Rational-design process and evaluation of street-lighting design for apartment complexes

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Abstract

This study proposes the application of a rational-design process for street-lighting design considering the characteristics of space and the apartment complex on the basis of the recommended illumination levels for such. In this study, space syntax theory, which is used to generate a strategic-design framework based on detailed analysis of spatial configuration and represent any urban area as a matrix of connected spaces using computer simulations, is implemented in the design process. Based on previous research, which utilized the application of the space syntax theory to street-lighting design in a commercial area, this study extends such research to include street-lighting design of residential areas. In addition, this study evaluates current street-lighting designs in apartment complexes including selection of proper luminaires and relocation of existing luminaires. This study proposes further detailed improvements of the street-lighting design process.

1. Introduction

1.1. Research background

The apartment has been the general house pattern of the middle class in Korea since the 1980s. The apartment, initially, was the target of the criticism due to the standardization of the house culture as well as spoiling the beauty of the townscape. However, since the 1990s, the importance of the residents’ point of view, instead of the providers’, in the market of the apartment complex came to fore, as residents began to take an active interest in the quality of their housing environment. The development of the outdoor space of apartment complexes as well as the interior environment has become considered one of the main concerns of present times. The apartment complex shows the fundamental changes in its outdoor areas the landscaping of which now, reflect the needs for well-being living patterns in terms of adaptation to the environment, the ecological environment, and the human beings who reside there.

These changes have an effect on pedestrian ways so that a pedestrian network of multiple functions such as a communal square, a promenade, and a jogging track have appeared. The people interested in self-enrichment programs but who only have free time during the night have been catered for due to the extension of many daytime activities into the nighttime. The qualitative needs of the illumination of these public environments is increasing as the residents’ frequency of using these outdoor space is extremely high from sunset to 10 p.m. To reflect such changes and needs the new design concept of street lighting in apartment complexes and multi-sided approaches to street-lighting design, are essential. Surveillance for promoting pedestrian safety, and a well lit and comfortable visual environment in the street lighting as well as the function of the space and street, and changes in pedestrian usage patterns should be considered. In addition, appropriate recommended illuminance levels for each classification of street are required and should be implemented throughout the apartment complex to yield a well-balanced
illumination environment. Thus, a partial approach to illumination should be avoided.

Up to now, the design of the street lighting in the apartment complexes compromised simple arrangement of outdoor luminaires at regular intervals along the pedestrian ways. Such an arrangement, however, could lead to the visual fatigue and stress of the residents becoming enhanced due to the imbalance of the illumination distribution in apartment complexes, which occurs when the street lighting is organized in compliance with monotonous and uniform standards, and light pollution from the luminaires having undesirable luminous intensity distributions. The streets need well-balanced lighting, considering the overall luminaire layout plan for the entire complex taking into account useful illumination over the economic viewpoint. Thus, function-oriented and diverse composition street lighting requires rational design techniques.

Regarding these, this study proposes the application of a rational design process for street-lighting design considering the characteristics of space and the apartment complex on the basis of the recommended illumination levels for such. In this study, space syntax theory [1], which is used to generate a strategic design framework based on detailed analysis of spatial configuration, is implemented in the design process. The space syntax theory is based on the fact that any urban area can be represented as a matrix of connected spaces, and that mathematical properties of this matrix can be measured using computer simulations [1]. Previous research based on the application of the space syntax theory to street-lighting design in a commercial area has been conducted [2]. Based on such a newly developed methodology of quantitative street-lighting design, this study extends such research to include street-lighting design of residential areas. In addition, this study evaluates current street-lighting designs in apartment complexes including selection of proper luminaires and relocation of existing luminaires. This study proposes further detailed improvements of the street-lighting design process.

1.2. Research scope and procedure

This study conducts an evaluation of street-lighting designs for two apartment complexes, which were recently constructed and located in residential areas within Seoul, Korea. One apartment complex consists of 882 households (called site ‘A’) and the other consists of 1168 households (called site ‘B’).

The illumination elements have influence on the street, but the illumination in the living space and near shopping streets were excluded because they were irregular in quality and quantity. The illumination was designed with bollard and floodlight taking into consideration the lighting of the park, a children’s playground, and the physical exercise facilities joined with the pedestrian passage. This study, however, focused on the pedestrian ways.

