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Article

Natural Surveillance for Crime and Traffic Accidents: Simulating Improvements of Street Lighting in an Older Community

Yeo-Kyeong Kim, Yun-Kyu Lee, and Donghyun Kim *

Department of Urban Planning and Engineering, Pusan National University, Republic of Korea

* Corresponding author (donghyun-kim@pusan.ac.kr)

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Abstract
This study aimed to plan an alternative for community street lighting in an older community by simulating illuminance improvements. We applied the natural surveillance principle of crime prevention through environmental design to an older community in Busan Metropolitan City in South Korea. We conducted four field investigations to identify lighting sources and measure their illuminance and heights. Using the Relux Pro program, the gaps in lighting were identified and alternative plans for improvement for night lighting were simulated. Narrow alleys and houses were sources of light disruption and lighting blind spots. We determined the location and type of lighting within the community and considered the continuity necessary to meet natural surveillance standards in alternative settings. We considered visibility, facial recognition, the risk of traffic accidents, and other variables (i.e., lamp type). Our results confirmed that the community's average horizontal illuminance met the requirement of the Korean Agency for Technology and Standards and the minimal illuminance criterion of the International Commission on Illumination in all community lighting spaces—which was improved by about 2.2% to 85.7% compared to the previous situation. The results of this study are meaningful in that they present an effective planning support tool using simulation methods to establish community street lighting alternatives and determine their suitability.

Keywords
Busan; facial recognition; illuminance; natural surveillance; Relux Pro; street lighting; walkability

Issue
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1. Introduction

Walkability is important in community planning. Community walkability creates various social effects, such as social interaction enhancements, community interests, and invigoration for local businesses. Personal health promotion, such as reducing the risk of obesity and preventing chronic diseases, is another benefit (Chen & Zhou, 2016; Lund, 2002, 2003; Osama & Sayed, 2017). The quality of community walkability is determined by various factors, such as the subjective quality of the walking environment, access to parks, public open spaces, environment for bicycles, access to retail stores, and safety (Clifton et al., 2007; Lund, 2002, 2003; Sugiyama et al., 2014).

The elements constituting community walkability can be divided into two main categories: the physical environment, which comprises the community as related to the ability to walk, and safety of walking. Existing studies on walkability have focused on communities' physical environments (Oakes, 2004; Riggs, 2014). Those studies discuss how communities' environmental factors exert a major influence on walkability, even after considering related individual socioeconomic characteristics and preferences (Cao et al., 2009; McCormack et al., 2012; Norman et al., 2013). Regarding safety, previous walkability studies have examined the risk of crime and traffic accidents, both of which threaten pedestrian safety, but which are approached differently. Newman (1973) suggested that discussions related to crime must be examined through the crime prevention through environmental design principle, while discussions related to traffic accidents should focus on the relationship between pedestrian accidents and environmental conditions (Kim & Park, 2017; Lee & Lee, 2019; Woo & Yu, 2017).

Discussions regarding crime prevention through environmental design related to crime focus on three conditions that increase pedestrians' fear of crime: darkness, disorder, and being alone in a threatening situation (Painter, 1996). Darkness is related to visibility in a walking environment, which is linked to fear because facial recognition of people and objects is reduced. Even after considering that fear originates from various levels of individual psychological factors, a basic requirement of the physical environment to resolve fear is to secure visibility with nocturnal street lighting (Kyttä et al., 2014; Nasar et al., 1993). In a nighttime walking environment, factors like adding CCTV, police patrolling, and increasing lighting enable natural surveillance and make people feel safer (Armitage et al., 2011; Marzbali et al., 2012; Welsh & Farrington, 2008).

Discussions related to traffic accidents focus on physical environmental factors that create a high risk of accidents. Regarding walkability, many pedestrian traffic accidents occur in residential areas and about 50% occur on community roads (Park et al., 2020). The higher the ratio of commercial areas, the higher the risk of traffic accidents while walking (Ukkusuri et al., 2012); wider roads and higher speed limits are also associated with increased risks of pedestrian traffic accidents (Chen & Zhou, 2016). The higher the density of intersections and public transportation in a region, the more pedestrian safety is threatened (Dumbaugh & Li, 2010; Woo & Yu, 2017). An increased ratio of sidewalks separated from roads is associated with a higher risk of pedestrian traffic accidents and a lower level of damages from accidents (Osama & Sayed, 2017; Woo & Yu, 2017). The brightness of lighting on the road in communities increases visibility for both drivers and pedestrians, thereby reducing traffic accidents, while having no light at night decreases the distance at which drivers can recognize a subject, increasing the risk of traffic accidents (Park & Byeon, 2012).

Street lighting at night is required to create a physically walkable environment that increases the safety of pedestrians in respect of both crime and traffic accidents. Visibility increases concomitantly with the level of luminosity, which also increases safety perceptions (Blöbaum & Hunecke, 2005; Boyce et al., 2000). Street lighting enables natural surveillance by facilitating facial recognition and is key to walking safely in a nighttime environment (Kim & Park, 2017). Street lighting can be measured using illuminance and the minimum illuminance required for pedestrians' safety varies according to the surrounding conditions and lighting class. The Commission Internationale de l'Eclairage's (2010) presents requirements for facial recognition per lighting class. In Korea, the Korean Agency for Technology and Standards (KATS) suggests a lighting standard for roads—Korea Standard Association (KS A) 3701—according to traffic volumes and area characteristics (residential or commercial; KATS, 2019).

