IDENTIFYING ILLUMINATION COVERAGE IN UP DILIMAN CAMPUS USING GIS

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ABSTRACT:

The University of the Philippines Diliman faces challenges for pedestrians, particularly at night. Hence, this study proposed the creation of a detailed map using QGIS to showcase the illumination coverage of street lights around the UP Academic Oval. The project aims to establish a safer and more secure environment within the university community, ensuring optimal visibility and reducing the risk of accidents through a map that provides crucial insights into the spatial distribution of street lights, highlighting areas with sufficient lighting and areas in need of improvement. It considered significant factors that affect illumination quality across the campus such as terrain, lamp height, and bulb specifications. Based on the gathered data, increasing the lamp post height by a meter expands the illumination coverage around Roces Street and along paths towards University Avenue, but decreases light intensity. Changing the beam angles of the lamp posts from 112 to 140 degrees causes clustering of illumination areas along the left side of the Academic Oval, enhances those along Beta Way, and weakens light intensity of the lamp posts though not as much as in the first case. Lastly, increasing both the height of the lamp posts and their beam angles by a meter and at 140 degrees results in the significant increase of illumination coverage along the Academic Oval. However, increasing the heights of the posts may be costly. Therefore, to economically provide better coverage and maintain safety around the area, beam angles of the lamp posts should be increased to 140 degrees.

1. INTRODUCTION

1.1 Street Lighting in the University of the Philippines Diliman Campus

Street lighting is essential in ensuring pedestrian safety, security, and convenience. Adequate lighting not only improves visibility but also acts as a deterrent to crime and accidents. Data from a study by Painter, K. (1994) give evidence that the project of proper design and focused street light improvement can reduce crime, disorder, and fear of crime. Given recent issues of stalking and the like in an esteemed educational institution such as the University of the Philippines (UP), proper lighting is critical, particularly in heavily trafficked areas such as the Academic Oval. The renowned UP Academic Oval in the UP Diliman Campus serves as a vibrant hub of academic activities, social interactions, and recreational pursuits. As a result, ensuring the illumination coverage of street lights within this area becomes critical for the university community's well-being and safety.

While streetlights are installed to illuminate roadways, walkways, and public spaces, their effectiveness is affected by a number of factors. Street light design, placement, spacing, and maintenance can all have a significant impact on the coverage and uniformity of illumination provided (Gong, n.d.). Concerns have arisen in recent years about the illumination coverage and quality of street lights surrounding the UP Academic Oval, necessitating a thorough investigation.

1.2 Objectives and significance of the Study

This study aims to fill in existing knowledge about the illumination coverage of street lights within the UP Academic Oval by creating a map that portrays the actual illumination coverage of street lights near the UP Academic Oval using Geographic Information Systems (GIS). Variables considered include differences in elevations, the height of lamp posts, lumens emitted, and beam angles. Results of this study may provide valuable insights into the effectiveness and efficiency of the existing street lighting system given a systematic evaluation of the current lighting infrastructure incorporating the said variables. Additionally, potential areas for improvement can be identified and data-driven recommendations can be made to improve lighting coverage and quality.

It also aims to identify potential areas for improvement and make evidence-based recommendations to improve lighting coverage and quality for the benefit of the university community. The findings of this study will have far-reaching implications for urban planners, lighting designers, and policymakers involved in the management and enhancement of public spaces. This study aims to contribute to the creation of a safer and more secure environment, fostering a conducive atmosphere for learning, research, and overall well-being within the university community, by addressing the illumination coverage issues around the UP Academic Oval.

2. MATERTIALS AND METHODS

2.1 Methodology

This study is conducted through the general processes indicated in Figure 1. Each of this process is described in the succeeding sections.

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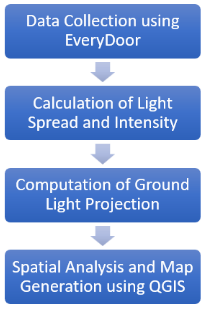

Figure 1. Flowchart of the Study

2.2 Datasets and software

To achieve the objective of the study, the corresponding height, beam angles, and light intensity values of the lamp posts were determined. Specifically, for the observation of lamp posts around the UPD academic oval (see Figure 2), an onsite survey was conducted with the aid of Every Door, an OpenStreetMap application for marking the positions of the lamp posts around the study site. Plotting of field measurements was done in QGIS.

