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Modelling of Lighting in Urban Parks for Investigation of Environmental Impacts

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Abstract

The urban parks are representing the nature in urban space. Residents visit these parks for the purpose of relaxation, recreation, or free time activities. Urban parks help them with enjoying this time with their content like trees or bushes that provide shade, grass areas, flowers or small animals which take place in these parks. At night, these parks are illuminated and often the lighting can not only illuminate benches or sidewalks, but also the whole trees and other parts of park. Does this light have an environmental impact on the urban park? By modelling the lighting in urban parks, we can simulate situations in which we illuminate directly content of a park, like trees. By creating multiple simulations, we can choose which kind of lights and their light sources, and which kind of overall light system, have a greater or lesser impact on the urban park.

Index Terms: urban parks, obtrusive light, environmental impacts, modelling, simulations

1 Introduction

Obtrusive light, a problem that almost everyone has encountered, even if they haven't directly perceived it. Obtrusive light refers to light that is scattered around without a specific purpose, and its characteristics such as quantity, direction, or spectral composition cause irritation, discomfort, distraction, or impairment of the ability to perceive essential information [1].

To improving and protecting the nighttime environment, it is necessary to limit obtrusive light as it can have physiological and ecological consequences for the surrounding environment, people, and nature [2].

Obtrusive light includes the portion of light that is not used for its intended purpose. Specifically, it refers to light that inappropriately falls outside the illuminated area, light scattered in the vicinity of the lighting fixture, and the brightening of the night sky caused by direct and indirect reflection of radiation scattered by atmospheric components in the direction of observation. The undesirable effects of disruptive light can be categorized as glare, sky glow, or improperly scattered light.

In nature, disruptive light can cause problems in the nighttime environment and threaten plants and animals. Urban parks, which represent a part of nature within the city, can be influenced by the effects of obtrusive light. The areas of these parks are more affected by obtrusive light than nature outside the city. The brightness of the sky above the city is higher, making it rare to find animals that rely on the starry sky for orientation in urban areas [3].

The habitats of urban parks are not typically rich in species; they tend to be more homogeneous in nature. The majority of the habitat consists of lawns, various types of flowers, and trees. However, several species of birds, insects, and smaller nocturnal animals can nest in parks [4], [5].

Several indicators are used today to assess the effects of obtrusive light. However, in non-expert public discourse, a common argument is often made that lighting should not be directed towards the upper space. It is not always possible to meet this requirement, as it is often necessary to illuminate the surroundings of the object being lit, rather than just the object itself. In urban parks, the focus is primarily on illuminating the pathways that cross the park. However, in some urban parks, we may come across situations where parts of trees are illuminated or even entire tree canopies. In the following chapters, specific situations in the urban park "Medická záhrada" in Bratislava will be presented, including the current state of lighting, simulation of the object under investigation, and potential ways to improve the situation.

2 Lights in „Medicka zahrada“

In Medická záhrada, lights can be considered as historical pieces. The park contains fixtures with globe-shaped diffusers that emit a significant portion of the light flux into the upper space. The examined fixtures are dirty, some parts of the diffusers are damaged, and even selected fixtures lack diffusers altogether. This condition reflects the situation in urban parks in our area. Municipalities and companies responsible for park lighting often only perform maintenance at the level of replacing non-functional light sources. The mentioned used fixtures in Medická záhrada can be observed in Figure 1.

Figure 1 Lights in the medical garden during day and night [6]

In Figure 1, it is also possible to see the mentioned fixture in the nighttime environment. From this image, it is evident that not only the pathways but also parts of the tree canopies are illuminated in the park, indicating that the used fixture emits a significant portion of the light flux into the upper space.

2.1 Impacts of obtrusive light

External artificial lighting is not the only aspect that impacts human life, nor is it the most important one. Other influences such as noise or smog harm humans to a much greater extent, but attention is directed towards obtrusive light due to its visibility. Neglecting disruptive light as a problem is not correct. In a nighttime environment, disruptive light can affect humans, fauna, and flora. With its long-term effects, it can cause certain health issues [7].

