (FREEMAN et al. 2021). In the digital transformation of urban design, we can innovate the participatory design method through a gamification method utilizing VR. We can actively accept the opinions of citizens, encouraging participation (SANCHEZ-SEPULVEDA et al. 2019). Immersion is a core perceptual characteristic of VR. Immersion in VR means recognizing a non-physical virtual space as a real physical environment. In an immersive VR system, by wearing the HMD, users can become immersed in a VR space and feel the change of perception and emotion toward a landscape more strongly through various interactions (NOH & LEE 2019). By utilizing the high immersion characteristics of VR, it has become possible to measure and evaluate not only a physical landscape but also the emotional feelings of individuals (JE & LEE 2020). These characteristics of VR can provide new possibilities for streetscape simulations.

This study presents an immersive simulation method that includes tangible and intangible elements in a streetscape using VR. We can predict the visual change of streetscape design elements in real-time through an immersive VR simulation. In addition, we evaluated the importance of the tangible and intangible elements of a streetscape on pedestrian comfort using an analytic hierarchy process (AHP) method.

2 Methods

We produced an immersive VR simulation for a redeveloped street space. First, we set up streetscape simulation elements. Second, a 3D modeling-based VR simulation was applied using Unreal Engine 4 (UE4). Finally, we conducted a survey and AHP evaluation through an immersive VR experiment.

2.1 Research Site

The research site is a street of approximately 300 m in length connected from Gileum Station in Seoul. Because the site was designated as an environmental improvement project by the Seoul Metropolitan Government, it became necessary to plan and design a new street space. An 8-lane road will be next to a sidewalk, and a number of apartments and commercial buildings will be nearby. Because new high-rise buildings will be built next to the sidewalk, the width of the sidewalk will be expanded from 2.5–6 m to 10–12 m.

Fig. 1: Research site: the street near the Gileum Station in Seoul

2.2 Streetscape Simulation Elements

First, we set the streetscape simulation elements. Simulation elements were set by referring to the tangible and intangible elements of the streetscape as classified in a study by Ko (2004). As the tangible elements, representative landscape architecture elements, such as street paving and street planting, were selected. The detailed sub-elements of the street paving, including the color, pattern, size, and texture, were set by referring to the composition of the pedestrian pavement design elements (Choi 2010). The detailed sub-elements of street planting are divided into composition, interval, row arrangement, and tree species, referring to street tree design elements (Shin & Jung 2014) and Seoul's road tree planting and management ordinance. Among the intangible elements, we choose the change of season, the change of sunlight, and the movement of people as simulation elements by considering the design elements that have a relatively significant influence on the streetscape. As the detailed sub-elements of seasonal change, planting changes during the four seasons was set as a detailed element (Han et al. 2011). The other detailed sub-elements are the change of sunlight, shadow, and pedestrian movement by referring to the evaluation elements related to the amenities perceived by pedestrians (Kim 2010).

2.3 3D Modeling Based Virtual Reality Simulation

This study developed a 3D modelling-based VR simulation for a streetscape simulation, consisting of two main steps. The first is 3D modelling. We initially set the 3D modelling range and level of detail (LOD). In this study, we set the 3D modelling LOD by referring to the LOD setting index of CityGML (Groeger 2007). We applied a detailed expression and high-resolution material mapping of objects such as buildings, pedestrian paths, street facilities, and trees directly visible to pedestrians along the street space with the goal of LOD 3. For the buildings forming the skyline of the pedestrian's view were implemented with the goal of LOD 2 and expressed the shape and material of the building through image mapping. We implemented an efficient visualization of the 3D models by reducing the computer computations through this process. Subsequently, various objects such as buildings, driveways, pedestrian paths, and facilities around the site were modelled using Rhinoceros 3D. This process also includes texture mapping for material visualization.