The street lighting was rationally reconstructed with the master plan of the intensity of illumination on the basis of the features in the apartment complex and the special qualities of the street space. To do so, firstly analyzing the present street-lighting condition including the illumination level and the controversial points of the present street lighting was conducted. The illumination appraisal and the space analysis in the apartment complex are highly objective inflecting the space syntax theory. The procedure of this study appears in the Fig. 1.

2. Background

2.1. Luminous environment in the apartment complex

The outdoor lighting should support the design concept of the building and its immediate area, provide orientation, and be visually comfortable. Especially for street lighting, quantitative aspects of light such as recommended illumination, luminance, and uniformity of these should be verified and applied for both vehicles and pedestrians.

The present trend of segregation of pedestrian and vehicle movements in the apartment complex is increasing, but the perfect segregation has not been settled yet. Therefore, most street lighting in the apartment complex has features geared toward both vehicle and pedestrian movements (see Fig. 2).

Pedestrian lighting, which is installed in the road, park, and square, has a role to provide safety for walking and instill a clean ambience. Namely, the role of the street lighting is to create a nighttime environment in which pedestrians can quickly identify objects and maintain their orientation. The higher illumination is also able to enhance the safety of people and the security of property. It has been established that crime and other deviant behavior can be diminished in well-illuminated places [3]. The lower illumination yielded from bollard type luminaires and tree lighting can produce a special space with the rhythmical features of such light.

The keynote of the street lighting plan is to reflect diverse patterns of the anticipated traffics. Providing uniformity in lighting distribution is essential because too many contrary patterns and differences between dark and bright areas may perplex the pedestrian, and can lead to dangerous situations involving hidden latent obstacles. In general, the features of street lightings to be considered include variety, accessibility, and image. To satisfy the street pedestrians’ physical and psychological needs the lighting should be designed on the basis of it’s variety and accessibility, which can determine the imagination of the pedestrian, and can be used as qualitative standards to measure the visual satisfaction of the space.

(1) Feature of variety: The street should sufficiently provide several functions which are both passive and dynamic for all pedestrians. Compared to the other elements of the street, illumination has a significant influence on the
Fig. 1. The procedure of this study.

Fig. 2. The street lighting of the apartment complex.
passive functions such as the creation of a fine view and repose, and the dynamic functions such as providing exercise and amusement. The required quantities of illumination differ according to the utilization and ability to distinguish between the facilities, and the types of activities in the streets of the apartment complex.

(2) Feature of accessibility: Accessibility embodies the idea of being able to easily get from one point to any other within the complex, which is the same concept as physical movement. Consequently, the illumination during the night is a fundamental environment element, and it contributes to the accessibility of the user. Primary reasons for street lighting are safety and security, which in turn can improve accessibility.

(3) Feature of imagination: The feature of imagination refers to a comprehensive thinking about the subject, and satisfaction by means of an experienced barometer. Therefore, lighting itself can be a key factor for imagination of the space where someone is fronting.

### 2.2. Recommended illuminance level for street lighting

Table 1 shows KS (Korean Standard) recommended illuminance level for pedestrian walkways in Korea standard [4]. This table shows two types of area classification: residential and commercial for pedestrian movement, which is also divided into two subcategories based on pedestrian movement rate. Table 2 from IESNA (Illuminating Engineering Society of North America) handbook [5], shows recommended average maintained illumination level for pedestrian ways. There are two kinds of criteria namely, minimum average horizontal illuminance and average vertical illuminance.

While IESNA suggests Illuminance standards, which concentrate on the safety of pedestrians, KS focuses on the recognition of pedestrians. KS determines the average illuminance according to the pedestrian movement rate and how much the land is utilized (land classification). These factors, however, are relative aspects of quantity and thus are difficult objectives to reflect in the design process. Besides, it is very hard to estimate the quantity of traffic movement in newly developed apartment complexes since the surroundings of the apartment complex have to be considered. Therefore, we need an objective tool for estimating pedestrian movement rate and land classification.

As in Table 3, CIE (Commission Internationale de L’éclairage) also suggests lighting levels according to use by pedestrians [6]. The average and minimum horizontal illuminances for different road types are recommended to ensure that pedestrian can move across road and along footpath safely.