2.2 Impact on the nature of the urban parks

Animals in nature, as well as in urban parks, are guided by the alternation of day and night. This characteristic is disrupted by lighting. Certain bird species migrate at night. It happens that under artificial lighting, they circle around buildings at night or alter their life rhythms, singing at night, continuing to feed, or nesting at the wrong time. However, the most affected species is insects. During nighttime hours, insects are attracted to artificial lighting. Around the light source, insects search for food, mates, or places to lay eggs. Due to artificial lighting, insects become easy prey, as they become tired from circling around the light and eventually perish [8], [9].

3 Measurement of obtrusive light

Unintentional scattered light, which becomes obtrusive for humans, can also be observed in the premises of „Medicka zahrada“. *Note: In the following text, only as a medical garden*. In Figure 2,the situation can be observed where the lighting of windows on a building located outside the park boundaries is visible. However, the measurement of illumination values was only measured on the grounds of the park, so we cannot definitively state the specific illumination values involved [7].

Figure 2 Lights illuminating the windows of an adjacent building [6]

Photometric measurements were conducted in the medical garden on May 10, 2022, after sunset, under clear sky conditions with a nearly full moon, starting at 9:20 PM.

During the measurement, the lighting system was in a steady state, and no changes in intensity or color of the illumination were observed.

The measurements in both locations were conducted at specific points according to the proposed measurement grid. The layout of these measurement grids can be seen in Figure 3 and Figure 4. The red points indicate locations where horizontal illuminance measurements were taken, while the green points represent the positions for vertical illuminance measurements. The points where both measurements were conducted are marked with a combination of green and red colors.

Figure 3 Measured location No. 2, [6]

Figure 4 Measured location No. 1, [6]

In the first location, with a single standalone luminaire, the measurement was conducted at 15 points arranged in the same lines. The first row of measurements was 3 meters away from the luminaire's axis, the second row was aligned with the luminaire's axis, and the third row was also 3 meters away from the luminaire's axis but on the opposite side. Vertical illuminance was measured in the same lines as the horizontal measurements but at distances of 2, 4, and 10 meters from the luminaire's axis towards the adjacent grassy area, at heights of 1 and 2 meters from the ground.

In the second location with four luminaires, the measurement was conducted at 18 points. Within the enclosed area delimited by the luminaires, 9 points were evenly distributed, and horizontal illuminance was measured at these points. In the remaining nine points, also located 2, 4, and 10 meters away from the playground as in the previous case, both horizontal and vertical illuminance were measured.

The necessary quantities were determined through subsequent calculations based on the measured values. The first quantity of interest is the average maintained overall illuminance E_m over the measurement grid area, which was determined using the equation (1).

$$E_m = \frac{\sum_{i=1}^{n} E_i}{n} \tag{1}$$

Where: E_m - maintained average illuminance, E_i - illuminance at the point, n - number of points

3.1 Measurement results

In Table 1, you can find the results of the measurement of horizontal illuminance in both locations.

Location	E_m [lx]	E_{min} [lx]	E_{max} [lx]	U_O [-]
1	0,457	0,1	2,2	0,219
2a	3,286	0,56	13,98	0,17
2b	0,884	0,12	3,1	0,136

Table 1 Results of horizontal illuminance measurement

Where: E_m - maintained average illuminance, E_{min} – minimum illuminance at the point, E_{min} – maximum illuminance at the point, U_O – overall uniformity

The obtained values of horizontal illuminance are sufficiently low. When illuminating the children's playground, the average illuminance is higher due to the increased number of luminaires.

If we compare the values of the average sidewalk illumination with a single light fixture to the intensity value during a full moon, which is approximately 0.1 lux, it can be concluded that there is only roughly a fourfold higher intensity with the standalone light fixture.

The maximum illuminance value at the children's playground is interesting. It represents a relatively high value in the urban park area.

Location	E_m [lx]	E_{min} [lx]	E_{max} [lx]	U_O [-]
1 - 2 m	1,272	0,18	5,4	0,142
1 - 4 m	0,751	0,15	2,4	0,2
1 - 10 m	0,293	0,2	0,47	0,683
2 - 2 m	4,752	0,43	13,67	0,09
2 - 8 m	1,543	0,48	2,27	0,311
2 - 10 m	0,552	0,37	0,84	0,671

Table 2 Results of vertical illuminance measurement

In the Table 2, it is possible to see the resulting values of vertical illuminances. A rapidly decreasing illuminance value with distance can be observed. Worth mentioning is the measured value at the children's playground, two meters away from the light fixture. The maximum value of 13.67 lux may cause disturbing effects for humans.

