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Targeting the Light Pollution: A Study Case

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***Abstract*— Light pollution is being studied today from a much wider perspective that goes beyond narrow approaches based on visual comfort and energy saving. After a review of the main ways of assessing the effects of light pollution, based on global measurements or statistical studies, a method based on direct imaging is identified, looking at both the sources of light pollution and its effects. These imagistic measurements have differential character for the target surfaces of light pollution (façades of buildings), to obtain a quantitative estimation of the luminous flux that represents effective light pollution. The method is susceptible to widespread use, and therefore the main stages are presented and discussed in this study-case: Pacific Hotel, Jeju – Korea.**

***Keywords*— differential luminance measurement, light pollution assessment, luminance map**

I. Introduction

Measuring light pollution on the ground, where it is generated, is a less-used practice. There are many other ways to measure from space, from a plane, global measurements, which most often measure the effects of light pollution (e.g. the sky glow), but do not allow to highlight the particular sources of pollution. The main trends in the assessment of the effects of light pollution and measurement modes will be reviewed to highlight the utility of the proposed method.

II. Trends In Light Pollution Survey

Light pollution is a phenomenon that is in continuous expansion, and that is why it is studied more carefully. A measurement of the light pollution (LP) is the sky glow. A monographic paper on this subject is [1], where it is emphasized the usefulness of the digital camera calibrated with Fisheye lens. The main benefit is the possibility of referral to the changes in the spectrum of the artificial light, even if it is not examined all the spectrum. As a result of [1] is the fact that the overall measurements generate information on the *effect* of LP, without having a correlation with the sources of pollution.

Measuring the sky glow becomes even more complex if the aerosol effect or the clouds are considered. In [2] is studied the effect of clouds, which darkens the natural landscape, but *has the opposite effect* in the case of artificial lighting. Hence the obligation to further limit artificial illumination if the effect magnification of sky glow is considered. The cloudy sky can also be used as a "screen" on which differential measurements can be made [3]. These measurements compare the brightness of the sky when various bright scenes (architectural lighting, decorative, advertising, street lighting) are active or not. One can estimate the effect of each light source. A similar principle will also be used in this paper, by measuring luminance on a façade in different operating situations.

Classical approaches, based on visual comfort and energy efficiency, have failed to limit light pollution, as will be seen further. This has happened because the specific efficiency of the LED (lm/W) leads to the tendency to impose higher levels of illumination or to illuminate supplementary dark places. Hence, in [4] there are three principles for limiting illumination: intelligent dimming, limitation of the maximum level of illumination, and specific energy efficiency (kWh / km / year) for roadways. These criteria cannot apply to façade lighting, as is the purpose of this paper.

The issue of light pollution has far outweighed the issue of energy efficiency, recent research [5] involving extremely delicate ecological balances, with possible avalanche effects, described as an authentic Armageddon [5]. This is the case with pollinating insects, whose population is steadily decreasing. Pollination may lead to the disappearance of some plant species, but the effect may be extreme, including the animal kingdom.

Light pollution also has manifestations coupled with other phenomena. Thus, if we accept that artificial lighting prolongs the duration of human activities, then it is sufficient to add another pollutant: noise [6]. The light accompanied by noise turns into a much firmer barrier for a multitude of living, terrestrial or even flying.

If the impact on the environment can be neglected, it is more difficult to accept the effect of light pollution on people's health. Inhibition of melatonin secretion, the only anticancerogenic hormone, is such a phenomenon [7]. This process is influenced not only by the level of lighting, but also by the blue component of the light spectrum. Another element entering the equation is the exposure duration of each individual, in contrast to exposure from the natural environment. It has been shown [8] that there are some professions with a non-circadian cycle of activity where the

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incidence of various cancers is significant: breast or prostate cancer [9]. This discovery is all the more important as the differentiation of other risk factors (obesity, stress, smoking, air pollutants, etc.) has been achieved. The second correlation demonstrated in [9] is which of the incidence of prostate cancer in highly urbanized areas, where artificial light at night (ALAN) is obviously more intense. There is also differentiated studies of breast cancer between rural and urban [10], where the main variable is ALAN. Without exhausting the effects of light pollution, we can consider that the measurement of this phenomenon is very important.

III. Global Light Pollution Measurement

Light pollution is a natural consequence of increasing the level of civilization. The overall effect of light pollution is to increase the brightness of the sky [11]. At the same time, sustainable lighting development also means judicious lighting design, imposed locally and individually, for every possible source of light (pollution), which must be identified and limited, as is the purpose of our research.

There are very advanced methods for the imaging monitoring of light pollution, based on the use of satellites [11]. Images cannot be processed without compensation for variations caused by local weather conditions, as well as atmospheric loading with aerosols. These methods, based on high tech and limited accessibility, justify the promotion of our method, which is insensitive to these perturbations. The results obtained by the satellite imaging observations indicate the continuing trend of ALAN expansion [13], as a geographical spread (naturally through urbanization) but also as intensity (most worrying). One can find correlations with the economic growth of different countries, but the high energy efficiency of the LED has a secondary effect of amplifying the installed light flux. It is noted that anti-pollution legislation fails to limit this trend. In addition to economic development, spatial differences can highlight differences between cultures of local communities [14], even if they apply the same technical regulations for lighting or very similar (between continents, for example). This observation reinforces the need to study the various sources of pollution on the ground, the only way to limit them. This approach we support is an active one, as opposed to passive approaches, of the type [15], in which an original database of images of the Night Planet is made, made by passionate astronaut photographers. Similar to sociology, as science, it cannot give particular solutions for certain bright scenes to reduce LP.