The second step was to build a VR environment and create the simulation contents. UE4 was used to create a VR simulation. The workflow for creating the VR simulation is shown in Figure 2. The completed 3D modelling data are quickly imported into UE4 using the datasmith format. A realistic texture of the objects was achieved using a blueprint system. Then, by utilizing Blueprint, a visual scripting system in UE4, various interactive functions that users can apply were built. Participants can freely change the simulation element options,

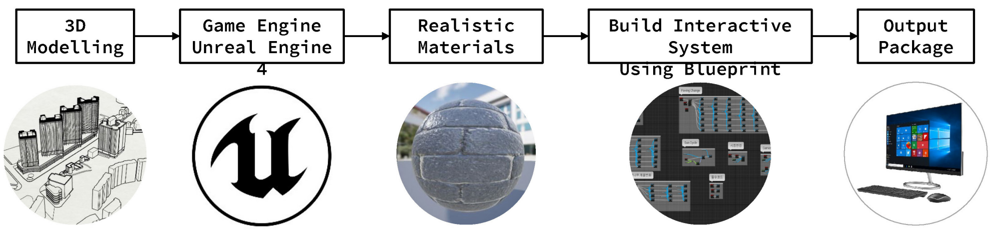

Fig. 2: Workflow of creating a VR simulation contents

such as paving design options and street planting options, using HMD controllers. In addition, we implemented 24-h changes in sunlight and changes in the movement and density of the pedestrian avatar. We also implemented street sounds, including the sounds of vehicles, people, and city background noises. Street sounds were recorded on-site using a sound recording device, converted into WAV format using Audacity, and imported into the UE4. We set the sound to play continuously in a seamless loop. Finally, we exported the completed VR simulation as a package application to run on other PCs.

2.4 Immersive Virtual Reality Experiment

Through an immersive VR simulation, the participants could experience changes in the tangible and intangible elements of the streetscape in real-time. We evaluated the importance of these elements in the comfort of the streetscape using the AHP method. The subjects of this experiment were graduate students in landscape architecture and urban design, and a total of 25 people participated in the experiment. All participants have studied their majors for more than 5 years and have basic knowledge regarding street design and planning.

Fig. 3: Streetscape immersive VR experiment participants

During the experiment, the participants could experience freely immersive VR simulation contents while wearing an HMD. Although the participants were free to experience the simulation elements at their discretion, they had to experience each element at least once. After experiencing the VR simulation, they took a survey evaluating the AHP questions and other questions related to the characteristics of the VR simulation. We conducted a pilot experiment to improve the quality of the main experiment and reflected the participants' feedback in the main experiment.

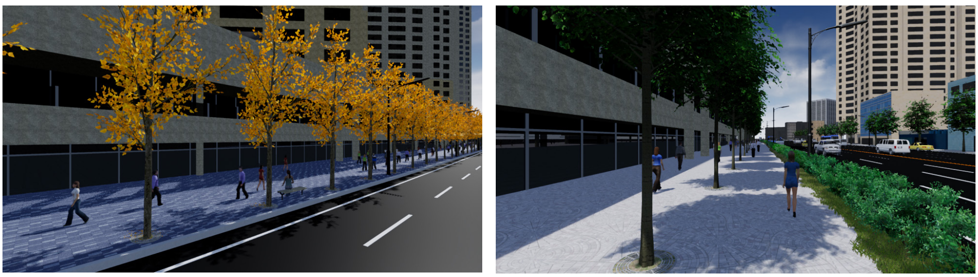

Fig. 4: Streetscape VR simulation display views

2.5 Survey and Evaluation

The survey questions were mainly composed of two types. The first type is AHP questions to evaluate the importance of tangible and intangible elements affecting the comfort of the streetscape as perceived by the pedestrians. We chose the AHP method for this study because it helps measure emotional factors and set the priorities (SAATY 2005). We used a 9-point scale for evaluation and set the AHP evaluation hierarchical structure shown in Figure 5.