The studies on community walkability mentioned above focused on various environmental requirements for walkability but are limited because they did not discuss the safety of the walking process at the community level. Safety from crime or traffic accidents must be ensured for pedestrian walkability in communities. In older communities, narrow alleys, mixed roads for pedestrians and cars, illegal parking, and restrictions on installing street lighting reduce safety. Therefore, this study started with the following research question: What alternative plan for street lighting can increase visibility in communities, and what is its effect regarding basic requirements for improving walkability in an older community?

The scope of studies on smart cities varies. The spectrum is wide, ranging from technical applications for smart cities, to smart tools that can make existing plans more effective. Existing planning processes for establishing community alternatives focus primarily on how participatory processes can be designed and how opinions can be constructed. In terms of the tool that communicates most effectively with citizens, many cases favor participatory planning techniques, and studies discussing the use of visualized simulation tools are scarce. Visualized results of alternatives and ideas discussed by citizens during the participatory process can raise the discussion level during said process, and possible changes in these communities can only be imagined. This study explores the applicability of Relux Pro as a smart tool that can be used when engaging citizens in the planning process.

This study aimed to use a simulation to derive an alternative plan for street lighting that could improve nocturnal safety in an older community. The target area was the community around Bongrae Elementary School in Yeongju-dong, Jung-gu, in the Busan Metropolitan City (BMC). This community is a typical example of older communities in Korea that were formed since the 1920s, and still exist. Narrow roads, dated infrastructure, and increased traffic volumes have impaired walkability in the community. Issues related to pedestrian safety at night were raised during a workshop with community residents in June 2021, and this study was initiated based on the need for residents to plan alternatives to reduce the risk of crime and traffic accidents. From August 3 to 14, 2021, four field investigations assessed the status of the community's street lighting. The community was then divided into six zones and, considering visibility, facial recognition, and traffic accident risks, an alternative plan was derived according to the standard of installing similar lamps for consistency with the surrounding street lighting. Finally, to determine the plan's effectiveness, simulations were conducted with the existing status and the improved status under the alternative plan, using Relux Pro to evaluate whether the required illuminance for safety had been met.

2. Materials and Methods

2.1. Study Area

The area studied was the community around Bongrae Elementary School located in Yeongju-dong, Jung-gu, BMC, in South Korea (Figure 1). BMC began to develop with the opening of the port in 1876. During the Korean War, the population increased rapidly, and naturally occurring dwellings with insufficient infrastructure formed around hilly areas. Currently, urban decline is continuing, concomitant with a continual population exodus and an increase in the number of vacant houses (Kamata & Kang, 2021). This community is representative of old town communities in BMC. It was established in the 1920s and grew over time, many of its residents being refugees from the Korean War. The community's characteristics include many narrow alleys and outdated buildings, as well as various facilities such as public offices (e.g., the Yeongju 1-dong Community Center), religious facilities, hospitals, and local markets, all in proximity of Bongrae Elementary School. Vehicle and pedestrian roads are mixed, and illegal parking frequent occurs because of a lack of parking facilities.

The community's biggest concern is children's safety regarding traffic accidents. Residential and commercial facilities have many entrances and exits, and the consequent high risk of traffic accidents to children is exacerbated by illegal parking and mixed road usage. The roads are narrow and complex, creating many areas with lighting blind spots, and installing adequate lighting would be challenging. Although streetlights are installed, the level of brightness throughout the area is not the same, with some sections having many dark areas. Natural surveillance in the community is difficult and leads to the possibility of being exposed to various risks, such as crime and traffic accidents.

2.2. Data

To understand the current conditions related to street lighting in the study area, we conducted four field studies from August 3 to August 14, 2021. The location of street lighting, illuminance, height of the light source, number of streetlights in the community, and types of lamps were identified. The investigations were conducted between 20:00 and 22:00, using a TES-1330A illuminometer and a Murray laser rangefinder D-35. Measurements were performed four times for each streetlight, and the luminous (lm) was calculated using the mean of the values. The location of street lighting was investigated based on road lines.

2.3. Simulation Methods: Relux Pro

Relux Pro is a software program produced by Relux Informatik AG, which is used for simulation analysis of street lighting in communities (Kim & Park, 2017). This