4 Modelling of urban park

The urban park, Medical garden, was subsequently simulated in the lighting simulation program Dialux after a successful measurement. The park was created in the software at a scale of 1:1.

The construction of Medická záhrada was based on satellite images, aerial shots, cadastral records, as well as on-site measurements and personal photographic documentation of the park.

The simulated model includes selected light fixtures, trees, selected plants, buildings, and roads. In order to reduce the system load during calculations, certain details such as sidewalk curbs or specific types of flowers and plants are not included in the simulated model.

The following images show the final model of the park in Dialux software.

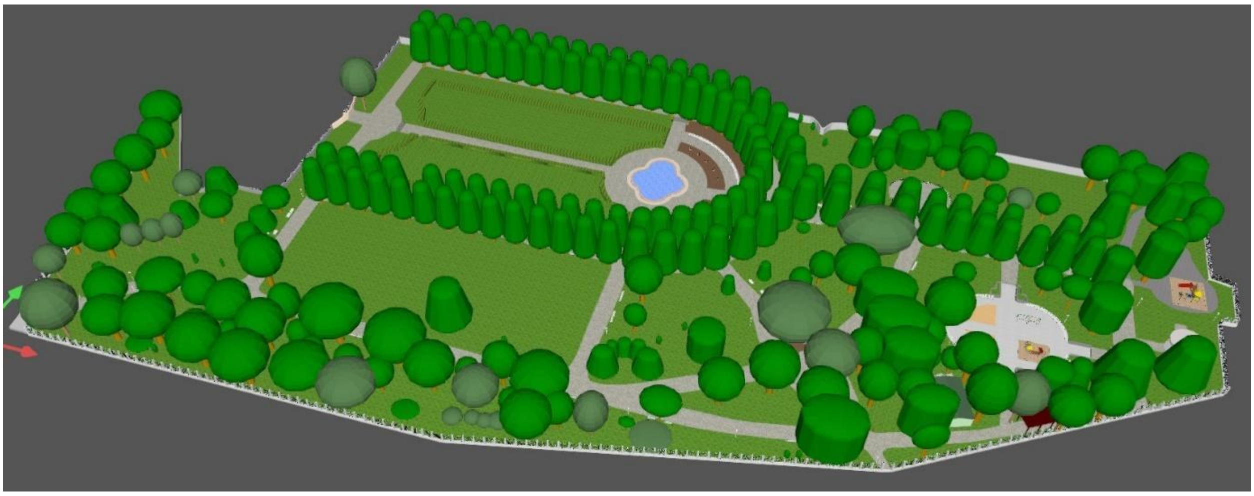

Figure 5 Model of the medical garden, view from the south

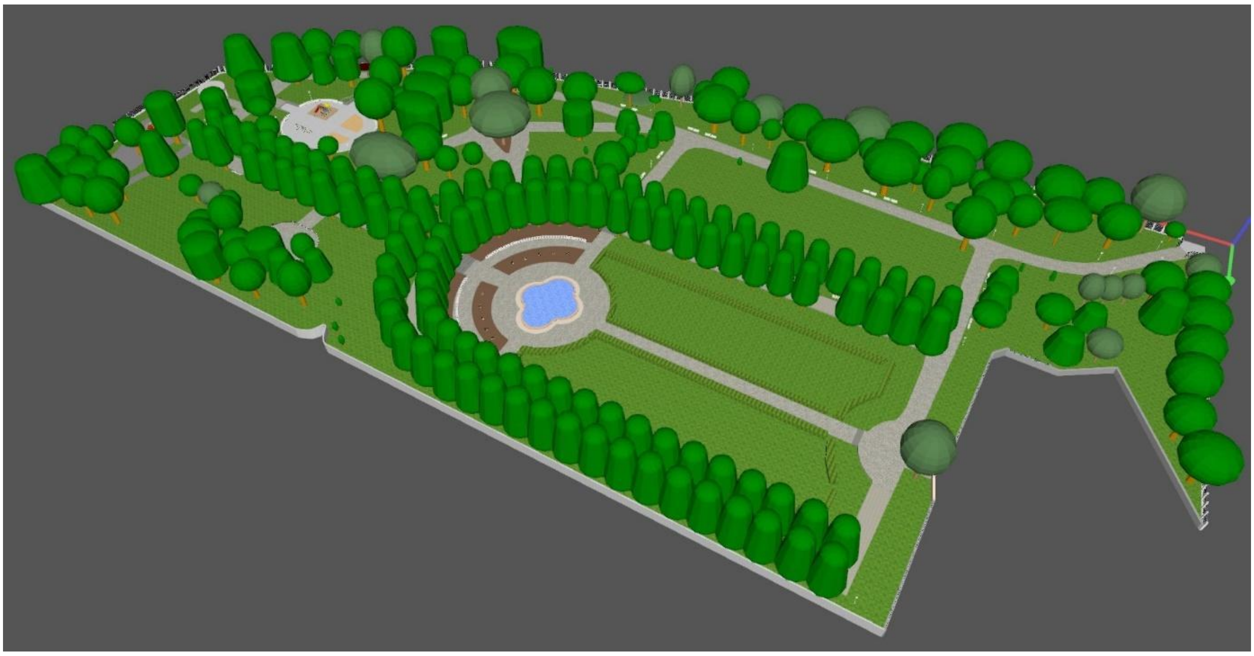

Figure 6 Model of the medical garden, view from the north

In the examined medical garden, there are 41 light fixtures installed on white poles. In the simulated model, the selected light fixtures are positioned in the same locations as in reality. The height of the light fixtures is chosen so that the light source is at a height of 2.5 meters above the ground. Due to illuminating small areas of sidewalks in parks, the light fixtures do not require higher placement. Furthermore, above these sidewalks, tree canopies are often present, making it difficult and unnecessary to install light fixtures within them.

The proposed design of the medical garden includes four types of light fixtures, and the results of their illumination were compared. The selected light fixtures were:

- Schréder Altra with a compact fluorescent lamp, power of 36 W, and a luminous flux of 2900 lm.
- Schréder Zafír with a sodium discharge lamp, power of 50 W, and a luminous flux of 3600 lm.
- Schréder ZYLINDO 5103 with an LED light source, power of 25.8 W, and a luminous flux of 3439 lm.
- RZB Leuchten basic ball with an LED light source, power of 36.5 W, and a luminous flux of 3900 lm.

Examples of selected light sources and their construction, along with the luminous intensity curve, can be seen in the following images.