In addition, the images from space have limitations due to the resolution of the usual digital cameras. To increase this resolution, airplane images prove to be more useful [16]. Observations can be made with 1*m* resolution for road lighting, but architectural lighting cannot be investigated. In order to overcome this limitation, more complex methods based on images obtained from two digital cameras [17] mounted on an airplane have been proposed. This method can also identify the direction of the source of pollution. The terrestrial imaging method, presented in our research, provides this information based on the analysis of the luminance distribution on the façades.

Façade problem becomes important when we associate them with advertising. They have seen an uncontrolled development in many places in the world, and Korea is a recognized example. The history of this phenomenon has been studied since 1995, according to [18], when the explosive development of the country began but uneven across the regions. At the same time, exposure of the population to light pollution was uneven, causing different incidences of cancer. The situation required the introduction of specific regulations, and yet the effect was not the one expected [19, 20]. The Korean phenomenon was specific to a developing country that reaches higher development thresholds, especially in Seoul. The case study from [21], based on measurements, may be useful for other areas of accelerated development. The history of the amplification of light pollution records the moment when important regulation occurs in 2013, and with all this in 2018, according to [22], the trend is not stopped, as our measurements will show. Light levels exceeded regulated thresholds meets also in 2016 according to [23] and one could explain by the lack of current means for luminance measurement. A subjective comparison allows us to assert that classical pollution literature is very rich and specific [24], while light pollution has a relatively recent approach [18].

Reducing light pollution can only be achieved if the perception of risk is shared by the large population compared to other risks from other sources of pollution. This is one of the new directions of action [25]. Just as global warming is a widely popular phenomenon, broad population involvement is needed, as a successful project [26] does. Using a sky glow measuring device, very detailed data can be obtained in time evolution and geographical spread, with the involvement of the population. The present paper is also based on affordable measuring devices (commercial digital cameras), which are additionally calibrated for luminance measurement. These devices can be the basis of awareness of how light pollution is generated and could be perceived, a phenomenon that cannot be seen with the naked eye.

In addition, after seeing that despite the existence of technical regulations, light pollution does not decline, it is necessary to involve the entire population through the school-university collaboration [27]. Besides education, if the population has a technical means to measure light pollution, awareness of the phenomenon will be much faster, and this is the purpose of this paper, to present a method by which light pollution can be observed and measured.

IV. The Missing Link In The Chain Of Light Pollution Assessment

From the previous chapter it can be concluded that there are many methods for monitoring the phenomenon of light pollution, in particular [1]. The most important can be graphically illustrated in Fig. 1. The phenomenon of pollution is described simplified, schematically, by light directly distributed to the sky (integral light pollution – Fig.1 –LP1),

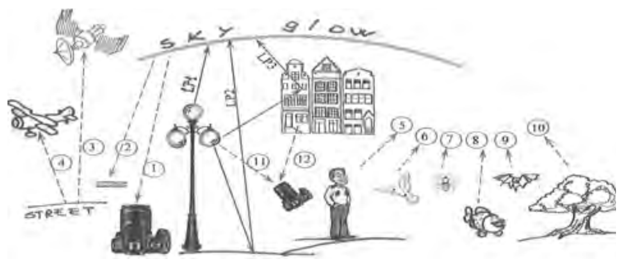

Fig. 1. Light pollution survey.

or by the light reflected on incident surfaces and from which part is scattered to the sky Fig.1 – LP2 (incomplete percentage of LP, because it can be necessary and therefore useful light, Fig.1 – LP3). The means of measurement targeting the sky and, implicitly, the glare of the sky (1, 2, Fig.1), aiming at artificial lighting from artificial satellites (3) or aircraft (4). There are many (5-10) other (indirect) methods of estimating the effects of LP through the study of the health of humans, mammals, insects, birds, fish, etc. Among all these methods, the present research brings another measurement, besides the existing ones, that address the facades of buildings used as screens that materialize the light pollution (11) and then direct studying of the sources of light pollution (12), which represent the missing link.

V. FAÇADE OF PACIFIC – JEJU HOTEL – STUDY CASE

Being prevented from previous lectures [18-22, 25] that light pollution in Korea is a significant phenomenon, observations on South Korea's Jeju City have been particularly attentive (*in Nov. 2017*), especially in the downtown area, which is the tourist area. At a visual observation nothing seems to exceed acceptable limits. Tracking the dynamics of lighting systems and especially the first measurements were the starting point for this case study.

A. Location

Pacific Hotel in Jeju can be located at GPS coordinates: 33.510801, 126.519147. For an overview, the aerial image of the site is shown in Fig.2:

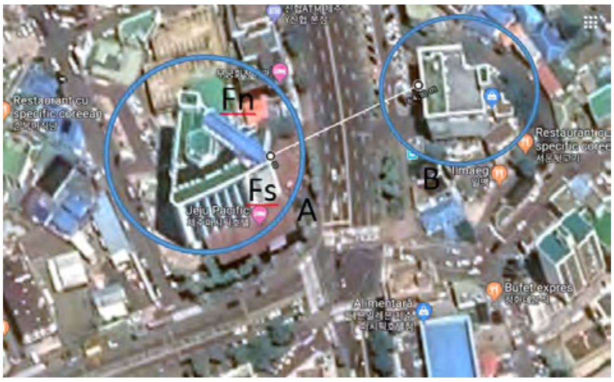

Fig. 2. Pacific Hotel in Jeju (A), GPS coordinates: 33.510801, 126.519147 and HiMart Store (B).

B. The landscape night vision

The studied scene has as its central point the north-eastern façade of Pacific Hotel in the Fig. 3 and Fig.4:

Fig. 3. The Nortd-Estern façade of Pacific – Jeju Hotel

Fig. 4. The Southern Façade of Pacific – Jeju Hotel

The façades of Jeju Hotel interact with a closer advertising lighting system, based interacting with the opposite façade of HiMart Store, in Fig.5:

Fig. 5. The decorative / advertising lighting system of HiMart Store

The store undoubtedly attracts attention due to the high luminances perceived by any pedestrian. The sensation is, however, of some harmony, because the whole area is illuminated at a relatively high level. For many days and numerous visual observations, between those two facades (Fig. 3 and Fig.4) couldn't be made any substantial differences.