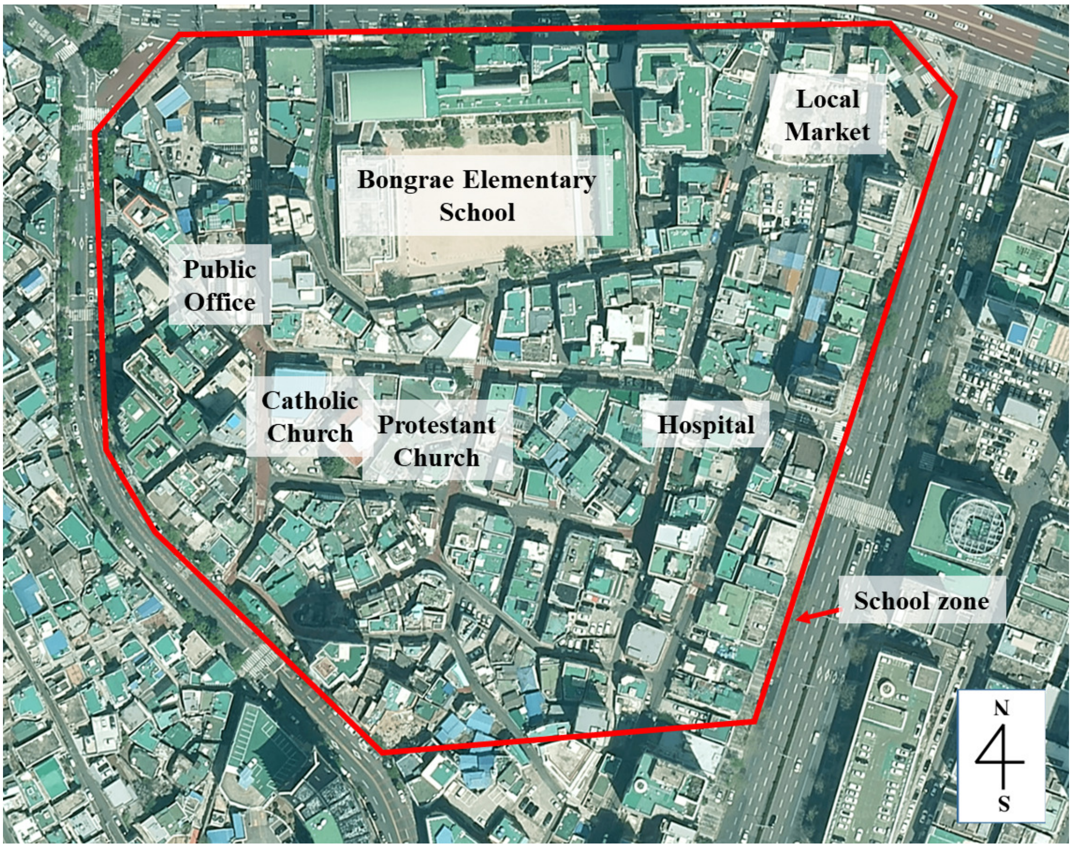

Figure 1. Study area.

study used Relux Pro to compare the current conditions with conditions after the development of an improvement plan. First, a base map of the research target area was required for the simulation. The numerical topographic map provided by the National Geographic Information Institute was used as the base map. The height buildings' floors were set at 3 m and the pilot part was the number of floors. Facilities on the roof of a building were considered an additional floor. The data on street lighting collected through the actual measurements were applied to the base map. Lamps providing street lighting were matched in Relux Pro by utilizing the lumen level and lamp type of each streetlight, and Philips Digi Street BGP671 and BGP760 were applied.

3. Results

3.1. Current Street Lighting Status

The current status of street lighting in the study area is shown in Figure 2 and Table 1. There were 74 streetlights in total. The average height of installed streetlights was 5.37 m and the average illuminance was 122.83 lx. The average luminosity was 3233.17 lm. The site under study was demarcated into six zones based on the main street and the central facility, Bongrae Elementary School, to facilitate the determination of the illuminance in the study area. Zone A contained 15 streetlights, Zone B had 13, Zone C had eight, Zone D had nine, Zone E had 21, and Zone F had eight. Zone F was the brightest and Zone E the darkest.

3.2. Alternatives to Improve Street Lighting for Community Safety

Four factors (visibility, facial recognition, traffic accident risk, and others), were used in this study to derive a natural surveillance alternative through street lighting (Table 2). Common alternatives were applied to all zones. First, the new street lighting took the height of the existing street lighting into account but installed it at 3–5 m above ground level. Visibility was set at 3–5 m, considering the BMC Nightscape Guideline's (BMC, 2020) installation standard of 3 m, and the average installed streetlight height of 5.37 m in the surveyed study area. Second, recognizing pedestrians became possible by applying KS A 3701 (KATS, 2019). It should be borne in mind that drivers should be able to see pedestrians, and that facial recognition between pedestrians also depends on the levels of road lighting, pedestrian traffic, and land use. This study applied the standards of KS A 3701, considering the characteristics of each zone. Third, in consideration of illegal parking and mixed-use roads, pedestrians and drivers could identify all movable obstacles on the road. To consider the traffic accident risk, each zone's characteristics were identified prior to deciding the new location of streetlights according to the standards of KS A 3701 (KATS, 2019). Fourth, similarity with the lighting of the surrounding area was maintained. Regarding the consistency of street lighting in