Figure 7 Schréder Altra

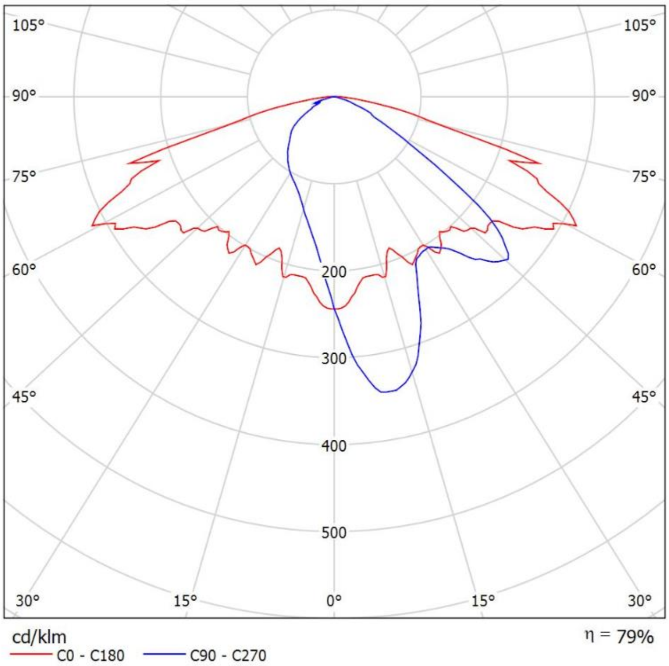

Figure 8 Luminous intensity curve of the Schréder Altra luminaire

Figure 9 Schréder Zafir

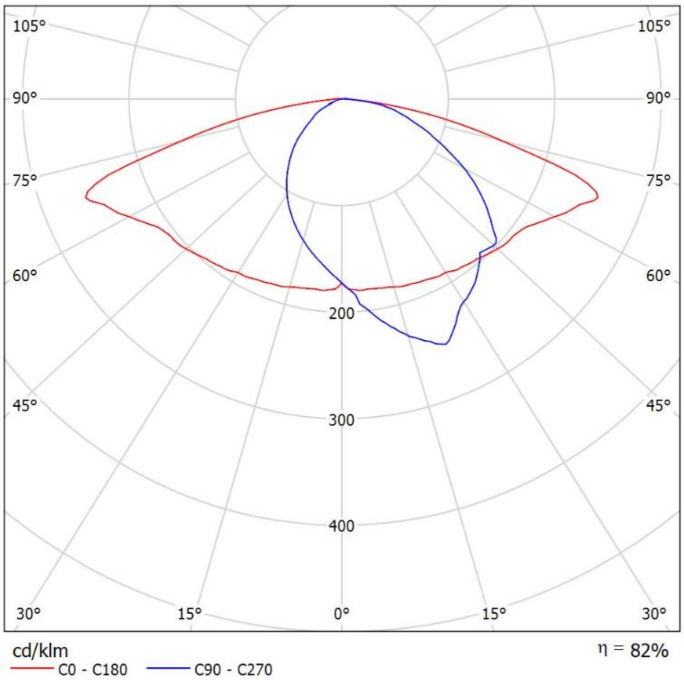

Figure 10 Luminous intensity curve of the Schréder Zafir luminaire

Figure 11 Schréder ZYLINDO

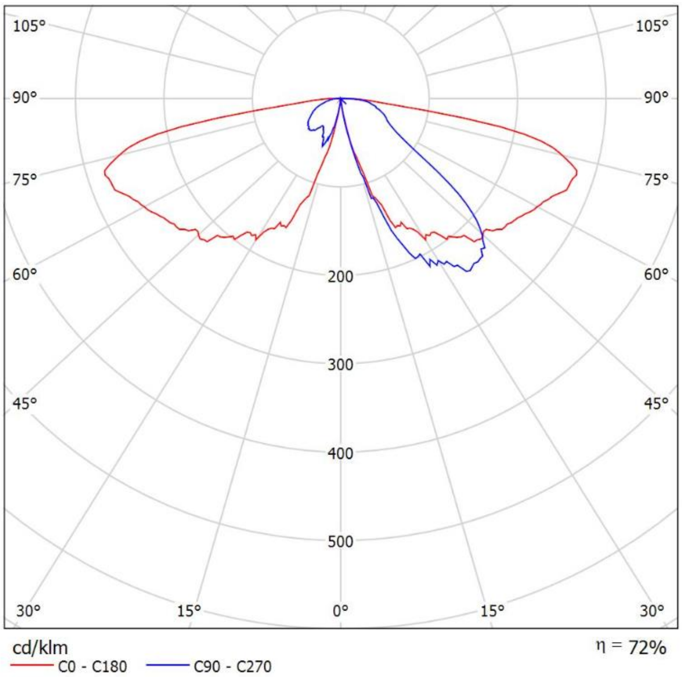

Figure 12 Luminous intensity curve of the Schréder ZYLINDO luminaire

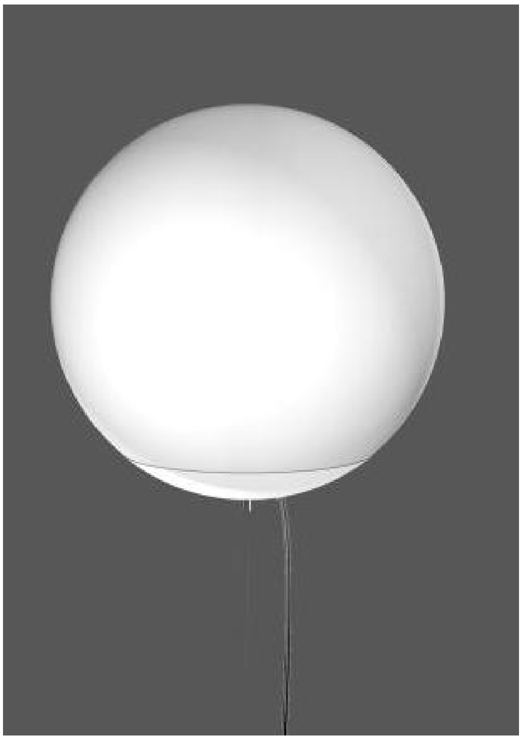

Figure 13 RZB Leuchten basic ball