### 2.3. Space syntax theory

Analyzing the composition of space requires that one begins with a recognition of the two basic factors that are most important in a human being’s space utilization behavior. The first factor is the visibility based on vision. Namely, how much and how far you can see is the biggest variable to the visibility. Human beings use space intuitively through recognition of the space, and during such a process, the visibility is the most important factor. The second factor is the accessibility. Whether you can access to a certain visible space and how likely you are to go to a certain space are the variables determining accessibility. The accessibility factor is more influenced by how much you can change your direction during movement rather than by actual distance to the destination, so that the spatial configuration of the surroundings is crucial to solving this problem.

A two-stage methodology for representing and measuring the pattern properties of open space in-built environments was developed by Hillier and Hanson [1], which reflected the need to develop methods for representing part-whole relationships in spatial configurations. “The first stage involves representing continuous open space as a series of linked elements such as maximal ‘convex’ spaces or longest ‘axial’ lines of sight and access (called the ‘axial map’). The axial map of an area is drawn on the basis of open space structure in a plan, and consists of the fewest and longest set of lines of sight and access that pass through all the open spaces in an urban area and minimize the number of changes of direction between any other pair of lines. The second stage of the process involves transcribing the axial map as a graph,
where nodes represent lines and edges depict their relations of intersection.” [1]

A simple measure of ‘depth’, which is the most important concept in the syntactic analysis, was introduced by aforementioned researchers. Depth is measured in steps and corresponds to a topological measure of distance in the graph, which differs from the concept of metric distance. The depth between two adjacent axial lines of spaces is 1. Thus, it represents the minimum number of spaces that must be passed through to go from one axial space to the destination.

Space syntax index integration is closely related to human spatial behavior. In particular, two are relevant here. First, there is a consistent relationship between spatial integration in the axial map and observed human movement flows in urban areas—all other things being equal, the more integrated the line the greater the traffic [7]. Second, researches show a positive relationship in urban areas between spatial cognition and syntactic integration [8]. These researches suggest that pedestrian-movement rate can be forecasted with other syntactic results from space syntax analysis.

A further detailed explanation about space syntax theory can be found in the previous research [2].

Space syntax theory can be applied to archeology, psychology, geography, and anthropology as well as architecture, designing a city and roads. The most fascinating property of space syntax theory is that you can easily estimate the traffic-movement rate through examining digitalized space formations without inputting the coordinates of some buildings. A correlation coefficient between ‘space formations’ variable obtained from analyzing the models of spatial layout and ‘the pedestrian movement rate’ variable is the determining factor for the accuracy of such estimations. As the value of the correlation coefficient gets higher, so it becomes more persuasive.

### 3. Application of space syntax analysis

#### 3.1. Evaluation of pedestrian-movement rate using space syntax analysis

An axial map from a map of Seoul (scale-1: 5,000) was analyzed with Axman 3.0, which shows a syntactic analysis of spatial configuration. Concentric circles with a radius of up to 1.4 km radius from the site area (site ‘A’) and 1.8 km from the site area (site ‘B’) were drawn to analyze the spatial configuration of the site (see Fig. 3). The size of each radius is generally determined by the covered area where it takes about 30 min to walk from the periphery of the site.

Fig. 4 shows the results of analyzing axial maps. Each global and local integration map represents the systematic quantification of the spatial structure of the site area. Each line has integration values ranging from red for the most integrated line through orange, yellow, blue to purple for the least integrated line.

A higher global integration value means higher accessibility to the site area from every part in a considered area. Local integration, like global integration, is also a factor of accessibility. However, it focuses on three spots around the center place, and shows more sectional accessibility. A local integration map measures the average depth of spaces within the immediate neighborhood, and shows how integrated or segregated each space is, which in turn is related with how well people recognize the buildings and the city, how well people utilize the space, and how much movement there is.

To measure pedestrian traffic volume, pilot observation was conducted during three days at site ‘A’. The observed pedestrian number for Thursday was 2316, that for Friday was 2523, and that for Saturday was 2652, respectively. We decided to measure pedestrian traffic volume on Saturday because on that day, the highest total pedestrian traffic volume was observed. The observations were carried for 5 min in each hour, from 12:00 to 22:00 p.m. at major street segments (see Fig. 5).

Once variables of spatial configuration and pedestrian traffic volume were obtained, the next step was to examine the relationship between them. Regression analysis showed that the $R^2$ (coefficient of determination) between local integration and hourly pedestrian traffic volume was 0.6155 (see Fig. 6). This confirmed statistical evidence that the pedestrian-movement rate can be forecasted using space syntax analysis. We could then apply such findings to
Fig. 3. Concentric circles of site ‘A’ and ‘B’.

