Overview of a method for lighting the facades of historic buildings by considering light pollution as a design factor

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Abstract. The objective of this research is the study of lighting the facades of historic buildings having as an orientation the reduction of dire effects of light pollution on the environment and humans. Lighting is an important way of underlining characteristics of historic buildings, such as beauty and identity, which form part of our cultural heritage. Scientists have outlined the effects of light pollution on the environment and people and therefore the lighting designer should apply efficient lighting design proposals that are environmentally and human friendly, according to the architecture of a building. This research proposes a methodology for calculating the levels of light pollution that are caused by different exterior lighting scenarios for historic buildings.

1. Introduction

One of the most important consequences of inappropriate façade lighting is the phenomenon of light pollution. It is a global phenomenon, which has been raising the interest of scientists and professionals in the field of lighting, especially with the advent of LED lighting in exterior installations [1-4]. The phenomenon of light pollution causes various effects and changes to the natural environment and people [5-7]. Light pollution can be defined as the change of the natural light levels in the night environment and change of the night sky illumination caused by artificial light sources, which are used for example for street lighting and façade lighting. According to the International Dark Sky Association-IDA, “light pollution is defined as any negative effect of artificial lighting” [8]. Lighting, which is used recklessly or is parasitic, can be considered as light pollution. Light pollution is a form of environmental degradation and is associated with ecological and health effects resulting from changes in the natural levels of light and circadian rhythm disturbance [9-11]. There are organisms that have adapted to natural light levels and can be affected by mere exposure to artificial lighting [12].

The increasing interest in light pollution requires methods of calculating its levels and consequences [13-16], along with an institutional framework related to ways of facing it [17-20]. The effects of light pollution on the night sky can be estimated by measuring the sky glow caused by artificial light sources [21]. The artificial light is scattered by the clouds, the atmosphere and its pollutants and thus the brightness of the night sky increases. As recorded by satellites, artificial lighting sources that lead to sky glow, have dramatically changed the image of the planet in recent decades. This artificial glow of the night sky affects the perceived visibility of the sky, the visibility of the stars and in general the perception of the universe by humanity. Satellite images of the Earth at
night can assist scientists to deal with the phenomenon of light pollution. The magnitude of light pollution is measured by studying Night Sky Brightness - NSB and overnight emission levels that vary depending on the population density of different cities and the use of land [22]. There are several methods for estimating levels of light pollution in an area. The brightness of the night sky can be calculated by using special photometers. Moreover, photography and other tools, such as special spectrometers contribute importantly to estimating light pollution and analyzing factors that lead to light pollution [23]. Calculations regarding light pollution are necessary to identify solutions to mitigate the phenomenon.

Scientists have expressed their concern about the possible effects of artificial lighting on humans and the flora and fauna and they have conducted scientific studies where the negative effects of misuse of artificial lighting have been presented [6]. As it comes to light pollution linked to façade lighting, the inappropriate application of lighting systems for facade lighting, the use of unsuitable luminaires and excessive lighting lead to this phenomenon. The problem is especially evident in the case of signs, where excessive luminance distributions are often observed [24]. Furthermore, improper placement and targeting of luminaires and failure to use appropriate light beam cut-off systems can result in light emission to the atmosphere and generally parasitic incidence of lighting in neighboring areas. Scientists have also outlined that light emitted by artificial light sources which emit light rich in blue radiation is scattered more intensely in the atmosphere and thus increases sky glow and glare [11, 25].

The aim of this research is to: a) investigate appropriate lighting techniques of lighting the facades of historic buildings by studying and estimating the possible levels of light loss to areas, such as the atmosphere, b) draw conclusions regarding how the levels of light pollution depend on the application of different lighting techniques and the use of different types of lighting fixtures.