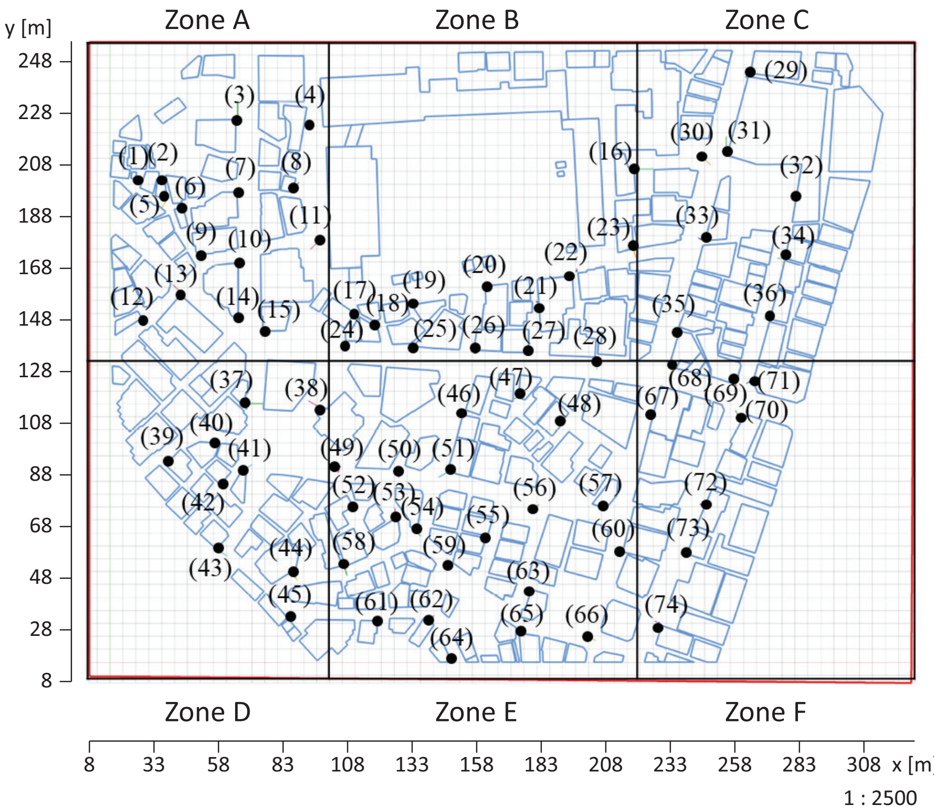

Figure 2. Current street lighting. Note: Black points indicate current street lighting.

Table 1. Lighting conditions.

Zone	Number of lights	Illuminance of lighting (lx)	Height (m)	Luminous (lm)	Zone	Number of lights	Illuminance of lighting (lx)	Height (m)	Luminous (lm)
A	1	27.8	7.3	1,478.8	D	37	148.0	6.3	5,781.3
	2	116.5	4.0	1,887.4		38	41.0	6.3	1,627.3
	3	100.5	7.3	5,392.4		39	324.8	3.4	3,754.1
	4	118.5	4.2	2,040.9		40	147.8	4.6	3,126.4
	5	78.5	5.6	2,483.8		41	53.0	7.6	3,081.5
	6	171.5	3.3	1,896.0		42	105.8	4.4	2,047.3
	7	174.0	6.2	6,742.6		43	54.5	6.9	2,557.3
	8	146.0	3.7	1,971.8		44	181.0	4.2	3,231.0
	9	172.3	3.5	2,050.2		45	75.8	4.8	1,763.5
	10	133.8	4.2	2,359.4	E	46	115.3	5.2	3,056.7
	11	67.5	5.2	1,842.8		47	114.8	3.9	1,700.9
	12	65.3	4.1	1,070.3		48	223.3	3.1	2,076.8
	13	225.3	5.3	6,267.7		49	65.0	7.9	4,056.7
	14	154.5	6.8	7,091.6		50	57.8	7.6	3,313.7
	15	147.8	5.6	4,592.2		51	155.5	5.8	5,231.0
B	16	485.0	2.5	2,970.9		52	373.8	2.9	3,035.8
	17	210.8	3.4	2,400.6		53	113.8	4.3	2,127.8
	18	138.3	3.6	1,791.7		54	48.0	5.4	1,386.8
	19	40.5	6.7	1,804.5		55	156.5	4.1	2,567.0
	20	106.0	5.3	3,005.7		56	59.5	5.0	1,472.7
	21	56.3	7.1	2,815.6		57	24.3	7.7	1,437.8
	22	157.5	4.3	2,912.2		58	53.3	5.1	1,398.6
	23	174.0	3.6	2,255.0		59	145.3	4.8	3,311.8
	24	150.5	6.2	5,785.2		60	56.5	5.4	1,647.5
	25	211.5	5.4	6,053.7		61	120.8	5.0	3,018.8
	26	121.0	6.7	5,350.9		62	71.8	5.0	1,758.1
	27	92.3	4.3	1,725.6		63	61.3	5.3	1,704.3
	28	107.3	6.6	4,636.5		64	125.8	5.0	3,112.4
C	29	205.8	5.6	6,510.1		65	106.8	4.2	1,905.6
	30	112.8	4.7	2,490.6		66	64.3	6.0	2,332.3
	31	189.8	5.7	6,219.2	F	67	67.3	4.8	1,549.4
	32	21.8	9.1	1,791.2		68	220.5	6.2	8,476.0
	33	93.0	5.4	2,737.0		69	186.3	6.3	7,451.0
	34	106.0	4.3	1,914.6		70	101.8	5.8	3,452.4
	35	132.5	5.6	4,192.4		71	70.3	6.1	2,614.0
	36	61.0	5.2	1,617.9		72	143.8	5.8	4,794.2
						73	96.0	6.5	3,993.8
						74	76.3	7.4	4,119.2

Note: lm = illuminance of lighting × height^2.

the area, the new streetlights reflected characteristics similar to the existing lamps, which leads to community improvement through the installation of additional streetlights rather than adjusting the community's brightness and color.

