The Effectiveness of Virtual Reality Simulation on the Qualitative Analysis of Lighting Design

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Abstract: This research explored the effectiveness of virtual reality (VR) simulation on the qualitative analysis of landscape lighting design. An urban plaza in Seoul was selected as the study site. After constructing the existing and proposed lighting models in Unreal Engine, an experiment with VR simulation was conducted. The experiment provided an immersive experience, presenting the plaza model with a lighting-design proposal and assessing the experience with a set of survey questions. The survey results demonstrated that the night environment of the improvement plan was superior in all categories to the existing lighting.

Keywords: Digital twin, outdoor lighting, Unreal Engine 4, Virtual Reality, Gwanghwamun Plaza

1 Introduction

Recently, the number of nighttime activities by urban residents has increased rapidly, and the importance of the night environment quality has increased considerably (KIM 2005). Lighting is an essential factor in the creation of a nightscape that contributes significantly to the safety and comfort of nocturnal city life (PAEK 2007). In the lighting-design process, both quantitative and qualitative analyses are important to assess the proposed design. However, current lighting simulation tools focus primarily on quantitative assessments, producing computational analyses of the physical environment using photometric data inputs and outputs.

There are several programs that enable quantitative analyses by providing 3-dimensional assessment of a proposed design. Relux and DIALux evo are the two most popular applications used for the lighting design of indoor and outdoor environments (SCORPIO et al. 2020). Both software tools generate quantitative analysis of average luminance values using 3-dimensional simulations. The programs report numerical, quantitative results that contribute to lighting-design proposals and to designers' communication with clients or contractors (HONG 2011).

In interior spaces where the architectural elements are solid objects that contain light sources, these analyses are effective tools for the quantitative assessment of the proposed design. However, there are critical limitations when the existing analysis programs are used for the qualitative assessment of outdoor lighting design. First, it is challenging to simulate accurate lighting effects for landscapes with plantings. Second, the continuity of illumination through space cannot be assessed from individual views. Third, the rendered images are low in resolution and lack details; they can only provide limited visual analyses of the design. Programs such as Relux or DIALux evo cannot obtain qualitative assessments, which are often substituted for by rendered model views or photoshopped images.

Virtual reality (VR) technology is used in architectural and landscape design as an efficient simulation technique with interaction, immersion, realism, and behavioral subjectivity. Among many VR systems, game engines can model virtual environments that the user can

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interact with fully. The user can explore the virtual environment through the game engine, making changes and viewing the effects of those changes in real time (SCORPIO et al. 2020). Unreal Engine 4 (UE4) by Epic Games supports an immersive experience and provides real-time renderings that enable instant visualization. The user can walk through the virtual space, look around, and change position with control devices in order to experience the space with illumination continuity. UE4 can generate high-resolution rendered images of lighting design results that can be analyzed instantly. Moreover, the engine can implement changes in different weather, seasons, or times, which is a strong advantage in the accurate assessment of outdoor lighting over time.

Relux
(Gu et al. 2012)

DIALux evo
(https://www.dial.de/en/online-course-dialux-evo-for-outdoor-lighting 2020)

Unreal Engine 4
(Scorpio et al. 2020)

Fig. 1: Comparison of 3-dimensional simulation views

This research explored the effectiveness of VR simulation on the qualitative evaluation of landscape lighting design. An urban plaza in Seoul's central business district was selected as the study site. The experiment provided an immersive experience, presenting the plaza based on a lighting-design proposal and assessing subjects' experiences with a set of survey questions. The goal was to test the utility of VR simulation as a new qualitative analysis tool for lighting design.

2 Simulation Models

Gwanghwamun Plaza is located in the central business district of Seoul. The plaza is a symbolic open space with historical value and statues of strong national characters. Despite the large number of people using the square at night, the plaza's illumination level is very low with only a few spot-lighting fixtures that are focused on statues. There is heavy daily traffic on the boulevard located on both sides of the plaza, creating unpleasant glare and shadows. The current lighting condition of the Gwanghwamun Plaza affects the safety of the users and undermines visual comfort of the plaza.

