How Useful are Virtual Reality Simulations to the Field of Crime Prevention Through Environmental Design? A Case Study

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Abstract: This study aimed to evaluate whether Virtual Reality (VR) technology could effectively simulate a park to reveal the psychological anxiety that the elements and the environment of the park generated in park visitors. VR technology is considered to be highly useful to simulate real-life situations that are otherwise too costly or risky to experience. Therefore, we attempted to utilize VR technology as a simulation tool for Crime Prevention Through Environmental Design (CPTED) process and review, along with conducting a stability evaluation of urban parks with a high crime rate. In this study, we created a computer 3D model virtual space based on an actual city park and then developed VR simulation which can be evaluated at the human eye level using Unreal Engine 4. The prepared VR simulation was conducted through the questionnaires and interviews with participants wearing Head-mounted display (HMD) devices.

Keywords: Virtual reality, unreal engine, landscape design tool

1 Background and Purpose

With the increase in the number of crimes in cities, urban parks have become a major site for the occurrence of crimes. In order to prevent crimes through design interventions, the Crime Prevention Through Environmental Design (CPTED) approach has been applied to many urban parks to prevent criminal activities and increase the sense of safety (YEOM 2017). In CPTED, it is important to consider dynamic environmental factors and ephemeral conditions such as the presence of people, light, weather, time of day, sounds, as well as static design elements. Regarding this, existing research suggests that social and environmental cues may jointly affect experiences of fear and that the presence of other people in a park environment and the gender of an individual may influence the fear of crime when engaging in recreational activities alone in a park setting. (JORGENSEN et al. 2013). In addition to the primary environmental factors reported in the literature, new aspects such as social and personal factors have been proposed to explore how they may evoke fear in park users (MAK & JIM 2018). However, current CPTED approaches are criticized as the evaluation criteria merely focus on designing static elements and there is insufficient consideration of the physical environment for crime prevention in urban parks (SONG 2009).

An immersive virtual reality (VR) simulation of space enables users to experience that space in its totality and interact with it. Potential contributions of VR in CPTED can go far beyond a high-quality visualization tool. Efforts have been previously made to utilize virtual reality technology and incorporate it into space design and CPTED design. In a previous study (KAVAKLI et al. 2004), the researchers tried to create a virtual environment to assess crime risk factors and provide an interface for training novices. Moreover, another study (PARK et

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al. 2008) suggests that simulation tools that utilize virtual reality and augmented reality technologies have the advantage that they can easily modify situations in a virtual environment while avoiding real danger or risk.

The present research investigates the following questions: Can the site elements in a virtual space create anxiety and threaten users' sense of safety? What are the differences in the user experience of image-based VR and model-based VR in day and night time? Can we test a CPTED proposal for design effectiveness and user experience prior to implementation through VR? In order to evaluate the applicability of the immersive VR simulation in the CPTED process, this research aims to examine the effectiveness of VR simulations in terms of spatial perceptions and psychological reactions.

2 Experiment Methods and Process

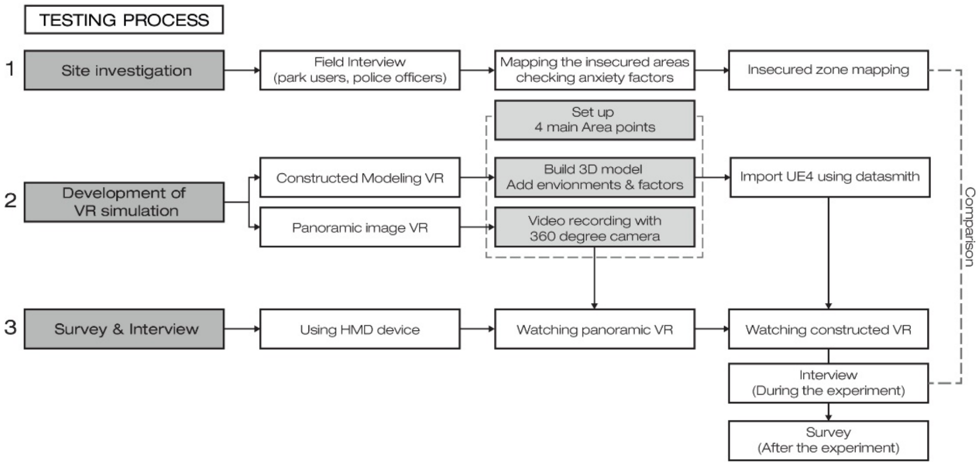

Fig. 1: The three-stage testing process

This research progressed in three stages: site investigation, development of VR simulation, and testing of VR experience through interviews and surveys (Fig. 1).