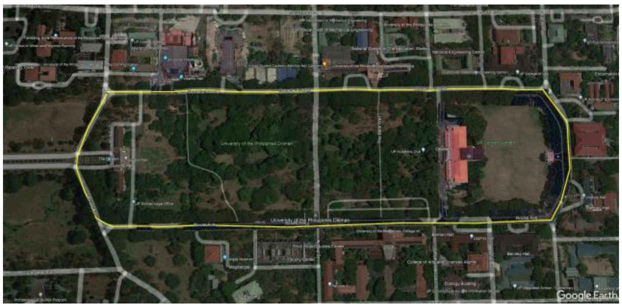

Figure 2. Academic Oval in the UPD Campus bounded by yellow lines (Base map source: Google Earth, 2023)

According to Cenit Lighting Philippines (n.d.), lamp posts located every 15 meters around the UP Diliman Academic Oval and along Beta Way use the Fumagalli Vivi 500 GX53 LED lights with a beam angle of 112° and lumens of 5,000. Meanwhile, the height of the lamp posts was quantified at 9.214 m (Zamora, 2019).

2.3 Light spread and intensity computations

Light is assumed to spread radially from the source of illumination. The diameter of the spread is determined by the distance from the light source toward the projected light source and the beam angle multiplied by a fixed constant (Parmar, 2014).

The beam angle (w) is typically a measured value that depends on the light source's design. In this study, the beam angle was initially quantified using the technical details of the GX53 LED light. Then, arbitrary beam angles and lamp post heights were used in the computation to observe their effects on the diameter of the spread. However, in cases where the beam angle is unknown, it can be derived using the formula for lumens.

$$lm = cd * \Omega, \qquad (1)$$

Where lm = lumens
cd = candela
Ω = solid angle of illumination

$$\Omega = 2\pi * \left(1 - \cos\left(\frac{w}{2}\right)\right), \qquad (2)$$

$$w = \cos^{-1}\left(-\left(\frac{lm}{2\pi * cd}\right) + 1\right), \qquad (3)$$

The Point Sampling Tool in QGIS was used to obtain the elevation of points that bounded the cluster of lines. Then, cluster line distance, slope of the line cluster, and change in elevation throughout the cluster line was computed using the formulas below:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}, \qquad (4)$$

Where x_1, y_1, x_2, y_2 = endpoints of the cluster
D = cluster line distance

$$S = \frac{(Elev_{p1} - Elev_{p2})}{D}, \qquad (5)$$

Where $Elev_{p1}, Elev_{p2}$ = elevation of the cluster endpoints
S = slope of the line cluster

$$\Delta Elev = |7.5(S)|, \qquad (6)$$

Where $\Delta Elev$ = change in elevation throughout the cluster

Light projection is dependent on the elevation the lamp is located on. Thus, light projection throughout the line cluster varies according to the difference in elevation. To represent the variation of the light projection radius, the lamp hight at lower and higher elevation per line cluster were used in computing the light projection radius.

$$Lamp\ Height\ at\ Lower\ Elevation: H_L = H_o + \Delta Elev, \qquad (7)$$

$$Lamp\ Height\ at\ Higher\ Elevation: H_H = H_o - \Delta Elev, \qquad (8)$$

Where H_o = measured lamp height

The radius of the light projection (R) was calculated using the computed lamp heights.

$$R_L = \frac{((0.018)(w)(H_L))}{2}\ ;\ R_H = \frac{((0.018)(w)(H_H))}{2}, \qquad (9)$$

Where w = beam angle

Two R values are produced for the lamp height at low and high elevation points respectively. The center offset or actual location the projection with respect to the difference in elevation were computed as follows:

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$$C = R_L - R_H, \tag{10}$$

Where C = center offset

The projection of light on the ground was assumed to act like an ellipse. The dimensions, width and height, of the projection were calculated based on the characteristics of an ellipse.

$$W = R_L + R_H, \tag{11}$$

Where w = width of the projected light

$$H_p = 2\sqrt{\left(\frac{w}{2}\right)^2 + C^2}, \tag{12}$$

Where H_p = height of the projected light

The intensity of light is not constant throughout its radial spread. The radial spread is divided into 3 sections to represent the difference in intensity across the area of spread. Values for light intensity at each section were calculated using the Inverse Square Law under the Law of Illumination (Brownson, 2014).

2.4 Calculating ground projection of light

To consider the projection of the street light on the terrain, the road was divided into segments as shown in Figure 3. Clusters 1 to 12 are the division of the road segments according to their slope or change in elevation. Clusters 1 to 10 are for the lamp posts around the Academic Oval, while clusters 11 to 12 are for the lamp posts around Beta Way. The slope measurements are provided in Table 1.