Fig. 2: Existing night environment conditions at Gwanghwamun Plaza

For the study's model, we utilized a preconstructed 3-dimensional model of Gwanghwamun Plaza. We obtained accurate information about the quantity and specifications of the lighting fixtures in the plaza from the Seoul Metropolitan Government. A series of field surveys were conducted to confirm that the specifications of the lighting fixtures matched the conditions of the actual site. UE4 was used to demonstrate the night environment of the current site and that of the improvement plan.

In UE4, there are two methods of generating lighting. The first is to create lighting fixtures within the software. The second method is to import Illuminating Engineering Society (IES) files to UE4. IES files are photometric data generated from the photometric standard of the Society of Illumination, also used in Relux and DIALux. We could not obtain an accurate IES file of the existing lighting fixtures at the study site, so we generated lighting fixtures directly in UE4.

UE4 allows the creation of point, spot, and rear lights using lumen (lm). Lumen is a measure of the luminous flux emitted at a one-steradian angle. In photometric measurements, the perceived force of light and the total amount of energy emitted are the same regardless of the light distribution (wide or narrow). Based on provided information, we were able to check the lumen values of the lighting fixture installed at the site to replicate that lighting in UE4 and reflect the nighttime status of the target site.

Existing lighting model: overview

Improved lighting model: overview

Existing lighting: eye-level

Improved lighting: eye-level

Fig. 3: UE4 simulation of the existing nightscape and the improvement nightscape of Gwanghwamun Plaza

For the improvement plan, we referred to the open space lighting guidelines in the Seoul Metropolitan Government's Nightscape Design Guidelines (2018). We applied three rules to the lighting-design proposal:

1. The lighting design of the plaza should not interfere with the view during the day or night.
2. The lighting fixtures in the plaza adjacent to the road should not result in glare to drivers.
3. Illuminance should be secured using pedestrian lights, bollards, etc.

Following these rules, we minimized the lighting equipment installed in the plaza to avoid inconvenience to the users of the plaza. In addition, we avoided using down-lighting fixtures such as pole lights in order to avoid any glare for drivers on the adjacent boulevard.

3 Experiment and Survey

After constructing the existing and the proposed lighting models in UE4, we conducted a VR simulation experiment. To start, we implemented a third-person character in UE4 to allow study subjects to experience the night environment by changing their point of view. Before conducting the simulations, we trained subjects so that they were familiar with the VR simulation controls, including specific keys that could move characters or change existing plans and improvements.

We turned the experimental environment into a darkroom and instructed subjects to sit in front of a large monitor. The experiment was conducted with one person at a time, and a total

of 11 people participated in the experiment. The subjects first experienced the existing lighting condition and then compared it with the proposed lighting condition. We provided the subject ample time to freely explore both conditions and to experience the night environment in real time.

Fig. 4: Set-up of VR experiment

After the VR experience, the subjects evaluated the existing lighting and the proposed lighting plan through a survey questionnaire. For items that assessed the outdoor night environment, we referred to the Introduction to Lighting Design (NAKAJIMA et al. 1997), which classifies landscape lighting elements into the categories of safety, direction, security, promotion, identity, and attraction. Because "safety" and "security" can be interpreted similarly, we converted "safety" to "visual comfort" to avoid potential confusion in this experiment (VAN DEN WYMELENBERG & INANICI 2014). The survey question responses were made using a 7-point Likert scale (7=agree very strongly, 1=disagree very strongly).