In the first stage, a site was selected based on its high-crime statistics and potential for improvements. We reviewed 18 parks in Seoul that are graded as "unsafe" by crime statistics. Among them, we investigated seven neighborhood-scale parks under 10,000 m^2 and interviewed park users and local police officers to identify insecure areas and unsafe factors of the parks. A park with the four target areas was selected for the VR experiments.

The second stage was the development of an image-based VR and a model-based VR. Each target area was documented by field mapping and the 360-degree camera at 3:00 pm and 8:00 pm, the most visited day and night times for both park users and loiterers (Fig. 2). The 360-degree video camera was positioned at the center of each target area. A 3D model of the park was constructed using AutoCAD, Rhino 3D, and 3D MAX. In order to provide realistic accuracy, buildings and surrounding environments were photographed to be applied to the 3D model as mapping sources. Subsequently, the 3D model was converted to a VR-ready file using Unreal Engine 4 and Datasmith as a bridging software. Using Unreal Engine 4, 3D objects such as people, vehicles, trees, lighting, sounds, and other objects or site elements to simulate the environment were applied to the 3D model. The cameras in the 3D model were set up at the same time of day and locations as the 360-degree camera (Fig. 2).

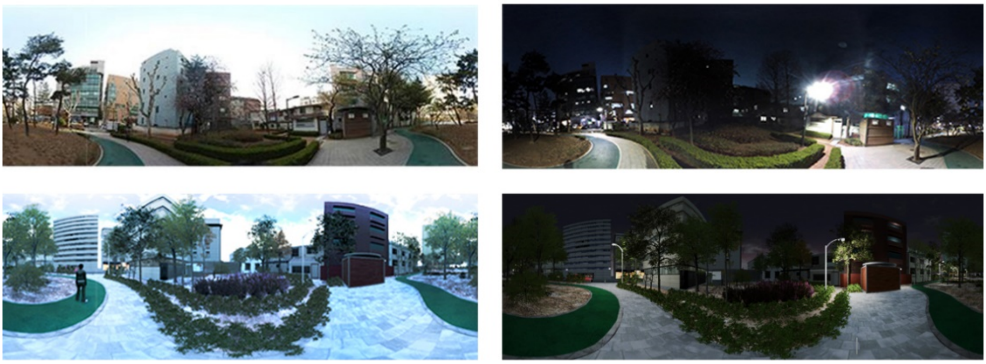

Fig. 2: Day and night time scenes of an image-based VR (above) and a model-based VR (below)

Fig. 3: Participation in the VR simulation experiment

The third stage was the documentation of user experience through interviews and surveys. Thirty students without previous knowledge of the site participated in the experiment. Each participant was positioned in a 3 x 3 m floor space and was instructed to use a Head-Mounted Display (HMD) device for both the image-based VR and the model-based VR (Fig. 3). A 20-min simulation was viewed as the interviewer simultaneously asked pre-determined questions and the interviewees responded verbally or marked the answers directly in the simulation. After the simulation, a survey was conducted with questionnaires comparing the experience of an image-based VR and a model-based VR.

3 Testing Result

The results of the experiments confirmed that the areas in the virtual space marked by the participants as the ones that made them feel anxious and insecure generally matched with the field investigation responses. Most non-matching portions were detected along the edge of the park. We determined that one of the reasons for this was the lack of details in the street-side 3D models of the surrounding blocks. Psychological anxiety can be influenced by the surrounding environment. The dynamic changes in the real environment around the park, such as lightings from buildings and streets or blind spots between cars parked on the street, can be important conditions that can affect users' psychological anxiety (Fig. 4).