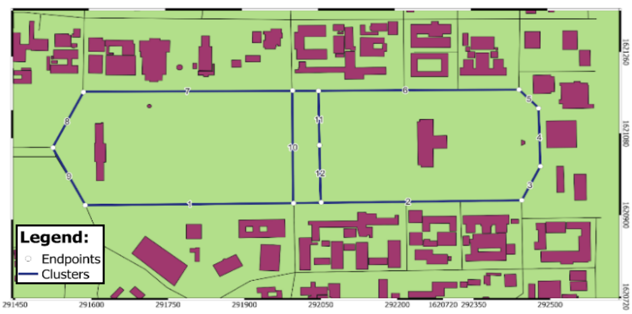

Figure 3. Division of road segments based on change in elevation

Segment	Slope (m)
1	0.014009
2	0.014704
3	0.00229
4	0.00098
5	0.003629
6	0.01771
7	0.00487
8	0.0245
9	0.009611
10	0.005592
11	0.03853
12	0.053052

Table 1. The Slope of Road Segments

2.5 Spatial analysis considering the effect of changing the lamp post height and beam angle

Field observations showed that the actual lamp post height in the Academic Oval is 8 m while in the Beta Way is 3 m. The illumination map based on the original beam angle is shown in Figure 4.

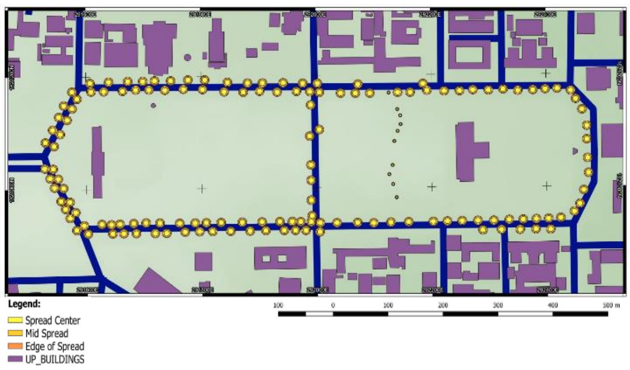

Figure 4. Illumination coverage considering original heights of lamp posts and beam angle

The effect of changing the height and beam angle to the coverage area and light intensity were further assessed given three test cases summarized in **Table 2**.

Variation	Lamp Post Height (m)	Beam Angle (°)
Original	8 m (Academic Oval) and 3 m (Beta Way)	112
Case 1	+1 meter to Original	Same as Original
Case 2	Same as Original	140
Case 3	+1 meter to Original	140

Table 2. Cases of Variations to the Height and Beam Angle of the Lamp Posts

The Lumens value for the LED light bulbs was also changed to see its effect on the coverage and intensity of light. The results of changing these values are discussed in the next section.

3. RESULTS AND DISCUSSION

The light intensity values (E) were calculated per cluster of the lamp posts considering their actual heights as measured on site and the beam angle, as summarized in Table 3.

Cluster	Central Section (Brightest)		Middle Section		Outer Section (Dimmest)	
	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)
1	272.37	18.36	544.73	9.18	817.10	6.12
2	272.36	18.36	544.73	9.18	817.09	6.12
3	272.39	18.36	544.78	9.18	817.17	6.12
4	272.39	18.36	544.78	9.18	817.17	6.12
5	272.39	18.36	544.77	9.18	817.16	6.12
6	272.35	18.36	544.70	9.18	817.05	6.12
7	272.39	18.36	544.77	9.18	817.16	6.12
8	272.32	18.36	544.63	9.18	816.95	6.12
9	272.38	18.36	544.76	9.18	817.13	6.12
10	272.39	18.36	544.77	9.18	817.16	6.12
11	38.13	131.14	76.25	65.57	114.38	43.71
12	37.97	131.70	75.93	65.85	113.90	43.90

Table 3. Illumination coverage and light intensity of lamp posts considering their actual or measured heights and beam angle

Changing the Lumens values was found to have no direct effect on the coverage of light but significantly increased the intensity of light throughout its area of coverage. Results of setting the Lumens value to 10800 show varying light intensities as summarized in Table 4.

Cluster	Central Section (Brightest)		Middle Section		Outer Section (Dimmest)	
	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)
1	272.37	39.65	544.73	19.83	817.10	13.22
2	272.36	39.65	544.73	19.83	817.09	13.22
3	272.39	39.65	544.78	19.82	817.17	13.22
4	272.39	39.65	544.78	19.82	817.17	13.22
5	272.39	39.65	544.77	19.82	817.16	13.22
6	272.35	39.65	544.70	19.83	817.05	13.22
7	272.39	39.65	544.77	19.82	817.16	13.22
8	272.32	39.66	544.63	19.83	816.95	13.22
9	272.38	39.65	544.76	19.83	817.13	13.22
10	272.39	39.65	544.77	19.82	817.16	13.22
11	38.13	283.27	76.25	141.63	114.38	94.42
12	37.97	284.46	75.93	142.23	113.90	94.82

Table 4. Calculated light intensities using a lumens value of 1080

Changing beam angles also resulted in varying light intensities at the clusters in the study site, with values summarized in Table 5 and a map showing the illumination coverage (in Figure 5), using a beam angle equivalent to 140 degrees.