C. The trigger event for light pollution revealing

All the bright scene could have gone unnoticed. A seemingly trivial event triggered a more thorough analysis, namely the end of the program at the store, with the decorative lighting off. The effect of this was noted on the hotel's northern façade. The large distance between the two buildings (64 m), the clear amplitude of the luminance variation led to some quantitative analyzes. This analysis consists of several stages in which the luminance is analyzed successively, allowing the quantitative assessment of the source of the light pollution.

The luminance map [28] of north-eastern façade when advertising lights will serve as reference Fig.6:

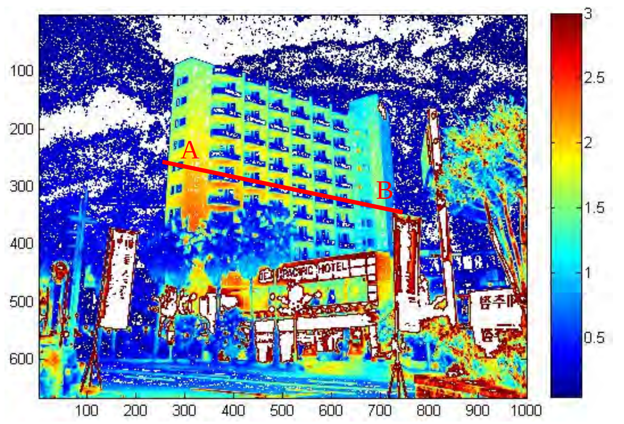

Fig. 6. Luminance map of North-Eastern Façade of Pacific Hotel with LP presence.

To highlight the limits of the visual observation, we also present the map of the southern façade luminance, Fig.7:

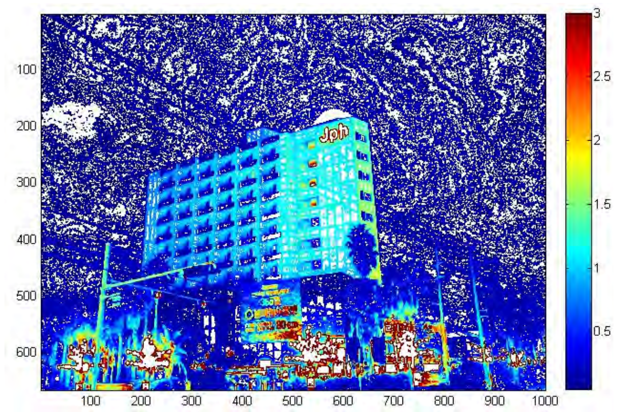

Fig. 7. The Southern Façade luminance map (cd/m^2) without LP

We can comment that the luminance are quite different, and yet they could not be estimated by simply change the observer position along the sidewalks, because the eye adaptation is faster.

D. *The north-western façade without Light Pollution*

The capture of the moment when the Light Pollution is *off* is very important for the differential analysis of the two situations, see Fig.8 against Fig.6:

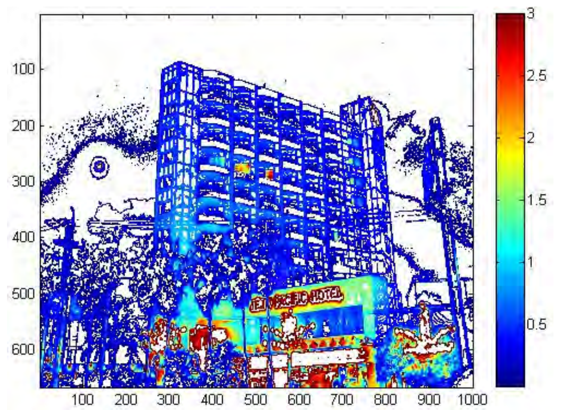

Fig. 8. The Noth-Eastern Façade luminance map (cd/m^2) without LP

We emphasize that the eye does not perceive the absolute values of the luminance on the façade (constant values, with or without LP source in operation), due to pupil adaptation. Only the sudden variation of the luminance is observable, the extinguishing of the LP source generating the situation in Fig.8.

Luminance maps analysis (Fig.6 against Fig.8) provides the first global information, but the distribution of luminance over a certain direction (transverse, or A-B in Fig. 6) can provide information relative to the direction of the source of pollution. This distribution is available in Fig. 9:

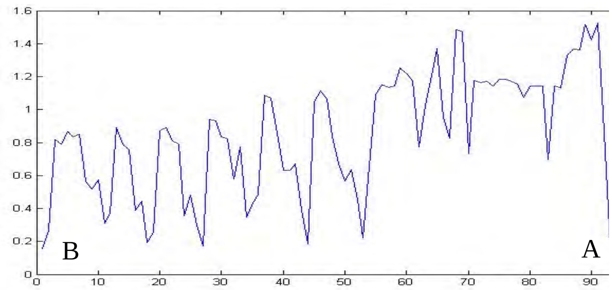

Fig. 9. Luminance distribution (cd/m^2) along A-B points (Fig.6) from North-Eastern Façade of Pacific Hotel with LP presence.