Table 1: Survey Questions

Category	Question	Response
Visual Comfort	The space is visually comfortable.	7 = agree very strongly 6 = agree strongly 5 = agree 4 = neither agree nor disagree 3 = disagree 2 = disagree strongly 1 = disagree very strongly
Direction	The lighting helps determine where to go in the space.	
Security	Space is a safe environment from crime.	
Promotion	The lighting in the space will improve the image of the city.	
Identity	The lighting in the space illustrates the identity of Gwanghwamun Plaza.	
Attraction	The lighting in the space is attractive.	

Survey results related to the existing model are shown in Figure 5. In the category of "visual comfort," 50% of the subjects chose negative responses (scale 1, 2, and 3), while 25% of the responses were positive (scale 5, 6, and 7). The "direction" and "identity" categories exhibited the most negative responses, as high as 75 – 80% and with little positive response. In terms of "security" and "promotion," the results were similar, as 60% of responses were negative. In the "attraction" category, 50% of responses were neutral (scale 4, neither agree nor disagree). Overall, 61% of the responses to the existing lighting model were negative and 17% were positive. In follow-up interviews, we found that the low illumination level caused by the lack of lighting fixtures significantly influenced the results of the survey. It was the primary reason given by subjects for low scores.

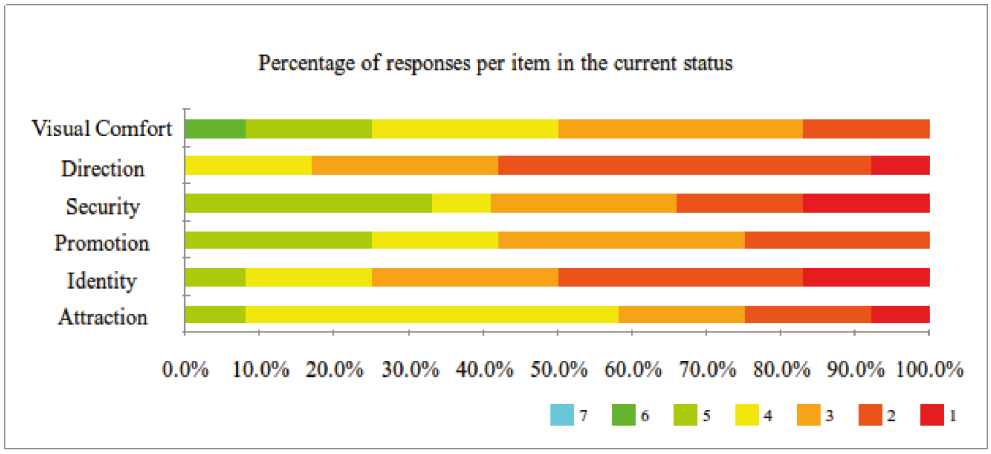

Fig. 5: Percentage of responses per category for the existing lighting

Survey results for the improvement plan are shown in Figure 6. In the "visual comfort" category, 75% of responses were positive (scale 5, 6, and 7) and 25% were neutral (scale 4). The "direction," "security," "promotion," and "attraction" categories showed over 90% of positive responses (scale 5, 6, and 7). The "promotion" category yielded only positive responses while the "identity" was the only category with negative response. Overall, the survey results showed more than 80% positive responses. We found that increasing the intensity of the illumination by adding a lighting fixture had a positive impact on the qualitative analysis.