Fig. 4. Global and local integration maps of site ‘A’ and ‘B’.
street illuminance design with recommended illuminance levels with respect to the pedestrian movement rate.

Based on the above result and results of previous research [2], further measurement of pedestrian-movement rate at site ‘B’ was not conducted. Once again, the theory that the pedestrian-movement rate can be forecasted using space syntax analysis was proved.

3.2. Analysis of the illuminance measurement

Analyzing the illuminance refers to the examination of how appropriate the illuminance is in street lighting using space syntax theory compared to the recommended illuminance values. The illuminance at site ‘A’ was measured from 21:00 p.m., 23 July 2003 at the same street segments where the pedestrian movement volume was observed, while the illuminance at site ‘B’ was measured from 19:00 p.m., 5 March 2004. Both measurements were conducted after sunset.

On the basis of the measuring method of KS and the IESNA lighting handbook, the illuminance measurement depicted in Fig. 7 was implemented. In the case that the width of the road was greater than 2 m (a), we divided the road into 3 parts; otherwise (b) we chose the center of the road as the standard measurement line along the road. In addition, we measured the horizontal illuminance values (less than 15 cm from the road) at a spacing of less than 5 m along the standard measurement line.
The street lighting of the apartment complex in site area ‘A’ is mainly composed of full-cutoff (see Fig. 8) pole luminaires with 175 W metal halide lamps. At the opposite side of the plaza, there are aesthetic pole luminaires with 55 W compact fluorescent lamps. In addition, non-cutoff pole luminaires with 175 W metal-halide lamps are installed in the playground. The highest illuminance value was measured near the entrance between the 109 and 201 apartment buildings (56.5 lx), whereas the lowest value was measured between the community facility and the playground, and near the staircase of the 101 apartment building. In general, the maintained average illuminance values are not appropriate compared with those of recommended illuminance. The illuminance uniformity was also not high enough (see Fig. 9).

The street lighting of the apartment complex in site area ‘B’ is only composed of non-cutoff (see Fig. 10) pole luminaires with 175 W metal halide lamps. The highest illuminance value was measured near the commercial buildings (30.5 lx), whereas the lowest value was measured near the staircase of the 110 and 106 apartment buildings. In general, the maintained average illuminance values are not appropriate compared with those of recommended illuminance and the illuminance uniformity was also not high enough (see Fig. 11) as in site ‘A’.

$R^2$ (coefficient of determination) between the measured illuminance and the number of pedestrian volume was 0.2366 (site ‘A’) and 0.1646 (site ‘B’), respectively. It seems that pedestrian movement rate was not considered fully at the stage of designing the street illuminance levels at both sites.

3.3. Street-illuminance master plan

Street-illuminance master plans of the apartment complexes in site areas ‘A’ and ‘B’ offer balanced light over the entire area according to the recommended illuminance levels. To do so, firstly, appropriate illuminance levels should be established. Tables 2 and 3 shows the appropriate illuminance levels for each street classified category of street and pedestrian-movement rate according to KS and IESNA recommended illuminance levels. The results of space syntax analysis predict pedestrian movement rates...
for each street segment, which in turn indicates street classifications in Table 2.

Fig. 12 shows the result of the illuminance master plan reflecting space syntax analysis and recommended illuminance levels in Table 2. The recommended illuminance values are designed for the main entrance and entrances of each apartment building, near the commercial area, and playground respectively according to the values in Table 3. For the street illumination, higher illuminance values (3–6 lx) are applied to the streets between two main entrances and near the theme plaza where predicted pedestrian movement volume is high and there is good accessibility, whereas lower ones (less than 3 lx) are applied to the rest of the streets.

4. Detailed design of street lighting

4.1. Selection of proper light source and luminaire

The conventional metal-halide lamp has proper color rendering index values, a higher efficacy value of around 100 lm/W (400 W basis), and an average lamp life of around 12,000 h (400 W basis). Generally, higher wattage
lamps show higher efficacy values, but result in more glare and light pollution. Recently, ceramic metal-halide lamps, which have higher efficacy values and color-rendering index values, have been developed and widely used. On the basis of aspects of lighting quantity and quality, ceramic metal halide lamps (50–200 W) can be appropriate light sources for apartment complex street lighting.