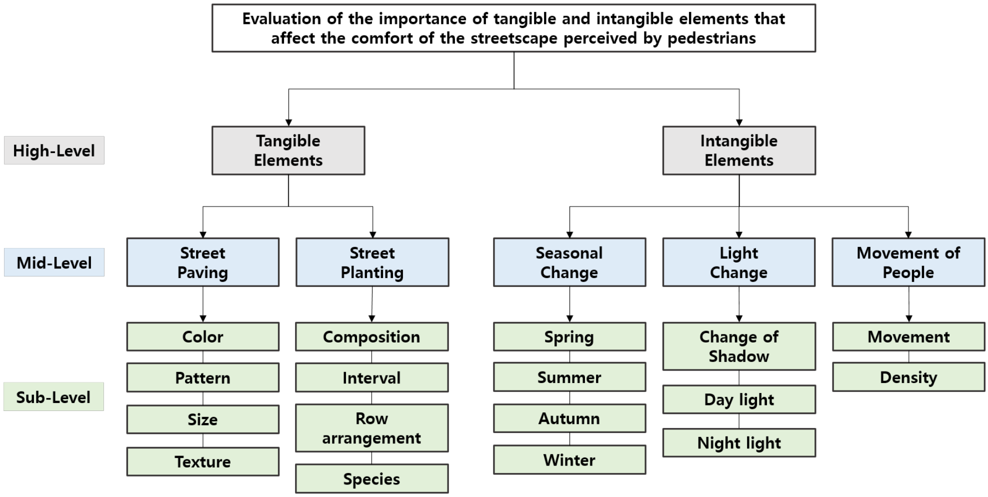

Fig. 5: AHP evaluation hierarchical structure and simulation elements

The second type evaluates the VR simulation characteristics, such as interactivity, immersion, presence, and subjectivity. This part's survey questions (Table 1) were reconstructed based on the questionnaires used in studies by NOH and LEE (2019), who conducted similar VR characteristic evaluations. And we used a 5-point Likert scale.

Table 1: VR simulation characteristics survey questions

Components		Questions
Interactivity		The operation was convenient when changing the simulation elements.
		It reacts immediately when changing the simulation elements.
		The interaction with the simulation elements was interesting.
Immersion	VR Simulation content related	I felt like I was in a real street space during the VR simulation.
		It felt as if the object in VR was right in front of my eyes.
		Objects, trees, and people in VR felt real.
		The sounds in VR felt like the sounds of a real street environment.
		The height of the viewpoint in VR is the same as the real.

Components		Questions
Immersion	HMD device related	The street environment screen in VR was clearly visible
		The resolution of the screen in VR was high
		The picture quality of the screen in VR was clear.
		The viewing angle in VR was the same as the actual viewing angle.
		There was no dizziness during the simulation.
		There was no visual discomfort during the simulation.
Presence	Static element	The street pavement in VR looks real
		Buildings in VR look like real buildings
		The scales of objects, trees, and people in VR seemed to match.
		The material of the object in VR looks real
	Dynamic element	Objects in VR felt as if I could hold them in my hand
		The street environment in VR was full of life
		The light in VR was real
		The plants in VR looked like the real
		Shadows in VR were natural
		The movement motion of human avatars in VR looks natural
Subjectivity		Moving in VR was easy
		I was able to move freely wherever I wanted to go in VR.
		I could comfortably take the position I wanted to take during the simulation.
		When I wanted to change a simulation element in VR, I could do it right away.