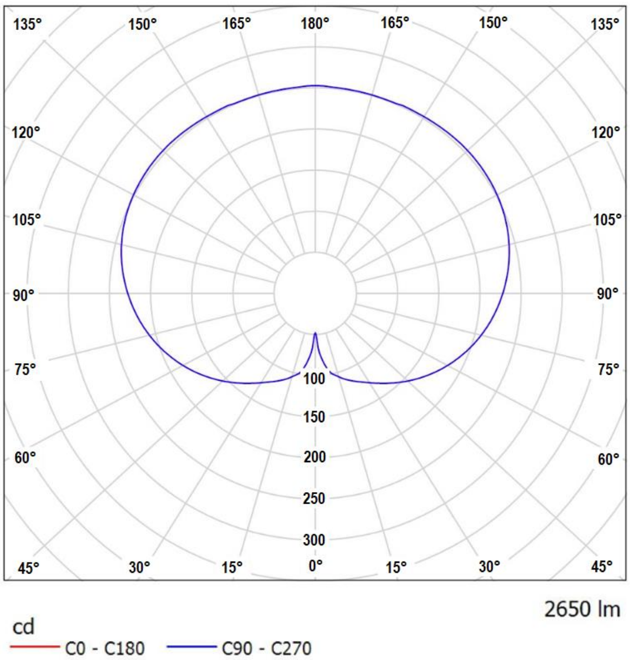

Figure 14Luminous intensity curve of the RZB Leuchten basic ball luminaire

The light sources of the selected light fixtures are each of a different type to compare their suitability for placement in the urban park area. The last light fixture is equipped with a spherical diffuser, highlighting the generation of disruptive light at higher ULR (Unified Glare Rating).

4.1 Results of simulation