The luminance distribution on the same A-B direction on the north-eastern facade highlights a obvious lower level in the absence of one source of light pollution (HiMart), according to Fig. 10:

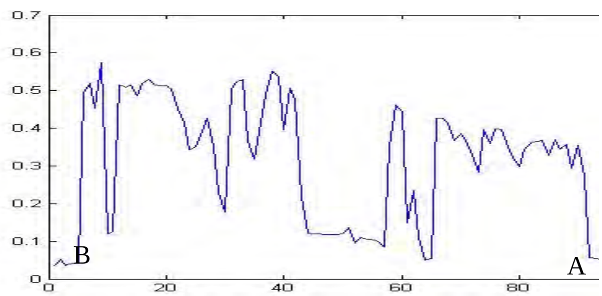

Fig. 10. Luminance distribution (cd/m^2) along A-B points (Fig.6) from North-Eastern Façade without LP presence (from Fig.8).

E. *The assessment of light pollution source*

From the asymmetrical distribution of the luminance profile, with a maximum in the vicinity of point B (Fig.9), it can be deduced that the pollution source is in the vicinity of the point B (in the field). From the location analysis (Fig. 1) it is quickly concluded that HiMart can be the main source of light pollution. At this point, a more thorough analysis of the HiMart façade and the luminances generating light pollution can be made.

The first observations of the luminous map (Fig.11) for HiMart façade indicate moderate values of the indirectly illuminated façade, but there are areas with very large luminance, well above 1000 cd / m^2:

- The interior of the shop, visible through clear windows, without blinds;
- The horizontal stripe at the top of the facade, with a lower distribution but also with an accentuated upper component;

- The horizontal stripe at the bottom of the facade, with superior distribution and thus a strong contribution to light pollution.

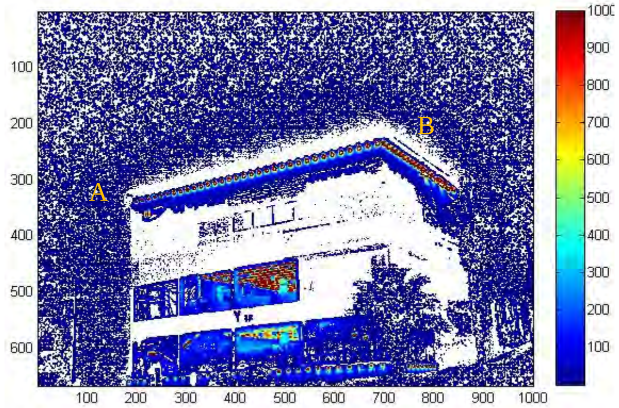

Fig. 11. Luminance map (cd/m^2) of the Western Façade of HiMart Shop

After this identification of the extreme zones, it is possible to extract the particular values that generate the light pollution, such as area A-B, for which the distribution profile of the luminaries can be extracted, Fig.12:

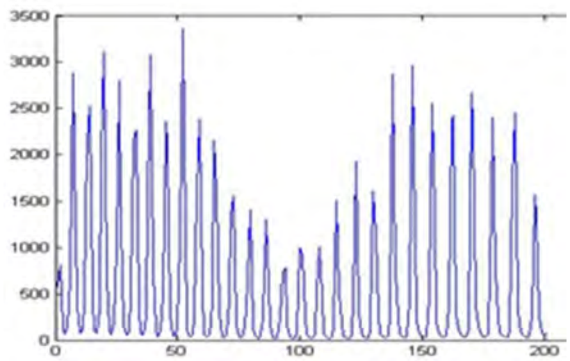

Fig. 12. Profile of luminance distribution (cd/m^2) on superior strip of the Façade of HiMart Shop

Very high values of luminance are observed in Fig.12. This analysis is made only from the position of a pedestrian vision, the luminous flux distributed upwards and obviously to the north-eastern facade being very high. The fact that this source of pollution is manifested without necessarily being identified by the observer from the first moment (even being integrated into the night landscape) strengthens the usefulness of using the quantitative assessment method based on imaging.

VI. Conclusions

There are many concerns in the world for assessing the effects of light pollution, from effects on human health to effects on insects, birds, mammals, fish, and plants. There are also many methods of measuring light pollution, most of them being global, based on the sky glow. Technical regulation in the field of light pollution makes significant progress, with Korea being a positive example. And all these, light pollution continues to grow, partly because of the high efficiency of LED sources. Against this trend, a way of approaching quantitative observations based on digital cameras can become widely available. The presented method of work is based on the observation of the luminance variation on the façades of the buildings, in the presence and in the absence of various sources of pollution. In this way, buildings are used as a "screen" by means of which light pollution (which is *almost invisible*) becomes palpable, measurable. It is possible to obtain information even about the direction of the source of light pollution, as is the study case in Jeju, Korea. By doing so, it is possible to increase the awareness of the population, the only measure by which light pollution can be diminished.

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Geometry Influence on the Precision of Light Flux Measurement with Ulbricht Integrating Sphere

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***Abstract*—Integrating sphere is a device that canhave important structural dimensions and weight, generating the possibility for somedeformations to occur. In general, the measurement chains are used with the analysis of the sources of errors, but no information was found about the errors generated by the integrating sphere itself. Geometric errors caused by imperfections could generate systematic errors, even immediately after sphere calibration with a standard source of light. The phenomenon of multiple reflections on a surface which is not spherical will induce errors that depend on the lighting distribution of the measured luminaire and his mounting position. The paper examines these assumptions to estimate the scale of the geometric imperfections (constructive or created in time) in correlation with the errors introduced in the measured luminous flux.Original MATLAB functions and DIALux are used to evaluate the light reflection between surfaces.**

Keywords—Integrating sphere; luminous flux measurement; source of errors

I. INTRODUCTION

The theory of integrating sphere is well known, but the influences of the sphere irregularities are not studied. In [1],wefind that "deviations from an ideal sphere can drastically affect the accuracy of the sphere equations" but no other quantitative approach. Also, "the real integrating spheres are not ideal. The sphere-wall coating is never a perfect Lambertian diffuser, baffles perturb the light distribution within the sphere, and all detectors exhibit some angular dependence." A qualitative solution is mentioned: „The inherent problems of sphere spatial non-uniformity are overcome through judicious use of the symmetries of the sphere design to establish symmetries in the measurement geometry", but again, no other quantitative assessment.