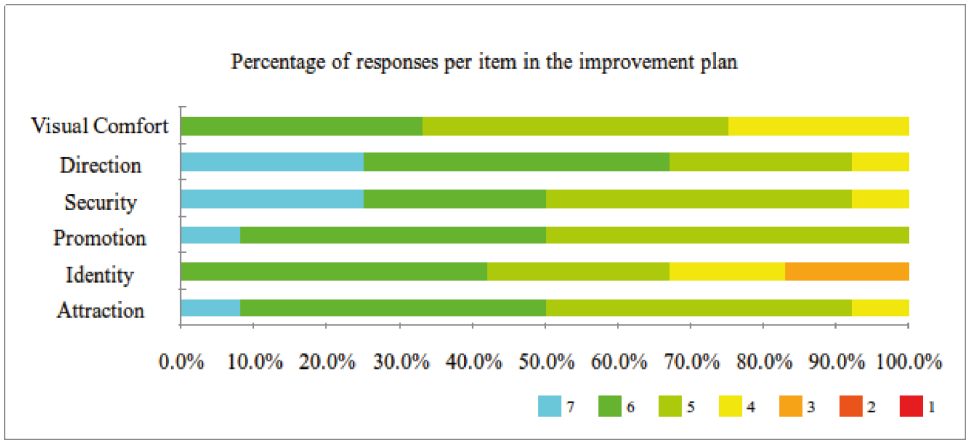

Fig. 6: Percentage of responses per category for the improvement plan

The dramatic differences between the results in Figure 5 (existing lighting) and Figure 6 (proposed lighting) are presented in Figure 7. Comparing the results, we see that the scores were lower for the existing lighting than for the improvement plan in all categories. The score for the direction item showed the most significant increase in the improvement plan, indicating that the lighting elements added by the improvement plan were the most helpful in reading the orientation of the space. In contrast, the visual comfort item score rose by the lowest margin. In sum, the survey results demonstrated that the night environment of the improvement plan was superior in all categories to the night environment with the existing lighting.

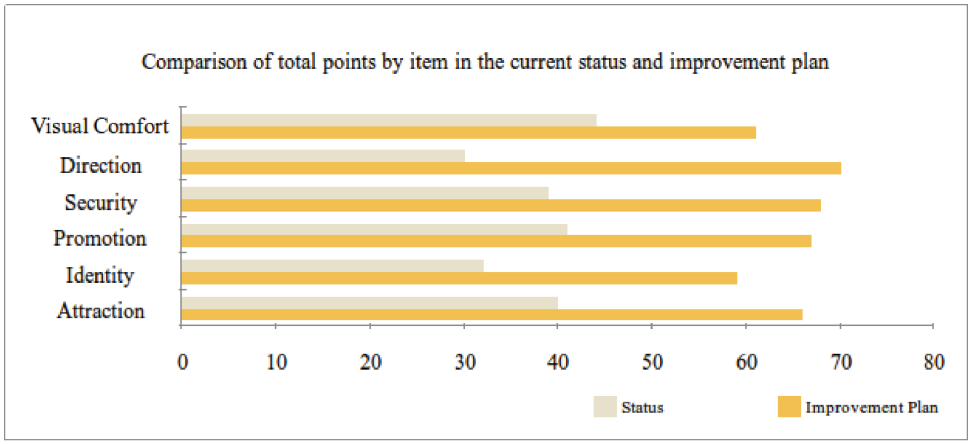

Fig. 7: Total point comparison: existing lighting and improvement plan

4 Conclusion and Outlook

This research explored the utility of VR simulation as a qualitative analysis tool for lighting design. When designers include immersive and realistic VR simulations in the lighting-design process, results show that the VR tool can help recognize a safer and more comfortable nightscape. Ultimately, lighting design using VR simulation can create more pleasant and safer night environments.

This study has several limitations. First, the experiment utilized a large-screen monitor instead of a head-mounted display (HMD), so the user experience is less immersive. Second, nighttime simulations are particularly difficult because there is no accounting for ambient lighting in the VR models. Therefore, the viewing environment needs to match this condition and the subjects must be given an appropriate length of time for their eyes to adjust to that condition. Third, a monitor does not produce enough light to cause the viewer to experience glare. Fourth, the absence of specific IES files that represented the installed lighting of the target site meant that we could not create an identical reproduction of the current lighting environment of the site. A more accurate qualitative assessment of the lighting environment would be possible if researchers utilize the IES file for lighting creation in UE4 and HMD in future, subsequent studies. We believe that the visualization of realistic lighting environments on UE4 and the resulting quantitative data can be sufficiently replaced by the existing lighting design simulation software.

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