To design apartment complex street lighting properly, not only safety of pedestrians, proper illuminance levels, regional property, and conditions, but also prevention of unwanted light influx should be considered. Recently, light pollution has become more problematic so that selection of appropriate lighting fixtures is more important now than ever before. Therefore cut-off types, one of the luminous intensity distribution types that improve on efficiency and visibility of the street by blocking the light from shining in unwanted directions, are popular nowadays. Other types can be found in Fig. 13.

All exterior luminaires can be divided into two categories, the static and adjustable. Luminaires permanently located on the top of a pole to produce light in a predetermined manner are of the first kind. In an international trend, luminaires with a head that can be rotated have been developed to overcome the problem of controlling unwanted luminous flux, and to aid the focusing of the luminous flux towards the wanted spots. Fig. 14 shows several luminaires that are simulated by Lightscape 3.2. These are arranged on the 6 m-wide vehicle road along with the 1.5 m-wide pedestrian road with a spacing of 50 m from each luminaire at 4 m high. The types of A–E luminaires are the common domestic street luminaires, while those of F–J luminaires are imported street lighting ones using metal halide 150 W lamps except for J luminaire which uses 250 W. In Fig. 14 symmetrical-light distributions of A, B, C, D, and E luminaires cannot be adjusted (static) to enlighten other areas, which results in inducing light pollution towards pedestrians. Meanwhile, F, H, I, and J luminaires can be rotated (adjustable) so that we can control the luminous flux extended.

As a general rule, maximum light occurs underneath a luminaire, whereas, the minimum is found at the midpoint of two luminaire spacings. A measure of an acceptable degree of uniformity is expressed by the ratio of average to minimum illuminance. According to the IESNA, the average-to-minimum ratio should not exceed 3:1 for most applications and should not exceed 6:1 for residential areas.

In the case of the G luminaire, it lights roads between pedestrian paths properly, and the illuminance is appropriate, so that it is considered as the best luminaire for the street in the immediate vicinity of apartment complexes.

### 4.2. Relocation of luminaires

In Korea, there is only one design guideline for street lighting of apartment complexes and that is the maximum spacing of 50 m for each luminaire. Other design guidelines

<table>
<thead>
<tr>
<th>Type</th>
<th>Candle</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Cutoff</td>
<td></td>
<td>Non intensity limitation</td>
</tr>
<tr>
<td>Semi cutoff</td>
<td></td>
<td>Luminous intensity does not exceed 5% at an angle of 90 above nadir and 20% at a vertical angle of 80 above nadir</td>
</tr>
<tr>
<td>Cutoff</td>
<td></td>
<td>Luminous intensity does not exceed 2.5% at an angle of 90 above nadir and 10% at a vertical angle of 80 above nadir</td>
</tr>
<tr>
<td>Full Cutoff</td>
<td></td>
<td>Does not emit light above 90 degrees</td>
</tr>
</tbody>
</table>

![Fig. 13. Luminaire types based on the lighting distribution.](image)

<table>
<thead>
<tr>
<th>type</th>
<th>intensity</th>
<th>illuminance distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td><img src="image" alt="Image A" /></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td><img src="image" alt="Image B" /></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td><img src="image" alt="Image C" /></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td><img src="image" alt="Image D" /></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td><img src="image" alt="Image E" /></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td><img src="image" alt="Image F" /></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td><img src="image" alt="Image G" /></td>
</tr>
<tr>
<td>H</td>
<td></td>
<td><img src="image" alt="Image H" /></td>
</tr>
<tr>
<td>I</td>
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</tr>
<tr>
<td>J</td>
<td></td>
<td><img src="image" alt="Image J" /></td>
</tr>
</tbody>
</table>

![Fig. 14. Simulations of each luminaire type.](image)
or regulations have not been settled yet. Therefore, in order to find the best layout of luminaires, lighting simulations have been conducted.

(1) Simulations based on the spacing and arrangement of luminaires
The luminaires of a mounting height of 4 m on the 6 m-wide vehicular road side and 1.5 m-wide pedestrian road side are selected to simulate several different luminaire spacings by Lightscape 3.2. The classification of the cut-off street luminaires with a metal halide 150 W lamp was simulated for all cases.