In order to understand the importance of the sphere geometry, it is useful to use [2] for some important observations. Anticipating, the particular geometry of sphere gives the possibility to locate the tested luminaire in any place or orientation in the sphere. Because the direct illumination is neglected (due to the use of a screen in front of the sensor) the *first reflected luminous flux will be uniform in the interior of the sphere*. The subsequent reflections will be also uniform, the final illumination representing the sum of all these reflections.

The geometry of the reflected beam between two differentialsurfaceelements, dA_1 and dA_2 inside of a diffuse spherical surface by radius R is available in Fig.1:

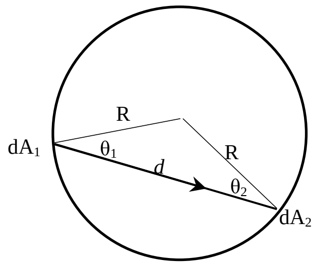

Fig. 1. The reflection from surface $dA_1$to dA_2, with incidence angles θ_1 and θ_2 and the distance d.

Radiation exchange within a spherical enclosure canbe found in numerous scientific papers, but also misunderstandings are possible. For example, in [2] or even in [3] (a well-known monographic book), the sphere reflections are described using the fraction of energy leaving $dA_1$and arriving at dA_2. For two random oriented surfaces, this fraction is known as the exchange factor dF_{A1-A2} or form factor [2]:

$$\mathrm{dF_{A1-A2}} = \frac{\cos\theta_1 \cdot \cos\theta_2}{\pi d^2} \mathrm{dA_2} \tag{1}$$

The equation is correct only in appearance, because the form factor is a real number, not a differential value. The final conclusion will be [2]:

$$\mathrm{dF_{A1-A2}} = \frac{\mathrm{dA_2}}{4\pi R^2} \tag{2}$$

where the result is independent of viewing angle and the distance between surfaces. The presence of differential dF makes the expression difficult to understand.

II. THE FIRST REFLECTION IN THE SPHERE

Usually, the reflections are calculated like a sum, but if we are interested to study non-spherical geometry, we need the expression for every reflected flux, because the errors will be generated in the same „additive"manner. To solve this, a fast demonstration is available, proposed by the author.We can start

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from the definition of form factor for surface dA_2illuminated by the reflection from dA_1, with initial illumination E_1 (Fig.1):

$$F_{A1-A2} = \frac{\text{Incident flux}}{\text{Reflected flux}} = \frac{\emptyset_2}{\emptyset_1} = \frac{dA_2 \cdot E_2}{dA_1 \cdot E_1 \cdot \rho} \tag{3}$$

And with

$$E_2 = \frac{I_1 \cdot cos\theta_2}{d^2} = \frac{\rho \cdot dA_1 \cdot E_1 \cdot cos\theta_1 \cdot cos\theta_2}{\pi \cdot d^2} \tag{4}$$

We obtain

$$F_{A1-A2} = \frac{dA_2 \cdot \rho \cdot dA_1 \cdot E_1 \cdot cos\theta_1 \cdot cos\theta_2}{dA_1 \cdot E_1 \cdot \rho \cdot \pi \cdot d^2}$$

$$= \frac{dA_2 \cdot cos\theta_1 \cdot cos\theta_2}{\pi \cdot d^2} \tag{5}$$

We can use:

$$\theta_1 = \theta_2 \text{ and } d = 2 \cdot R \cdot cos\theta \tag{6}$$

To obtain a very suggestive conclusion:

$$F_{A1-A2} = \frac{dA_2}{4\pi R^2} = \frac{dA_2}{A_{sphere}} \tag{7}$$

So, we have the demonstration that form factors are real numbers, independent of viewing angle and the distance between the areas. The immediate consequence is the fact that the *reflected luminous flux will be uniformly distributed, even if the direct illuminance is very irregular.*

We can use this *invariant* form factor (7) to write the expression of the illuminanceE_{ref1}(after first reflection) in a certain point, like a sum of reflections from all small surfaces that sent luminous flux:

$$E_{ref1} = \frac{\text{Reflected flux}}{dA_2} \tag{8}$$

$$E_{ref1} = \frac{1}{dA_2} \sum_{k=1}^{sphere} E_{dir_k} dA_k \cdot \rho \cdot \frac{dA_2}{4\pi R^2} \tag{9}$$

In (8) we find the total initial luminous flux of the source:

$$\emptyset_{lamp} = \sum_{k=1}^{sphere} E_{dir_k} dA_k \tag{10}$$

and

$$E_{ref1} = \emptyset_{lamp} \cdot \rho \frac{1}{4\pi R^2} \tag{11}$$

Considering the spherical surface:

$$E_{ref1} = \rho \cdot \frac{\emptyset_{lamp}}{4\pi R^2} \tag{12}$$

$$E_{ref1} = \rho \cdot E_{dir}^{medium} \tag{13}$$

This equation describes the integrating function of the sphere, showingthat thefirst reflected illuminance depends on the total flux of the lamp, even if the initial lightdistribution is very irregular. This particular property could be the explanation for the maintaining of the form factor as a calculation method, even for large spaces [4, 5, 6, 7].

The real problems occur if the sphere is not perfect. In this situation, the equations (7) and (9) are not valid because the form factors are not constant and must be calculated for every two surfaces.