The resulting average illumination intensities obtained through simulation in the entire park can be found in Table 7. For better clarity, the values are presented in a concise table format rather than as program outputs from Dialux.

In addition to the overall illumination intensity, the areas used in physical measurements were also subject to simulation. Visualizations of the simulated areas can be seen in the following images.

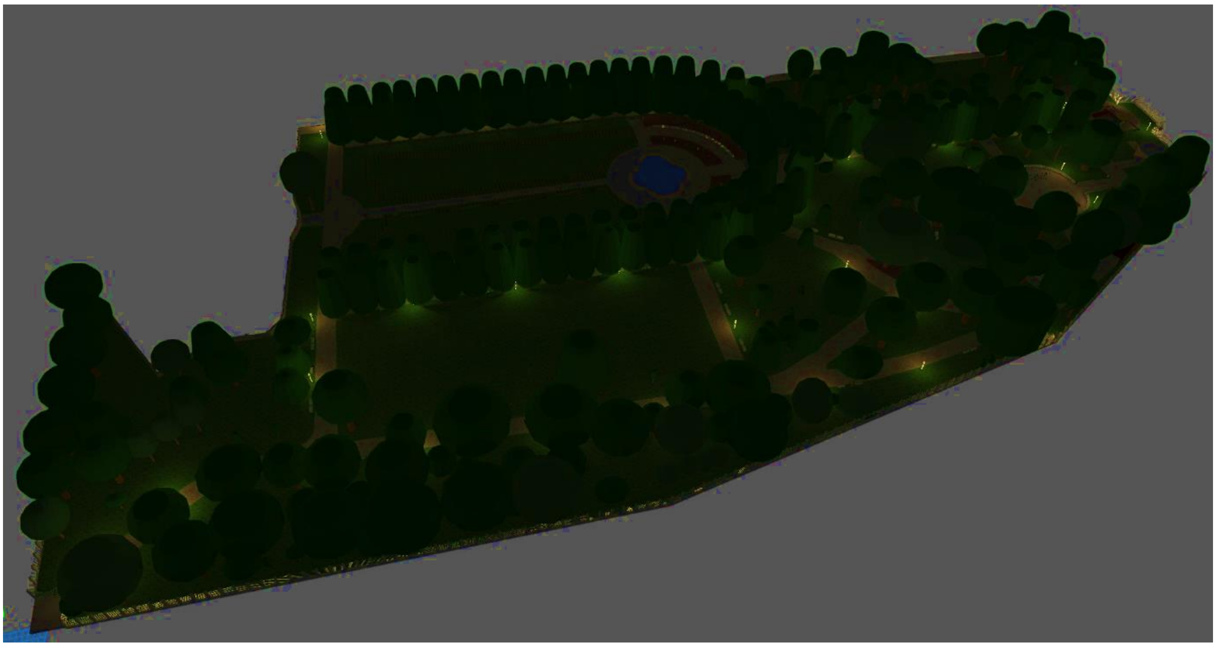

Figure 15 Model of the medical garden with spherical luminaires in the dark [6].