Next, in applying new street lighting, each zone's characteristics, such as visibility, facial recognition, traffic accident risks, and others, were considered. When determining the location of new street lighting in each zone, characteristics such as the outer wall of the buildings were used in all zones. In Zone E, it was possible to install some telephone poles. Facial recognition became possible in the spaces where new streetlights had been installed. Narrow alleyways and vacant lots should be considered in Zone A; schools in Zone B; parking lots and vacant lots in Zone C; parking lots, vacant lots, and narrow alleys in Zone D; and narrow alleys in Zone F. Considering the space for each zone, the average illuminance at the ground level required by KS A 3701 (KATS, 2019) should be 3 lx. Next, the risk for traffic accidents should be gauged, given the road junction in Zone A, school in Zone B, commercial facility in Zone C, parking lot and vacant lot in Zone D, entrance and exit in Zone E, and road junction in Zone F, to identify movable objects for both pedestrians and drivers.

Figure 3 shows the alternative plan where new street lighting is applied according to the criteria in Table 2. In Zone A, eight new streetlights, using the outer wall of

Table 2. Natural surveillance alternatives through street lighting.

Category	Common alternatives	Characteristics of each zone					
		Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Visibility	Install 3–5 m from the ground surface	Use of building outer walls	Use of building outer walls	Use of building outer walls	Use of building outer walls	Use of building outer walls and installation of telephone poles	Use of building walls
Facial recognition	Apply KS A 3701 (KATS, 2019) to enable pedestrian recognition	Narrow alley, vacant lot	School	Parking lot and vacant lot	Parking lot, vacant lot, narrow alley	Narrow alley, vacant lot	Narrow alley
Risk for traffic accident	Identify all movable objects in consideration of illegal parking and mixed-use roads (pedestrians, drivers) based on KS A 3701	Road junction	School	Commercial facility	Parking lot and vacant lot	Entrance and exit	Road junction
Others	Keep lighting similar to that of the surrounding area: 6.7–41W LED lamps	—	—	—	—	—	—

Note: According to KATS (2019), the requirement of average horizontal illuminance (ground level) is 3 lx (low traffic volume and residential area) for the study area.

the building, were introduced. N1 and N2 were installed in the dark vacant lot; N3, N4, N5, N6, and N7 in narrow alleys; and N8 was installed in the road junction. Six new lights were installed in Zone B, using the outer wall of the building. To increase the brightness around the school, lights were installed in an area that had been a blind spot along the nearby road. Zone C received six new streetlights; five were newly installed using the exterior wall of the building, and another one was added to improve the existing street lighting. N16 and N18 were applied to eliminate blind spots in parking lots and vacant lots around the local market, which is a commercial facility, and N15, N17, N19, N20, and N21 were applied to secure visibility in areas where illegal parking of commercial facilities occurred. In Zone D, five new streetlights were installed, using the exterior wall of the building. N22, N25, and N26 were installed to improve blind spots in narrow alleys. N23 and N24 were installed to eliminate blind spots in parking and vacant lots around two religious facilities. Zone E included narrow alleys, vacant lots, and entrances and exits to residential facilities. N28, N29, N31, N36, N37, and N38 were applied to eliminate blind spots in narrow alleys; N27, N30, N40, and N41 to improve blind spots in the vacant lot; and N32, N33, N34, N35 (improving existing street lightings), N39, and N42 to secure the visibility at entrances and exits. Zone F had five streetlights installed to improve blind spots at narrow alleys and road junctions. N44, N45, N46, and N47 were applied to improve blind spots in narrow alleys, and N43 improved visibility at the road junction.

3.3. Simulation of Street Lighting

Table 3 and Figure 4 present the simulation results, employing Relux Pro to examine the illuminance according to the street lighting of the study area and to compare the status quo with the improved status. Table 3 shows the degree of illuminance in all areas and lighting areas. First, the average illuminance of the current status in the study areas was 0.97 lx in all areas and 2.85 lx in illumined areas, i.e., falling short of KS A 3701's standard of 3 lx (KATS, 2019). The average illuminance for each zone in all areas was lower than 3 lx, and only Zones A and F in the illumined areas met KS A 3701's (KATS, 2019) requirement.