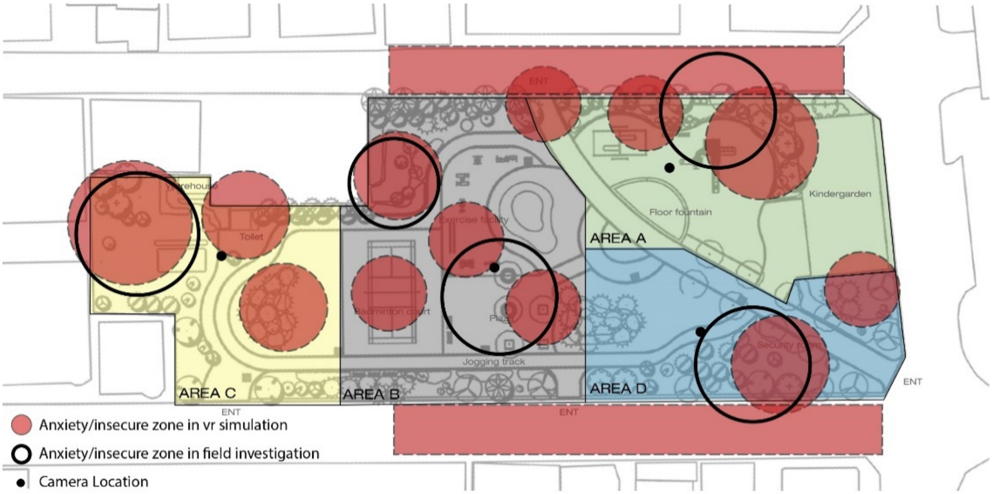

Fig. 4: Comparison of anxiety locations in real space and virtual space

Each area indicated in Figure 4 is a major part of the park, and all of them are of a similar size (approximately 1,000 square meters). Area A is a nursery area, which means that it has a room with a kindergarten and a playground. Area B is located in the sports facilities and the square. Area C is the area near the warehouse and toilet. Area D is located near the main gate of the park.

It is important to analyze the night-time environment in particular in addition to the daytime and reflect it in the CPTED design because the night is more dangerous than the daytime in the park. The presence of park visitors, homeless people, and offensive elements, and reduced visibility owing to night lighting have all contributed to the high crime levels. Korea's night-time parks are at risk for crimes because of limited use stemming from the inaccessibility for many users (CHOI & KIM 2001). Fisher and Loewen's study concluded that diminished night lighting is a common affecting factor in crime anxiety (FISHER & NASAR 1992, LOEWEN et al 1993).

Therefore, we administered a questionnaire to identify environmental and physical factors that were perceived as more dangerous at night. The responses of the questionnaires on the degree of anxiety experienced in areas A to D were marked on a Likert scale ranging from 1 (very safe) to 5 (very insecure) points. The result shows that the most insecure area was B, with an average value of 4.67 and a standard deviation of 0.55.

Participants' anxiety was influenced by not only factors in the immediate surrounding but also by far-off factors. Figure 5 shows the images of the elements who were reported as dangerous by the participants. People engaged in passive activities, such as loitering, drinking, or smoking, were the main factors of anxiety, and the degree of anxiety was affected by the distance from these people. Further, participants' anxiety was also affected by the presence of other park users in their vicinity. In the case of female participants, their anxiety decreased in the presence of other women in the park. These human factors should be considered as essential indices in the CPTED evaluation of parks; however, they are currently not included in the evaluation index.