III. The Validation Test for Matlab Simulation of Reflected Flux

In order to study the response of a real spherical surface, with irregularities, the authors present a method based on the original MATLAB function, capable to calculate the expression (9) but in the mostgeneral situation, practically for any two surfaces:

$$E_{ref1} = \sum_{k=1}^{surface} E_{dir_k} dA_k \cdot \rho_k \cdot \frac{cos\theta_1^k \cdot cos\theta_2^k}{\pi \cdot S_{k_{12}}^2} \tag{14}$$

Reflected illuminance is calculated not only for one point, but forall the elementary surfaces. Using this function in addition tothe visualization function available in MATLAB, we obtain an authentic experimental model of the problem.

The mesh generation for a sphere is immediately possible in MATLAB:

$$[x,y,z] = sphere(25); \tag{15}$$

In this command line, 25 represent the number of finite elements on a semiperimeter, for a sphere withradius equal to1, with the center at (0, 0, 0).

The values are used to validate the model presented in Table 1, and the justification for some of them will be found in the next paragraph.

TABLE I. VALUES FOR THE MODEL VALIDATION

No	Specification	Value	Units
1	R - Radius	4	m
2	P – Reflectance	0.86	-
3	M - Maintenance factor	1	-
4	Φ_L – Luminous flux of the lamp	4390	Lm
5	Position of the lamp	X_L=3; Y_L=0; Z_L=4	m
6	I – Omnidirectional luminous intensity of the lamp	392.3	cd
7	Coordinates of the center of the sphere	Xs=0; Ys=0 Zs=4	m

$$\begin{aligned} x &= border(x) \cdot 4 \\ y &= border(y) \cdot 4 \\ z &= border(z) \cdot 4 + 4 \end{aligned} \tag{16}$$

Here, function border introduces a supplementary series of elements on the contour of the sphere, with infinitesimal dimensions, in order to reduce the errors generated by the function surfnorm, which returns the surface normal components.

The direct component of illumination is calculated with a dedicated function *bec*:

$$Edir = bec(\Phi_L, [XL, YL, ZL], x, y, z) \tag{17}$$

Atthis moment, the results are available for visual examination, with *surf(x, y, z, Edir)*. In Fig.2 we have the result:

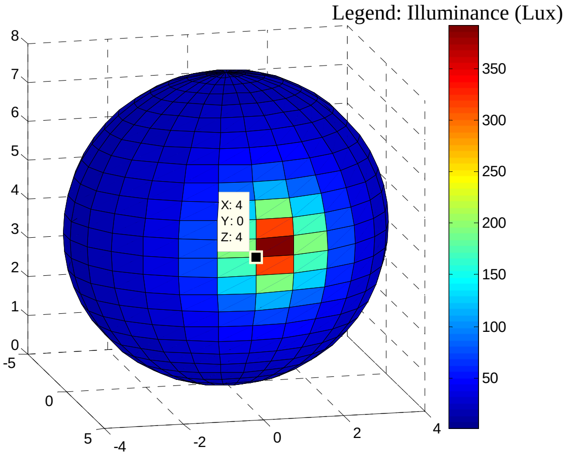

Fig. 2. The illuminance from direct flux from the lamp with 4930 lm.

We notice that the maximum value (392.31 lux) is obtained in the point by coordinates (4, 0, 4), when the lamp is situated at (3, 0, 4), and the minimum value (8.004 lux) is diametrically opposed, due to the distance of 7m from the lamp (with 392.31 cd).

A supplementary discussion is possible if we calculate the direct illumination for the central position of the lamp: 24.52 lux. This value will be very small ascompared to the final illumination, after multiple reflections (150.6 lux).

We need to prepare the reflectance of the material:

$$RO=zeros(size(x))+0.86 \tag{20}$$

and

$$[xx, yy, zz, ss1, ee1]=mesh2lux(x, y, z, Edir) \tag{21}$$

The function *mesh2lux*gives the coordinates of the center of gravity of discrete surfaces *[xx, yy, zz]*, the surfaces of finite elements *ss1* and average illuminance in the center of the surfaces. Here, a supplementary verification is possible:

$$Aria1=sum(sum(ss1))$$

$$Flux1=sum(sum(ss1 .*ee1)) \tag{22}$$

where *Aria1* gives the surface of the considered sphere and *Flux1*is the total flux of the lamp. After this small preparation, the first reflected illuminance will be calculated:

$$Eref1=luminas(x, y, z, x ,y ,z ,RO,Edir) \tag{23}$$

In this command, the surfaces *[x, y, z]* generate reflections on the same surfaces *[x, y, z]*.
The result is not so spectacular, nothing to visualize, because the result is a constant matrix, with the value 21.0837 lux. But the method gives us the possibilityto evaluate also the second and the third reflection (Table II).

TABLE II. VALUES OF ILLUMINANCE FOR THE TEST PROBLEM(LUX)

	Values	Reflection 1	Reflection 2	Reflection 3
1	Minimum	20.8969	17.8490	15.2456
2	Maximum	21.0535	17.9826	15.3597
3	Average	20.9669	17.9087	15.2965
4	Theoretical	21.0870	18.1348	15.5959
5	Error (3-4)/4	-0.569 %	-1.246 %	-1.919 %

These values will be compared with the simulation of the modified sphere. These outcomes are useful for an immediate confirmation of the simulation realized in DIALux (Fig. 3), for the same geometry, but for a real luminaire. This is one of the advantages of DIALux, that it gives the possibility to insert IES files.