3 Results

The results of the AHP evaluation are presented in Table 1. Based on the participants' responses, we calculated the importance of each element and composite importance in each level, such as high-, mid-, and sub-level. The AHP survey results of all participants showed a satisfactory consistency with a consistency ratio of less than 0.2 (SATTY & KEARNS 1985). The overall importance of a tangible high-level element (0.537) was higher than the intangible element (0.463). In the composite importance of mid-level elements, the most important was “street planting” (0.399), followed by “seasonal change” (0.236), “pavement” (0.138), “change in lighting” (0.119), and “movement of people” (0.108). In the detailed sub-elements, “pavement pattern” (0.487), “row arrangement of trees” (0.379), “autumn scenery” (0.433), “change in shadows” (0.598), and “pedestrian density” (0.624) were the most important in each area. In the composite importance ranking of the sub-elements, the most important was “row arrangement of trees,” followed by “autumn scenery,” “planting interval,” and “planting composition.” We find that most elements related to street planting had relatively high importance.

Table 2: AHP evaluation results

High-Level Elements	Importance	Mid-Level Elements	Importance	Composite Importance	Sub-Elements	Importance	Composite Importance	Rank
Tangible Elements	0.537	Paving	0.257	0.138	Color	0.286	0.039	12
					Pattern	0.487	0.067	6
					Size	0.120	0.017	16
					Texture	0.107	0.015	17
		Planting	0.743	0.399	Composition	0.231	0.092	4
					Interval	0.247	0.099	3
					Arrangement	0.379	0.151	1
					Species	0.143	0.057	8
Intangible Elements	0.463	Seasonal Change	0.510	0.236	Spring	0.234	0.055	9
					Summer	0.219	0.052	10
					Autumn	0.433	0.102	2
					Winter	0.114	0.027	13
		Light Change	0.257	0.119	Shadow	0.598	0.071	5
					Day	0.191	0.022	15
					Night	0.211	0.025	14
		Movement of People	0.233	0.108	Move	0.376	0.041	11
					Density	0.624	0.067	7

In evaluating the characteristics of the VR simulation, we received overall positive responses. The mean of the evaluation results shows that interactivity ranks first, followed by subjectivity, immersion, and presence (Figure 6).

4 Discussion

In this experiment, we found that although the tangible elements in the streetscape are still more critical for pedestrian comfort, the intangible elements are also important. It will be necessary to consider intangible elements more in future streetscape designs, such as seasonal change, light change and people's movement and density change. Among the sub-elements, those related particularly to street planting have relatively high importance. Street planting not only interacts with tangible elements but also interacts with intangible elements, such as seasonal changes. The planting design of the street is still an essential element requiring special attention.