Cluster	Central Section (Brightest)		Middle Section		Outer Section (Dimmest)	
	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)
1	425.57	11.75	851.14	5.87	1276.71	3.92
2	425.57	11.75	851.13	5.87	1276.70	3.92
3	425.61	11.75	851.21	5.87	1276.82	3.92
4	425.61	11.75	851.22	5.87	1276.82	3.92
5	425.61	11.75	851.21	5.87	1276.82	3.92
6	425.55	11.75	851.10	5.87	1276.65	3.92
7	425.60	11.75	851.21	5.87	1276.81	3.92
8	425.50	11.75	850.99	5.88	1276.49	3.92
9	425.59	11.75	851.18	5.87	1276.77	3.92
10	425.60	11.75	851.20	5.87	1276.81	3.92
11	59.57	83.93	119.15	41.97	178.72	27.98
12	59.32	84.29	118.64	42.14	177.97	28.10

Table 5. Calculated light intensities using a beam angle of 140°

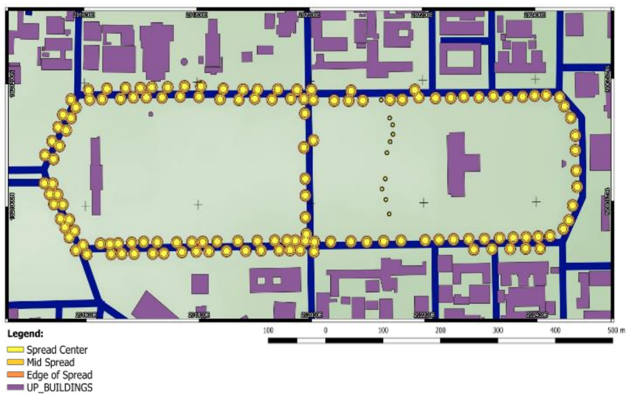

Figure 5. Illumination coverage using a beam angle of 140°

Changing the height of lamp posts also resulted to varying light intensities at the clusters in the study site, with values summarized in Table 6 and a map showing the illumination coverage (in Figure 6), using an additional 1 meter to the lamp post height. and beam angle equivalent to 140 degrees.

Cluster	Central Section (Brightest)		Middle Section		Outer Section (Dimmest)	
	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)
1	344.72	14.50	689.44	7.25	1034.16	4.83
2	344.72	14.50	689.43	7.25	1034.15	4.83
3	344.74	14.50	689.48	7.25	1034.23	4.83
4	344.74	14.50	689.48	7.25	1034.23	4.83
5	344.74	14.50	689.48	7.25	1034.22	4.83
6	344.70	14.51	689.41	7.25	1034.11	4.84
7	344.74	14.50	689.48	7.25	1034.22	4.83
8	344.67	14.51	689.34	7.25	1034.01	4.84
9	344.73	14.50	689.46	7.25	1034.19	4.83
10	344.74	14.50	689.48	7.25	1034.22	4.83
11	67.92	73.62	135.84	36.81	203.76	24.54
12	67.76	73.79	135.52	36.90	203.28	24.60

Table 6. Calculated light intensities upon adding 1 meter to lamp post height

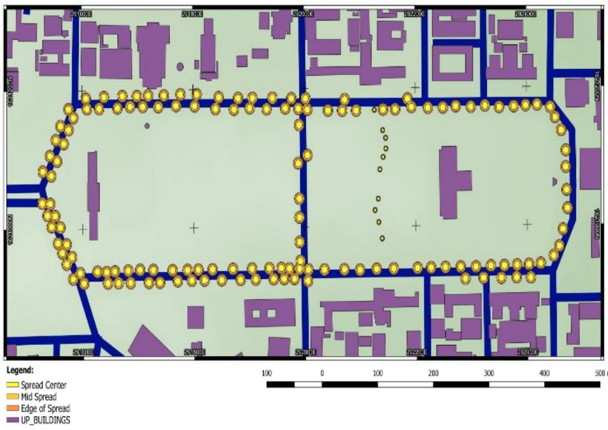

Figure 6. Illumination coverage upon adding 1 meter to lamp post heights

Combining the previous two cases, using an additional 1 meter to the lamp post height and beam angle equivalent to 140 degrees, light intensities subsequently changed at the clusters in the study site, with values summarized in Table 7 and a map showing the illumination coverage in Figure 7.