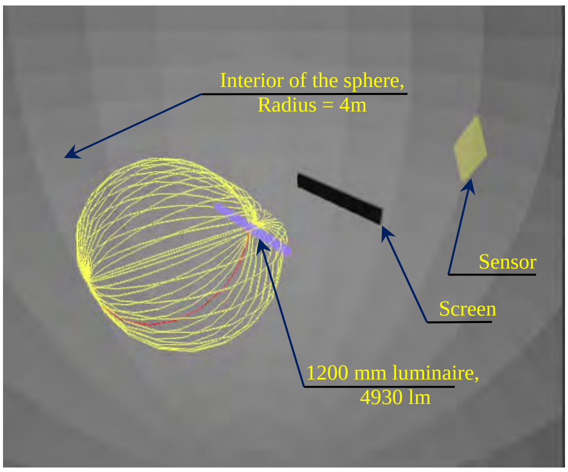

Fig. 3. The sphere simulation in DIALux EVO 6.1

The main result of the DIALux simulation is the final value (Er = 151 lx) for reflected illumination (direct illumination was eliminated introducing the screen between the luminaire and the sensor). If we write the sum of successive interior reflections:

$$\mathrm{E} = \mathrm{E_{dir}} \cdot (\rho + \rho^2 + \cdots) \tag{24}$$

With the well-known expression:

$$\mathrm{E} = \mathrm{E_{dir}} \frac{\rho}{1-\rho} = 24.51981 \frac{0.86}{1-0.86} = 150.6 \tag{25}$$

In the author's opinion, this is a confirmation of the precision of DIALux, because it includes ray tracing or radiance methods, but it also implements global illumination using the Monte Carlo method to sample light falling on a point.With this validation we have the argument that fast computation doesn't sacrifice the precision.

IV. The Imperfect Sphere Reflections

The model could be used for implementing an irregularity to the sphere, imposing a planar surface, at a distance equal to 3.6 m from the center. Mesh can be modified very easily:

$$x(16{:}24, 17{:}25) = 3.6 \tag{26}$$

First of all, the geometry must be visualized:

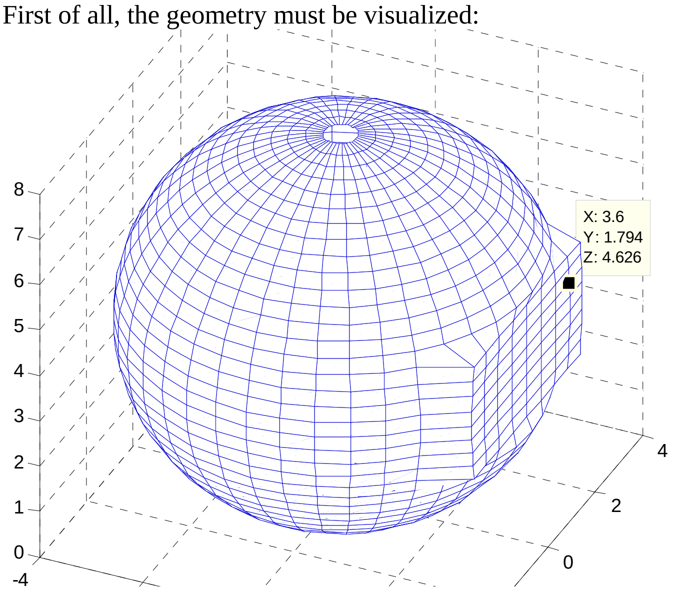

Fig. 4. The sphere irregularities, imposed like a partial planar surface

Using this geometry, weapply the function for direct illumination,and after that,all the steps of multiple reflections in the interior of the sphere. Direct illumination is available in Fig.5:

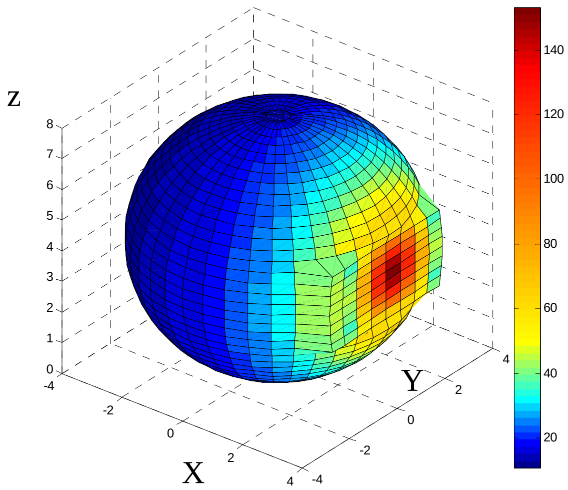

Fig. 5. The direct illumination, with the lamp positioned at (2, 0, 4)

TABLE III. Values of Illuminance for the Sphere with Partial Planar Modification

	Values	Reflection 1	Reflection 2	Reflection 3
1	Minimum	17.4684	17.9494	15.2694
2	Maximum	32.3831	23.8378	20.0475
3	Average	20.9669	17.9087	15.2965
4	Theoretical	21.0870	18.1348	15.5959
5	Error (2-4)/4	**53.6 %**	**31.4 %**	**28.5 %**

An interesting result is the average illumination, at every step. The results are identical, and an explanation could be accepted using the flux conservation in the interior of the sphere. The qualitative examination (Fig.6) indicates the importance of the maximum or minimum values of reflected illuminance, because the position of the sensor is not very easy to be located in relation with the spherical anomaly.

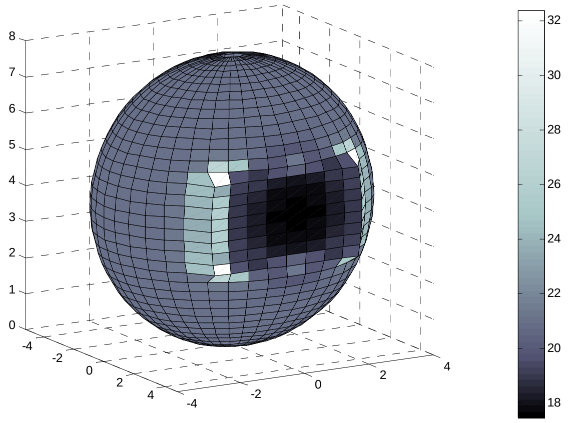

Fig. 6. The irregularities of the first reflected illumination

Based on Fig.6, the errors generated by the sphere's imperfection are calculated between maximum illuminance and theoretical illuminance. The obtained values confirm that the errors generated by the geometry of the sphere could influence the measurements.