The simulated spacings of luminaires are 30, 40, and 50 m, respectively, and two different arrangements (opposite and staggered) of luminaires are considered for each spacing case. Table 4 shows the results. Obviously, the differences of the average illuminances for different spacing cases are very small (less than 1 lx), but the differences of those for different arrangement cases are varied especially for the pedestrian road side. The uniformity of the staggered arrangement is higher than that of when the luminaires are arranged opposite of one another.

(2) Relocation of luminaires according to road shape types
If there are many intersections in the streets it is difficult to satisfy all conditions only by considering the spacing and arrangement of luminaires. Especially, for the regions where vehicular traffic intersects pedestrian streets, it is crucial that a consideration of the entire surrounding environment be undertaken since proper lighting directly influences the safety of people.

Fig. 15 shows the rearrangement of the existing luminaires at site ‘A’ based on the guideline of ‘KS A 3701 road lighting standard’, which was developed to improve safety of pedestrians and vehicles. This guideline specifies major and minor locations of street luminaires in accordance with the respective road shape. To rearrange the luminaires, the number of luminaires was fixed. In Fig. 15 case (a) by moving the decorative luminaire to the main entrance, we increased the visibility of the entrance at near roads. In case (b), we just moved luminaires to the parking lot area because of an overlapping with the public street lighting. In addition, in cases (c) and (d), we rearranged luminaires to best conform to the shapes of the road shapes.

For site ‘B’, cut-off luminaires were suggested instead of non-cutoff luminaires. In Fig. 16 case (a), the decorative luminaire was removed and the luminaires were rearranged with consideration to outside street lighting. In cases (b) and (c), the luminaires were rearranged to consider the road shapes respectively, based on the guideline of ‘KS A 3701 road lighting standard’.

Table 4
Illuminance simulation according to the luminaire layout and spacing

<table>
<thead>
<tr>
<th>Layout</th>
<th>Spacing (m)</th>
<th>Average illuminance (lx)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vehicle road</td>
</tr>
<tr>
<td>Opposite</td>
<td>40</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6.7</td>
</tr>
<tr>
<td>Staggered</td>
<td>30</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Fig. 15. Relocation of luminaires in site ‘A’.

![Diagram of Relocation of Luminaires in Site 'A'](image-url)
standard’ and each luminaire was added to increase the visibility of the street. One luminaire was also added to where the pedestrian crossing exists in case (d).

(3) The ultimate design plan of street lighting

Fig. 17 illustrates the final street-lighting designs at each site. If there is heavy pedestrian traffic, an illuminance level of 6 lx is applied, and if not, an illuminance level of 3 lx is applied. Therefore, it satisfies the established standard of the illuminance levels.

In site ‘A’, luminaires of bollard types were added to relatively more utilized areas to create a comfortable atmosphere and to consider the psychological condition of residents. The number of pole luminaires added was 9. In addition, 1 decorative luminaire and 8 bollard type luminaires were added.

In site ‘B’, luminaires of bollard types were also added as in site ‘A’. 10 pole luminaires were added. In addition, 1 decorative luminaire, 14 bollard type luminaires, and two flood luminaires for sport facilities were added. As indicated above, the luminaire type was changed from the non-cutoff type to the cutoff type.
5. Conclusion

This study proposed the application of a rational design process for street-lighting design considering the characteristics of space in the apartment complex on the basis of the recommended illumination levels. This research was conducted under the premise that the pedestrian movement rate can be forecasted using space syntax analysis. Resulting findings could then be applied to street illuminance design following the guidelines of recommended illuminance levels with respect to pedestrian movement rate. Based on previous research [2], which showed a newly developed methodology of quantitative street lighting design in a commercial area, this study extended such research to include street lighting design of residential areas. In addition, this study evaluated current street-lighting designs in apartment complexes including selection of proper luminaires and relocation of existing luminaires.

This study proposed further detailed improvements of the street-lighting design process. A master plan of street lighting can more synthetically and reasonably be designed, with respect to the pedestrian movement rate, using space syntax analysis in addition to analyzing the characteristics of the space involved. The street-lighting design database which includes such factors as the light sources, the shape of luminaire, its luminous intensity distributions, arrangement, and disposition needs, can be a stronger tool for designing the street lighting of apartment complexes than it is at the present time. On the other hand, this research focused on luminous quantitative data, and as such we could not reflect the psychological aspect and the characteristics of the space under consideration. As such further studies considering both qualitative and quantitative data should prove enlightening.

References