The average illuminance after the alternative plan was applied is presented in Figure 3. The average illuminance was improved by 55.7% at 1.51 lx for all areas, and

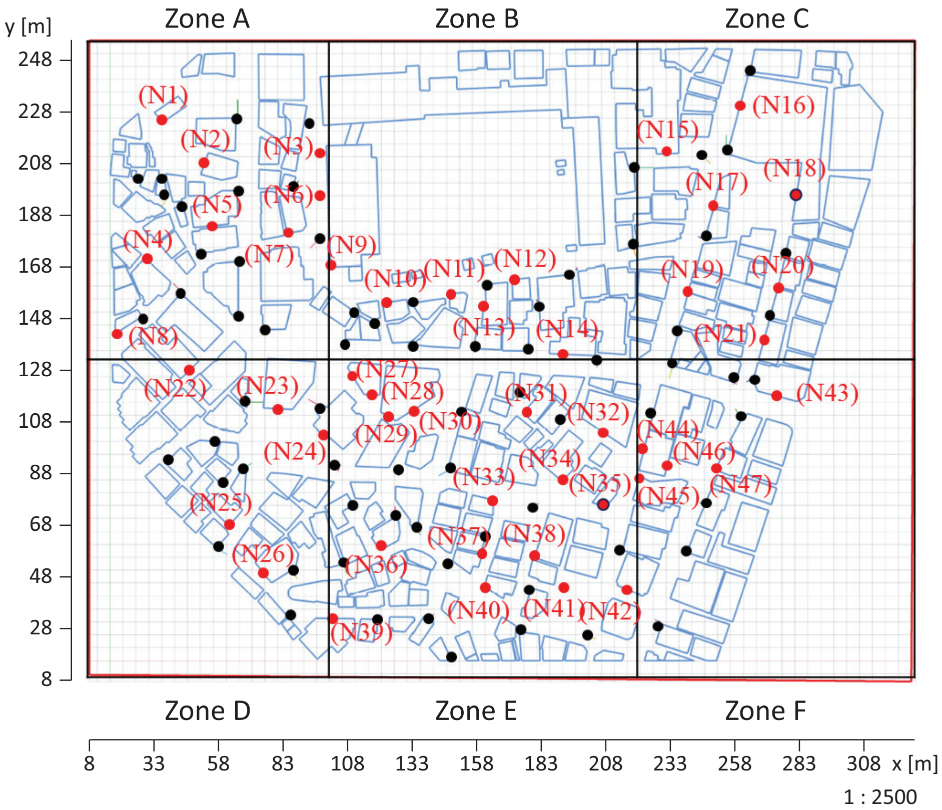

Figure 3. Alternative plan for improving the street lighting. Notes: Black points indicate current streetlights; red points indicate new streetlights with new locations; a red point with a black circle means improved street lighting in the current location.

by 28.5% at 3.66 lx for the illumined areas, meeting the requirements of KS A 3701 (KATS, 2019). Improvements for each zone ranged from 2.2% to 85.7%, with a particularly high improvement in Zone E. The latter zone included many blind spots in narrow alleys, vacant lots, and entrances and exits. In the whole area, illuminance was 1.63 lx, which was improved by 107.2%, indicating that most of the existing blind spots had been improved. Zone C's illuminance was 0.44 lx based on all areas, which showed a 30.1% improvement. When based on the lighting area, it became 1.42 lx, an improvement of 2.2%. The degree of improvement in Zone C was relatively low because there were almost no narrow alleys, and improvements were centered at parking lots, vacant lots, and commercial facilities. In Zones B and D, improvements were slightly lower than the requirements of KS A 3701 (KATS, 2019). In Zone B, the installation of new street lighting was limited due to school facilities. There were also some alleys that were too narrow to install lighting, which limited the improvement. In Zone D, there were restrictions on new street lighting in the vacant lot in terms of vehicle traffic and parking lot use, as well as a limitation to installing street lighting because of narrow alleys.

Table 3 and Figure 4 present the simulation results using Relux Pro to examine the illuminance according to the street lighting of the study area, and to compare the current and improved statuses. Table 3 shows the degree of illuminance in all areas and lighting areas. First, the average illuminance of the study area's current status was 0.97 lx in all areas, and 2.85 lx in the illumined areas. This did not meet the standard of 3 lx of KS A 3701 (KATS, 2019). The average illuminance for each zone in all areas was lower than 3 lx, and only Zones A and F in the lighting areas met the prescribed requirements (KATS, 2019).

Figure 4 shows a simulation map, depicting the illuminance of the study area in the current status and improved status, respectively. In the current status, disconnected lighting was noted in areas of roads and alleys. In Zone A, the disconnected lighting areas were at vacant lots and road junctions, and in Zone B, although existing streetlights had been installed, the range was limited, causing disconnected lighting areas. In Zone C, disconnected lighting occurred in the middle of the vacant lot, parking lot, and roads. In Zone D, disconnected lighting areas appeared in parking lots and vacant lots. In Zone E, there were disconnected lighting areas around narrow alleys. In Zone F, disconnected lighting occurred at road junctions. The simulation of the improved status shows the effect of the alternative plan (Figure 3), which was constructed as per the items suggested in Table 2. First, the disconnected lighting areas were improved at roads, vacant lots, parking lots, and entrances and exits in all areas. In addition, even without ambient light from surrounding buildings, the minimum horizontal illuminance of 1.0 lx (Commission Internationale de l'Eclairage, 2010)

Table 3. Changes of zones' illuminance of street lighting at ground level.