2. Methodology

The implemented methodology comprises the following steps (Figure 1, Figure 2, Figure 3):

**Step 1:** The first step is related to the study of relevant examples of architectural lighting of historic buildings. Photographs of preserved buildings illuminated at night in Belgrade were taken and other illuminated historic buildings have been considered as well. Furthermore, indicative examples are selected and lighting techniques of the considered type of buildings have been analyzed. Based on these examples, conclusions are drawn regarding the most common ways of lighting preserved buildings.

**Step 2:** In order to proceed with analysis and calculations, a cube which consists of calculation surfaces has been developed in Relux software. Photometric calculations are performed by using different types of lighting fixtures suitable for architectural lighting of facades which have been placed in the cube. A methodology for calculating the percentage of luminous flux emitted by each luminaire on each surface is proposed. The accuracy of the calculations is checked by calculating the percentage error. Each calculation surface consists of a number of points that form a grid. Calculations have been performed while changing the density of the grid. The appropriate grid density of the calculation surfaces is then selected in order to achieve higher accuracy of the calculation results.

**Step 3:** Further calculations have been performed by using a structural element and changing the direction of the luminaires.

**Step 4:** An existing preserved building is selected and different lighting methods have been considered in order to be applied on its three-dimensional model which was developed. Moreover, its morphology and its special characteristics have been assessed.

**Step 5:** Different appropriate lighting techniques have been selected and applied to the three-dimensional model for the selected building. For each lighting proposal, photometric calculations are elaborated according to the following scenarios: a) plain, without the effect of the building or the structural elements, b) with the effect of the structural elements, but without the effect of the selected building and c) only with the effect of the selected building. The aim is to calculate the light pollution levels in each case and to compare the different proposals based on the obtained results.

Finally, remarks are noted and the conclusions are developed.
Figure 1. Methodology diagram.

Step 1: Study and analysis of relevant examples of architectural lighting of historic buildings

Methodology for calculating the percentage of luminous flux emitted by a luminaire on different calculation surfaces

Photometric calculations while using different types of lighting fixtures suitable for architectural lighting

Control of the accuracy of the calculations and the proper selection of the calculation grid

Step 2: Calculations by adding a structural element and changing the direction of lighting

Step 3: Selection and 3D modeling of existing historic building

Step 4: Selection and application of different appropriate lighting techniques to the three-dimensional model of the selected building

Calculations according to the following scenarios:
- a) neither with the effect of the building nor the structural element
- b) with the effect of the structural element, but without the effect of the selected building and
- c) only with the effect of the selected building

Final remarks and conclusions

Figure 2. Testing of the proposed method by changing the direction of lighting and adding a structural element.

Figure 3. Selection of part of historic building’s façade for the application of different lighting scenarios.

Figure 4. Adjustment of the cube (which consists of calculation surfaces) to the selected part of the building’s façade.
3. Checking the proposed method and accuracy of the results (Step 2)
Table 1 shows the error results based on the calculations, for each luminaire and for different grid density (which means different distance between the calculation points). The relation between the density of the grid and the accuracy of the results is evident. Based on these results and the aggregate graph, it can be concluded that the grid density and the deviations of the results are disproportionate. The smaller the distance between the calculation points, the lower the error – deviation is. It is also evident that luminaire 4, which has the narrowest beam 8°, shows the highest percentage of error compared to the other luminaires.

Table 1. Error rate (%) for each luminaire and for different grid density.