Figure 16 The first measured area displayed in the Dialux software, [6].

Figure 17 The second measured area displayed in the Dialux software [6].

The aim of this work is not to compare the current state but to determine which light fixtures would be suitable for replacing the existing ones in the medical garden. Therefore, the light fixtures with a spherical diffuser do not match the parameters of the light fixtures currently installed in the medical garden. The parameters of real light fixtures are subject to degradation due to environmental factors, pollution, and aging. The resulting values of horizontal illumination intensity for each simulated light fixture can be found in Table 3.

Location		**Schréder Altra**	**Schréder Zafir**	**Schreder Zylindo**	**RZB Leuchten ball**
1	**E_m [lx]**	10,5	23,7	7,06	5,2
	E_{max} [lx]	118	245	62,4	35,7
	U_O [-]	0,002	0,003	0,002	0,037
2a	**E_m [lx]**	5,87	13,7	7,06	3,65
	E_{max} [lx]	75,4	145	62,4	19,2
	U_O [-]	0,003	0,005	0,002	0,003
2b	**E_m [lx]**	1,78	5,76	3,04	1,77
	E_{max} [lx]	16,5	36,9	18,5	8,24
	U_O [-]	0,079	0,16	0,072	0,023

Table 3 Simulated values of horizontal illuminance for individual surfaces.

The resulting values of horizontal illuminance are lowest for the spherical light fixture, where the majority of the luminous flux is directed towards the upper hemisphere. Among the downward-oriented light fixtures, the lowest intensity is observed with the LED source. In clear Table 4, you can find the resulting values of average vertical illuminance for the simulated models at various distances from the light fixture axis.

Location	Schréder Altra	SChréder Zafír	Schréder Zylindo	RZB Leuchten ball
1 - 2 m	10,8	18,22	16,12	7,67
1 - 4 m	3,1	5,28	5,77	3,81
1 - 10 m	0,43	0,97	1,13	1,54
2 - 2 m	16,5	29,52	21,21	23,82
2 - 4 m	3,84	8,26	7,2	10,24
2 - 10 m	0,76	0,99	0,99	3,09

Table 4 Simulated values of vertical illuminance for individual surfaces.

When comparing the resulting vertical values, it is possible to observe a decrease in the level of illumination intensity with increasing distance from the light fixture. Among the three simulated light fixtures, the one with a compact fluorescent lamp appears to be the most suitable for use in the urban park. This is because it illuminates only a short distance, and its color distribution is suitable for nighttime environments. The selected light fixture with a sodium discharge lamp would be suitable for use in the urban park if it were placed at a higher height than 2.5 meters.

With the LED spherical light fixture, the values of vertical illuminance decrease at a slower rate with increasing distance from the fixture. Among all the simulated models, the spherical light fixture performs the worst in terms of vertical illuminance. While aesthetically suitable for an urban park, it is not an ideal light source in terms of light pollution in today's standards. The resulting values from all the simulations are several times higher compared to the actual state. This could be due to the aging and contamination of the real light fixtures, as well as the specific type of light fixture used in reality. In the park, there are light fixtures with a spherical diffuser, whose exact technical condition has not been determined, and the reflectivity values of surfaces have not been measured. The low mounting height of the light fixtures also contributes to the high values of illuminance.

5 Conclusion

The measured values of the used luminaires in the medical garden comply with legislative requirements. However, the measurements revealed that a significant portion of the luminous flux is directed towards the upper half-space, which can affect the habitat of the urban park and contribute to the creation of intrusive light. The simulation helps to find a suitable solution to replace the currently used spherical luminaires. The simulation results showed that luminaires with predominantly downward light distribution are suitable for illuminating the urban park if the goal is to minimize vertical illuminance. By using luminaires that predominantly direct the light downwards, we can avoid illuminating the crowns of trees or windows of adjacent buildings. The use of spherical luminaires was often common in the past, but nowadays we have better and more suitable alternatives. However, the question arises regarding the future. Do we want to primarily illuminate only the pathways in parks or visually enhance the surrounding nighttime environment of the urban park? One thing is clear, we need and must have lighting.

6 References

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