	Zone	Illuminance in all areas (ground level, lx) Average	Max	Min	Standard deviation	Illuminance in lighting area (ground level, lx) Average	Max	Min	Standard deviation
Current status	A	1.45	24.50	0.00	3.44	3.44	24.50	0.10	5.87
	B	1.12	23.10	0.00	3.15	2.58	23.10	0.10	4.37
	C	0.34	9.20	0.00	1.34	1.39	9.20	0.10	2.43
	D	1.12	14.10	0.00	2.32	1.78	14.10	0.10	2.72
	E	0.79	18.20	0.00	2.60	2.42	18.20	0.10	4.10
	F	0.99	26.00	0.00	4.09	5.46	06.00	0.10	8.23
	Total	0.97	26.00	0.00	3.12	2.85	26.00	0.10	4.65
Improved status	A	1.95 (34.0%)	25.40 (3.7%)	0.00 (none)	4.88 (16.9%)	4.08 (18.3%)	25.40 (3.7%)	0.10 (0.0%)	6.42 (9.4%)
	B	1.48 (31.9%)	23.10 (0.0%)	0.00 (none)	3.37 (6.9%)	2.87 (11.2%)	23.10 (0.0%)	0.10 (0.0%)	4.24 (–2.8%)
	C	0.44 (30.1%)	9.20 (0.0%)	0.00 (none)	1.49 (11.0%)	1.42 (2.2%)	9.20 (0.0%)	0.10 (0.0%)	2.39 (–1.4%)
	D	1.77 (58.7%)	14.30 (1.4%)	0.00 (none)	2.76 (19.3%)	2.58 (44.5%)	14.30 (1.4%)	0.10 (0.0%)	3.01 (10.7%)
	E	1.63 (107.2%)	29.20 (60.4%)	0.00 (none)	4.61 (77.7%)	4.49 (85.7%)	29.20 (60.4%)	0.10 (0.0%)	6.84 (66.9%)
	F	1.78 (78.9%)	27.20 (4.6%)	0.00 (none)	5.42 (32.3%)	6.52 (19.3%)	27.20 (4.6%)	0.10 (0.0%)	8.76 (6.4%)
	Total	1.51 (55.7%)	29.20 (12.3%)	0.00 (none)	3.98 (27.4%)	3.66 (28.5%)	29.20 (12.3%)	0.10 (0.0%)	5.41 (16.4%)

Note: The numbers in parenthesis show growth rate.

was reached, which is the level at which both pedestrians and drivers can identify objects in a neighborhood (P4) when there is little pedestrian and cycling traffic at night. This means that facial recognition in the study area and responses to traffic accident risks are possible if two out of 74 currently installed lights are improved and 45 new streetlights are added—a total of 119 streetlights.

4. Conclusions

This study suggested an alternative plan for street lighting to improve pedestrian safety in an older community near Bongrae Elementary School in Yeongju-dong, Jung-gu, BMC, and compared the illuminance of the current and improved status through a simulation exercise. The target area had many narrow alleys and problems related to vacant lots, parking lots, and illegal parking, all of which limited visibility at night. The existing 74 streetlights did not meet the illuminance requirements for safe walkability in the target area. The target area was divided into six zones, and the common alternative was derived based on the categories of visibility, facial recognition, traffic accident risk, and other factors. The alternative plan was derived from the characteristics of each zone. Two of the existing streetlights were improved, and 45 new ones were installed, resulting in a total of 119 streetlights. As a result, the average illuminance in lighting areas improved from 6.9% to 77.3%, and the average illuminance in all areas improved from 30.1% to 107.2%. This means that the lighting areas increased in all zones, enabling facial recognition and reducing the risk of traffic accidents.

This study has three limitations. First, it did not consider the effects of buildings and signboards attached to buildings in the illuminance simulation. Light generated from buildings and signboards attached to buildings also increases the visibility of pedestrian environments. These factors were excluded from this study because the time and forms were not constant. When examining the effect of street lighting at a specific time, it is necessary to consider these types of lights. Second, this study did not reflect the presence of slopes in some buildings and roads in the target area. This was difficult to do because the target area was an older community, meaning that the land had an irregular shape with complicated slopes. To compensate for this, the direction and location of the lamps were reflected in the alternative plan, based on the field studies' results and in consideration of the minimization of blind spots. Nevertheless, blind spots due to slopes can still occur. Third, partial or total redevelopment is required to completely solve the community-related problems raised in this study, such