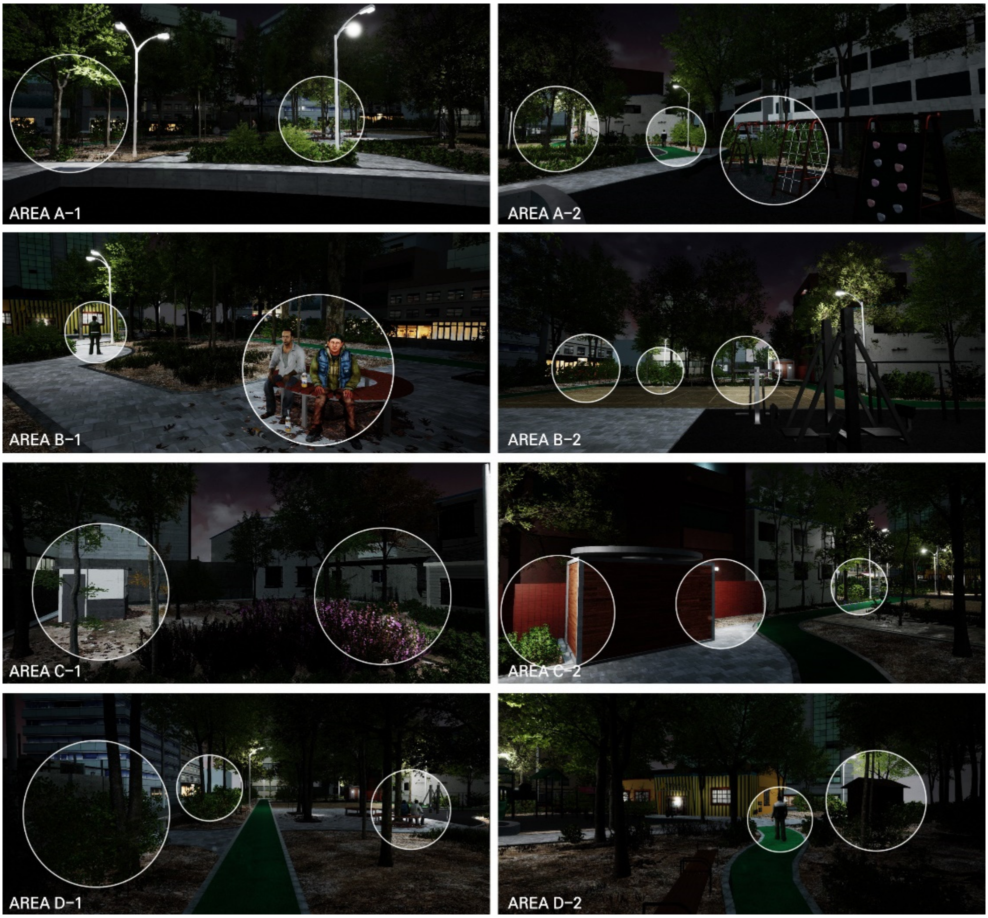

Fig. 5: Insecure factors in Areas A to D in screen-captured views

Table 1: Anxiety factors by area

Area	Anxiety Factors	Participants responded (%)
A	1. Darkness caused by the absence of streetlight	96.7
	2. Shielding/boundary planting of trees	86.7
	3. Presence or absence of building light	80.0
	4. Presence or absence of park users	73.3
	5. The form and materials of the building	60.0
	6. Shielding/boundary planting of shrubs	40.0
	7. Floor paving materials	26.7
	8. Parked vehicle	13.3
B	1. Homeless / drunken people	100
	2. Garbage (bottles, cigarette butts, newspaper)	80.0
	3. Presence or absence of park users	70.0
	4. Tree (blocking the street lights)	46.7
	5. Shielding/boundary planting of shrubs	36.7
	6. Location of CCTV	30.0
	7. Empty security house	26.7
	8. The form and materials of the building	13.3
C	1. Darkness caused by the absence of streetlight	96.7
	2. Shielding/boundary planting of shrubs	96.7
	3. Empty temporary buildings	96.7
	4. A blind spot between buildings	90.0
	5. Presence or absence of building light	86.7
	6. Toilet	83.4
	7. Shielding/boundary planting of trees	73.3
	8. Distant homeless / drunken people	60.0
	9. The form and materials of the building	60.0
	10. Presence or absence of park users	26.7
D	1. Darkness caused by the absence of streetlight	96.7
	2. Empty security house	83.3
	3. Presence or absence of building light	70.0
	4. Shielding/boundary planting of trees	60.0
	5. The form and materials of the building	60.0
	6. Presence or absence of park users	40.0
	7. Shielding/boundary planting of shrubs	40.0
	8. Parked vehicle	40.0

The specific factors causing psychological anxiety and the response ratio are indicated in Table 1. In addition to psychological factors, physical characteristics such as buildings, trees, and other objects, and blindness or blockage of the field of vision due to environmental factors such as the radius of the light from a streetlight were also major anxiety factors. This result suggests that blind spots due to physical and environmental factors should also be recognized and tested in a VR simulation.

The evaluation of the crime risk of domestic urban neighborhood parks is mostly carried out by field inspection based on a checklist. However, the park has various conditions that cannot be confirmed during a field survey, especially the presence of homeless people or strangers. However, it is difficult to determine when they come to the park. Additionally, if they are notified and the police are dispatched, homeless people cannot be apprehended unless they engage in any threatening behavior. As such, park users object to the presence of homeless people in the park but there is no easy way to solve this problem.