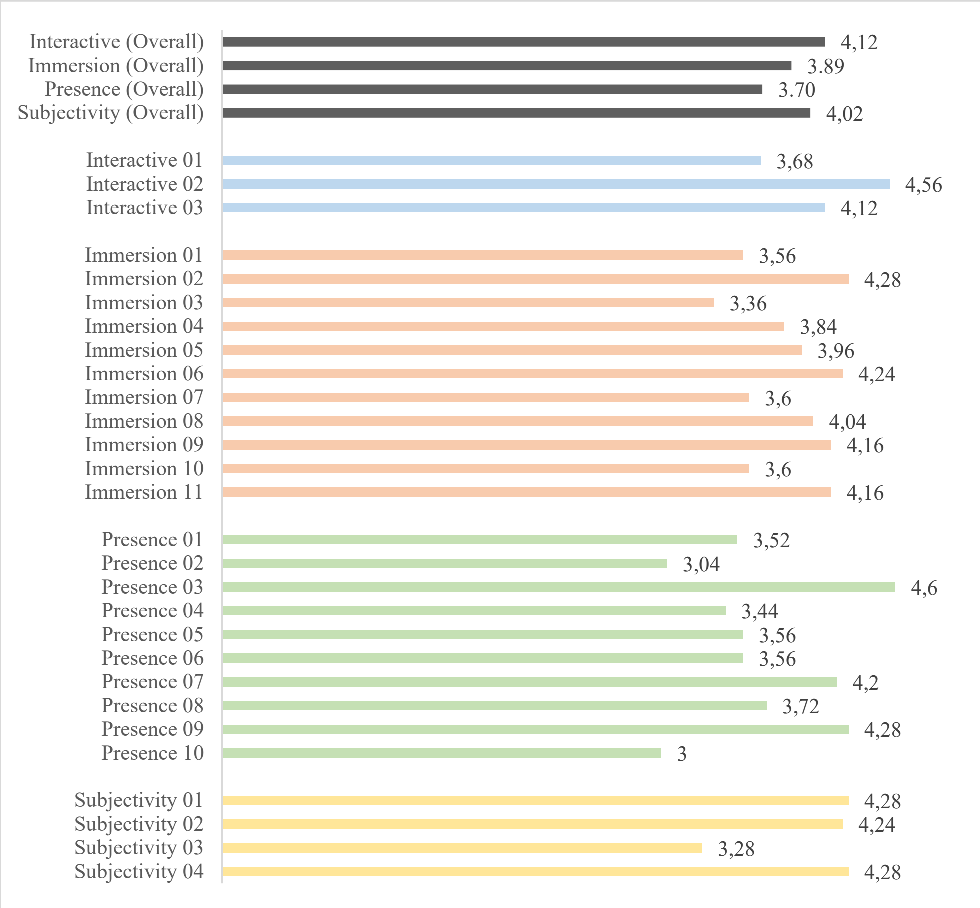

Fig. 6: VR characteristics survey results

The results of this study indicate several points that need to improve to provide a more immersive and present VR environment to the participants. The items that received relatively low scores in the survey were regarding the realism of buildings, trees, and avatar people. Because the realism of the buildings received the lowest evaluation in terms of presence, the realism of objects in VR is related to the static expression of objects such as buildings. In the future modelling and expression of static objects in VR, it will be necessary to use other realistic expression technologies, such as point clouds and photometric modelling technologies to improve this problem. In addition, the realism of objects in VR is also related to their dynamic expression. During this experiment, the participants indicated that the movements of the avatar people in the VR simulation were unnatural, which lowered the sense of the presence of the experience. In addition, some participants said that the tree modelling expressing the movement of the leaves was more realistic than static tree modelling. In future research, it will be necessary to implement dynamic changes more naturally, such as the movements of trees and avatars. In addition, it will be necessary to compare and verify whether there is a difference between immersion in VR and one's sense of presence according to the degree of change in these dynamic elements.

5 Conclusion

This study created a digital twin of an urban street space using VR technology and presented an immersive streetscape simulation method. Through the simulation, the participants were able to experience various VR characteristics. Moreover, various tangible and intangible elements of a streetscape were simulated through an immersive environment from the perspective of a pedestrian. The significance of this study is determining the possibility of a new method for evaluating the tangible and intangible elements of a streetscape on the same platform using VR technology. And also recognize the importance that intangible elements of the streetscape affect the pedestrians' comfort of the street.

This study has certain limitations. First, we did not simulate a large number of tangible and intangible streetscape elements. The streetscape components are diverse and vast, and there is a limit to including all of them in a single simulation. Second, there was a limitation in providing the participants with a sense of immersion and presence in this study owing to limitations of realistic expressions of static objects in VR, such as buildings, and dynamic expressions of objects, such as trees and avatar people. This may be overcome by combining with other realistic modelling expression techniques. Third, there were limitations to the resolution and comfort of wearing about the HMD device used in this study. This is expected to be overcome in the future with the continued development of HMD devices.

Through this study, it was possible to confirm the possibility of using VR technology as a digital twin in the field of landscape simulations. By applying immersive technology such as VR to the landscape field, we were able to improve the existing simulation method and evaluate not only the tangible elements of the landscape but also the intangible elements together. It was also possible to grasp the influence of both intangible and tangible elements on the urban landscape and human perception. Using this VR technology for landscape simulation, we can predict the effects of a landscape on people by building a digital twin before creating the actual landscape. And it will help us to create a more attractive and pleasant urban landscape by understanding the influence of such a landscape and human perception based on various aspects.

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