| Luminaires/ Beam angle | 10 calculation points per 0,50 m | 20 calculation points per 0,25 m | 30 calculation points per 0,167 m |
|------------------------|----------------------------------|----------------------------------|----------------------------------|
| Luminaire 1/ 32°       | 1,35%                            | 0,28%                            | 0,15%                            |
| Luminaire 2/ 50°       | 0,08%                            | 0,23%                            | 0,11%                            |
| Luminaire 3/ 40°x 96°  | 0,03%                            | 0,04%                            | 0,02%                            |
| Luminaire 4/ 8°        | 21,05%                           | 2,20%                            | 0,71%                            |
| Luminaire 5/ 10° x 40° | 6,85%                            | 1,48%                            | 0,76%                            |
| Luminaire 6/ Wall washer| 1,31%                            | 0,00%                            | 0,02%                            |
| Luminaire 7/ 35°       | 0,09%                            | 0,09%                            | 0,09%                            |
| Luminaire 8/ 30°       | 0,11%                            | 0,20%                            | 0,04%                            |
| Luminaire 9/ 45°       | 0,08%                            | 0,19%                            | 0,04%                            |
| Luminaire 10/ Asymmetric Wall washer | 0,10% | 0,04% | 0,19% |

Figure 5. Aggregate graph of error rates (%) for each luminaire and for different grid density.

4. Lighting scenarios and calculations
Photometric calculations are done for each lighting proposal according to the following scenarios: a) without the effect of the selected building and b) with the effect of the selected building. The aim is to calculate the light pollution levels in each case and to compare the different proposals based on the obtained results. The levels of light which is not useful and the levels of light pollution were calculated for every lighting scenario. The different lighting scenarios and results are presented through the following figures and bar charts. For the first lighting scenario, four different versions are demonstrated with different luminaires or different position of the luminaires.
Figure 6. 1.A Lighting scenario—Luminaires 1/32°.

Figure 7. 1.B Lighting scenario—Luminaire 2/50°.

Figure 8. 1.C Lighting scenario—Luminaires 1/32°.

Figure 9. 1.D Lighting scenario—Luminaires 3/29/86°.

Figure 10. Second lighting scenario—Luminaires 4/8° and third lighting scenario—Luminaires 5/10°x40° κατ Luminaires 6/ wall washer.

Figure 11. Fourth lighting scenario—Luminaires 7/35° κατ Luminaires 8/30°.
5. Findings and Conclusions
Based on the implementation of scenarios with different lighting techniques in a three-dimensional model created for an existing building, the percentages of light emitted in areas outside the building have been calculated. These results contributed to calculating the percentages of light pollution. It can be observed that by using different types of luminaires, it is necessary to use a dense grid of calculation points in order to accomplish better accuracy of calculations. The relation between the density of the grid and the accuracy of the results has been evident. It can be concluded that the density and the deviations are disproportionate. Furthermore, it has been also found that the narrower the beam of the luminaire, the greater the deviation of the photometric calculations is.

Factors such as the type of luminaire, the luminaire’s beam angle and distribution, direction, their placement and their targeting affect significantly the final percentage of light pollution. The different calculations show the effect of reflections on light pollution rates and how the combination of proper placement and targeting can lead to lower light pollution levels, by considering the architectural structure of the building facade and the way in which the emitted light is reflected. It can be observed that the luminaires with asymmetric beam targeted on the facade and the wall washer type of luminaires cause lower levels of light pollution than the luminaires with symmetrical and wide lighting beam. It can be noticed through this research that the use of modern tools, such as photometric calculation programs, before the implementation of a lighting design proposal is of great importance. These tools do not limit the design of a lighting proposal but it is necessary to pay close attention to the specifications of the used luminaires. Nowadays, with the help of technology, lighting methods can be selected in a way to offer an aesthetic result which at the same time does not have negative effects
such as the phenomenon of light pollution and high energy consumption. In addition, in order to achieve proper lighting design of historic buildings, the importance of the relevant regulations and specifications is emphasized [26-28]. These regulations and specifications offer guidance regarding the lighting limits of the facades in order to avoid negative impacts on environment and people. Additional attention has been given to the sector of street lighting in terms of reducing light pollution. However, it is necessary to take measures in order to limit the phenomenon in terms of lighting the facades. This part of lighting can be further examined by scientists and lighting designers. It is important to provide information and raise awareness not only to professionals but also to the general public about light pollution [29] and the adoption and implementation of relevant measures and regulations.

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