Cluster	Central Section (Brightest)		Middle Section		Outer Section (Dimmest)	
	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)	Area (m^2)	Light Intensity (E)
1	538.62	9.28	1077.25	4.64	1615.87	3.09
2	538.62	9.28	1077.24	4.64	1615.86	3.09
3	538.66	9.28	1077.32	4.64	1615.98	3.09
4	538.66	9.28	1077.32	4.64	1615.98	3.09
5	538.66	9.28	1077.32	4.64	1615.97	3.09
6	538.60	9.28	1077.20	4.64	1615.80	3.09
7	538.66	9.28	1077.31	4.64	1615.97	3.09
8	538.55	9.28	1077.10	4.64	1615.64	3.09
9	538.64	9.28	1077.29	4.64	1615.93	3.09
10	538.65	9.28	1077.31	4.64	1615.96	3.09
11	106.12	47.11	212.25	23.56	318.37	15.70
12	105.87	47.23	211.75	23.61	317.62	15.74

Table 7. Calculated light intensities using a beam angle of 140° and adding 1 meter to lamp post height

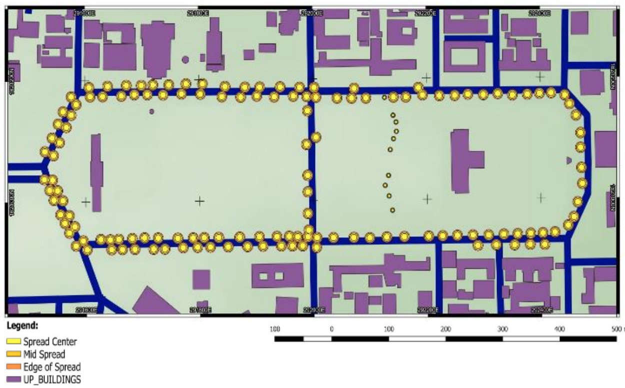

Figure 7. Illumination coverage using a beam angle of 140° and adding 1 meter to lamp post heights

Areas located on lower elevations generally received a larger radius of light coverage from the lamp posts. Moreover, higher illumination was observed from lamp posts in the Academic Oval compared to those located in the Beta Way. Increasing the lam post height by 1 meter and beam angle changed to 140° resulted in a significant increase in the illumination coverage within the study site, from an area coverage of 28530.09 m^2 to 52690.34 m^2 as summarized in Table 8.

Variation	Lamp Post Location	Lumens (lm)	Height (m)	Beam Angle (deg)	Total Area of Coverage (m^2)
Original Lamp Post and LED Bulb Parameters	Beta Way	5000	3	112	28530.09
	Acad Oval	5000	8	112	
Lamp Post Height Increased by 1 meter	Beta Way	5000	4	112	35844.22
	Acad Oval	5000	9	112	
LED Bulb Beam Angle Changed to 140 degrees	Beta Way	5000	3	140	43110.73
	Acad Oval	5000	8	140	
Lamp Post Height Increased by 1 meter and LED Bulb Beam Angle Changed to 140 degrees	Beta Way	5000	4	140	52690.34
	Acad Oval	5000	9	140	

Table 8. Total Area Coverage per Variation

4. CONCLUSION

The results of the test cases indicate that modifying the factors lamp post heights and beam angles affects the extent of illumination around the UP Academic Oval. Specifically, it can be observed that when the heights of the lamp posts are increased by a meter, the diameters of their respective lighting coverage also widened – resulting in clustering or overlapping of illumination coverage at the start and endpoint of Roces Street and along the portions going to the University Avenue. However, this resulted in a decrease in light intensity. Meanwhile, in the case of increasing the beam angles of the street lights from 112 to 140 degrees, the clustering of illumination coverage along the roads on the left side of the Academic Oval became more pronounced while the ones along the Beta Way also started to be more noticeable. Similarly, this caused a decrease in the light intensity, but not as much as in the first case. Finally, by increasing both the heights of the lamp posts and their beam angles by a meter and at 140 degrees, the illumination coverage along the entire oval would also be greatly increased.

Considering all these observations, it is evident that modifying both the heights and beam angles of the street lights would result in a larger coverage of lighting around the UP Academic Oval. However, economic-wise, it would not be efficient to implement these changes as increasing the heights of the lamp posts may be costly. Thus, the most efficient way to widen the lighting coverage and maintain safety around the study area is to increase the beam angles of the lamp posts up to an angle of 140 degrees since it would cost less and provide better light coverage.

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