Table 1 presents the results of the experiment. In addition to the factors used in the existing CPTED checklist (size and type of trees, brightness of street lamps, etc.), the type and number of park visitors and the presence of homeless people affected the anxiety experienced in the park. Therefore, it is necessary to include such movable elements in the park as an index for evaluating its safety.

Table 2: Survey results by categories

Category	Question	Average	SD
Materiality	Q1. Things look natural.	4.00	0.59
	Q2. The VR space looks like the real world.	3.47	0.82
Degree of actual environment	Q1. Daytime in panoramic video coincides with the VR simulation.	3.20	0.91
	Q2. Night-time in panoramic video coincides with the VR simulation.	3.87	0.78
Realistic Immersion	Q1. While experiencing the VR simulation, this place felt real.	4.23	0.73
	Q2. Upon experiencing the VR simulation, the park seemed to be real.	3.70	0.79
Unnaturalness	Q1. In the VR simulation, things, people, and trees felt artificial.	2.63	0.85
Fatigue	Q1. I felt dizzy while experiencing VR.	2.83	1.42
	Q2. Eye fatigue increased while wearing HMD	3.00	1.31
	Q3. I can focus on the VR simulation through HMD.	3.17	0.75
Screen quality	Q1. I can watch the view clearly while wearing HMD.	3.23	1.25
	Q2. The resolution of the HMD screen is high.	2.83	1.05

The survey results were analyzed in six categories: Materiality; Degree of resemblance to actual environment; Realistic immersion; Unnaturalness; Fatigue; and Screen quality. The "Screen Quality" and "Fatigue" categories were added because they could differ according to the display performance of the HMD device. The survey was conducted with four to six questions for each category. The analysis of the results by these categories is presented in Table 2. The questionnaire survey was conducted using a 5-point Likert scale. The results of the questionnaire were analyzed using mean and standard deviation based on a recent study (LEE 2018).

In the analysis, the Materiality of the VR simulation was about 4.00 on average, but the Degree of resemblance to actual environment was lower than the average. This may be because, although the participants were able to perceive space and objects in the virtual space, the VR simulation may have felt different than an actual space.

There was a difference in the degree of resemblance to the actual target area according to day and night times. The day time and the night time 3D models were the same; therefore, this result could be interpreted as the differences in saturation, texture, and the light reflection degree of the object. However, in CPTED simulations, crime safety during the night is more at risk, and it is rather advantageous that the same degree of night time space was generated.

Regarding realistic immersion, the participants could feel that they were inside a VR space. This means that the HMD device imparts an adequate sense of perspective to the participants. However, the inadequate quality of mapping and graphical problems in the production of 3D objects were the reasons why they could not feel they were in a real space and were observing real physical objects. In the future, these issues should be improved.

4 Discussion and Conclusion

This study highlights the potential of VR simulation and experimental evaluation for improvements in landscape design. Based on the results of this research, we anticipate that VR simulation technology can be used in CPTED in various ways. For example, the physical and environmental elements relevant to CPTED such as lighting, shading, sounds, and movement can be simulated and tested. While a real space provides more accurate conditions of a site, the virtual space can be used as a useful testing bed for design remedies for problematic conditions. VR simulations can be used to engage with ordinary users for CPTED evaluation in a safe setting.

However, we also identified limitations to the technology: the lack of technical expertise in the production of the simulation for specific areas such as lighting and animation programming, and the lack of appropriate methods to verify the analysis of the simulation evaluation. The survey result indicated the association of psychological anxiety and spatial perception in VR simulations, but it could not measure the degree of individual elements in this research context. Therefore, more accurate and reliable analysis methods need to be developed. An experimental simulation experience should be provided, and further reviews should be conducted regarding items on the CPTED evaluation lists.

VR simulations can be used during the landscape design process for various outdoor spaces. Because the use of outdoor spaces is influenced by dynamic elements such as light, sounds, weather, and seasons, these conditions must be considered in the design's assessment. Although it is difficult to predict the environmental conditions and the dynamic elements of a landscape, it is possible to program those factors for simulation and testing in a virtual space. Since VR technology can be utilized as an active design tool in addition to simulation, it is also important to link the technology with other tools such as computer programming for a more efficient and ultimately effective landscape design.

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