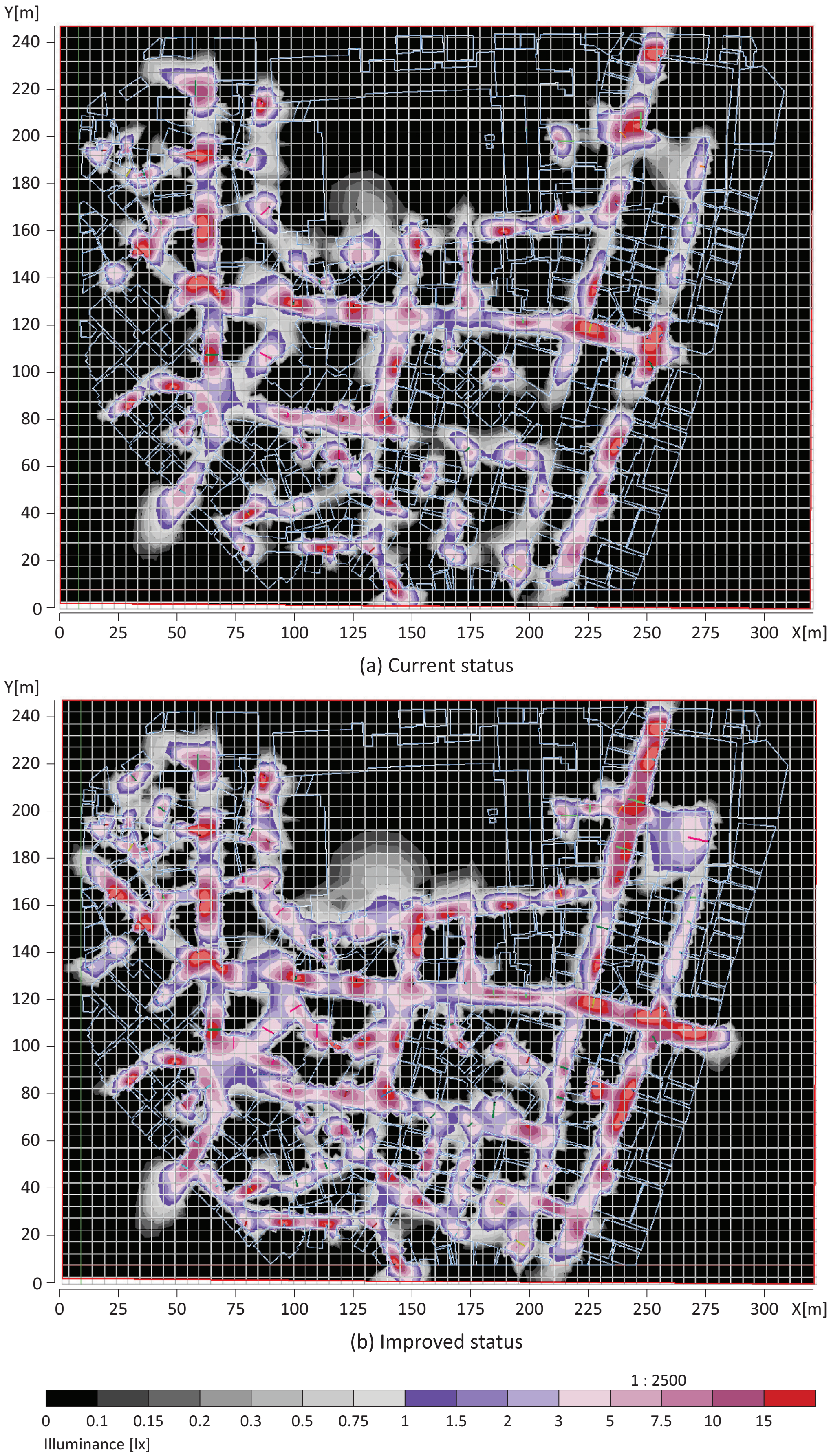

Figure 4. Changes of illuminance of street lighting at ground level.

as illegal parking, narrow pedestrian pathways, and the absence of sidewalks. In this study, street lighting is a limited alternative to address problems raised by communities where it is not easy to apply partial or total redevelopment. Street lighting cannot solve these fundamental problems. Community pedestrian safety requires many factors (e.g., surveillance cameras, police patrols, bollards, speed bumps, etc.) that can more directly affect safety. However, street lighting is a prerequisite for the safety of pedestrians in the community. If there is no street lighting, the effectiveness of any other solutions will be limited. Although this study only highlights the example of one community, it is meaningful in that street lighting is the most basic nighttime safety infrastructure that exists in any community.

The implications of the study findings are as follows: First, this study focused on the safety of the walking process, which is a requirement for walkability. It specifically focused on improving street lighting to secure visibility at night. Public infrastructure in communities is important to increase walkability. Still, if walking safety is not secured, people will prefer other modes of transportation over walking, even for short distances. Therefore, street lighting is a prerequisite for walkability and a way to reduce the risks of crime and traffic accidents. In the case of older communities composed of irregular streets, there is a high probability for lighting blind spots during walking, and street lighting needs to be actively considered in renewal plans for these communities. Second, this study compared the target area's current status and improved status through an illuminance simulation, and suggested the degree of improvement that can be achieved. This result can be used to decide where lamps can be installed to improve a community's street lighting. It can also be used as a planning tool that can locate blind spots through simulation and, when combined with field results, can identify optimal points for improvement.

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Conflict of Interests

The authors declare no conflict of interests.

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About the Authors

Yeo-Kyeong Kim is a graduate student in the Department of Urban Planning and Engineering at Pusan National University. Her current research interest includes urban welfare policy and community development.

Yun-Kyu Lee is an undergraduate student in the Department of Urban Planning and Engineering at Pusan National University. His current research interest is real estate and community development.

Donghyun Kim is an associate professor in Department of Urban Planning and Engineering at Pusan National University. His work lies at the field of urban resilience, community development, urban and regional development, and community participatory planning.