V. The Quantitative Approach

Until in this point, we have the confirmation about the connection between sphere flattening and systematic error. In real situation, a local fault of the sphere is more probable. Also, the maximum excentricity was limited at 5% (in the exterior and in the interior of the sphere). In Fig.7 we can observe the shape of the linear strain (with higher amplitude than 5%, in order to be visible).

In order to underline the errors in luminous flux inter-reflections, the mesh generations considered a higher number of elements (10^4) and also a supplementary number of reflections ware calculated (nine). In Table IV we have a selection of significant values

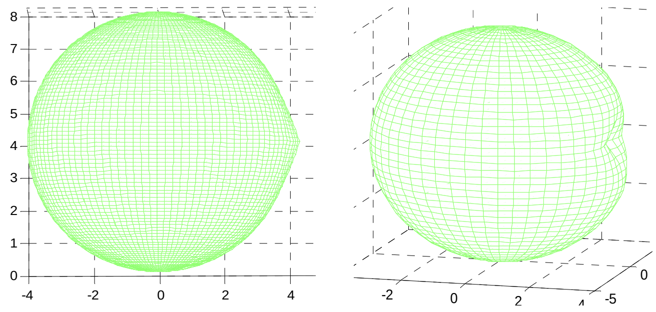

Fig. 7. The linear strain of the sphere, positive (the left side) and negative (the right side)

TABLE IV. ERRORS IN SUCCESIVE INTER-REFLECTIONS FOR THE POSITIVE LINEAR STRAIN OF THE SPHERE (ILLUMINANCE IN LUX)

	Maximum	Minimum	Theoretical	C-B
	A	***B***	***C***	***D***
1	21.689	20.965	21.870	0.905
2	18.567	17.963	18.135	0.172
3	15.901	15.383	15.596	0.213
4	13.617	13.174	13.412	0.239
5	11.661	11.282	11.535	0.253
6	9.986	9.661	9.920	0.259
7	8.552	8.274	8.531	0.257
8	7.324	7.085	7.337	0.251
9	6.272	6.068	6.310	0.242

In column D, Table IV, we find the errors (successive reflected illuminance, in lux) and these errors are also additives. The sum for the first nine reflections will generate an error of 2.79 lx, already inacceptable comparing with the total illuminance of 150.6 lx (23). Off course, this error will have effect only if the sensor will be exactly in the place of the strain. For the negative strain we have the results in Table V.

TABLE V. ERRORS IN SUCCESIVE INTER-REFLECTIONS FOR THE NEGATIVE LINEAR STRAIN OF THE SPHERE (ILLUMINANCE IN LUX)

	Maximum	Minimum	Theoretical	C-B
	A	***B***	***C***	***D***
1	21.044	20.618	21.870	1.252
2	18.078	17.746	18.135	0.389
3	15.531	15.246	15.596	0.350
4	13.342	13.098	13.412	0.314
5	11.462	11.253	11.535	0.282
6	9.847	9.667	9.920	0.253
7	8.460	8.305	8.531	0.226
8	7.268	7.135	7.337	0.202
9	6.244	6.129	6.310	0.180

The sum for the first nine reflections (column *D*) will generate an error of 3.45lx, even higher than in previous case. This hypothesis generates also interesting aspects, the errors generated by the *maximum* values (Columns *A*-*C*) change the sign on successive reflections, and this will determine a smaller total error.

VI. CONCLUSIONS

The errors generated by the geometry of the integrative sphere can be studied using MATLAB simulations and also DIALux. The absolute errors can be very important, if the position of the sensor or the zone of first incident luminous flux is in some coincidence with the sphere irregularities. Theseassessment methods are also useful in designing standard luminance sources, when the sphere gives the best uniformity.

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OPTICAL UTILIZATION FACTOR FOR ARCHITECTURAL LIGHTING

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Abstract
Optical utilization factor (OUF) is applied to architectural lighting, searching to obtain low light pollution. It is demonstrated that OUF could not be used for the assessment of light pollution, because the interreflections could not be neglected. Dialux simulations and MATLAB original functions are used. Onsite measurements for illuminance and luminance are performed. It is demonstrated that OUF could be greater than one for the façade. For the small scale interreflections, a luminance gain is demonstrate. Due to this, the floodlighting could be reduced. The understanding about the light pollution assessment is changed, which is a major achievement. It means that a greater OUF don't represent a lower light pollution, and also a façade could be more "visible" on lower level of floodlighting.

Keywords: Luminance gain, concave interreflections; luminance measurements; mesh generation.

1 Introduction

The traditional light pollution approach is based on visual comfort and saving energy. Light pollution is seen as an individual comfort criterion, and not at global scale as today, when one finds "studies for limiting the impact of light pollution on human health, environment and stellar visibility, the effects of light pollution on ecosystem and countermeasures or even focusing on society's disregard for the loss of a cultural asset that has been a part of art, science, and culture for as long as these things have existed" [1]. One direction of the researchers is to measure the global light pollution, observing the sky glow [2]. Other approach is focus on the sources of Light pollution. Obviously, the main source of light pollution is the street lighting, but the architectural lighting has also an important weight factor [3, 4]. Leaders in the fight of reducing the light pollution are astronomers, but with a wider approach [5]. Other interesting example is STARS4ALL network, a project funded by the European Union H2020 Program. This project is based on a comprehensive definition: "Light pollution is excessive, poorly directed or unnecessary artificial light at night" [6]. This definition is very clear with the terms excessive and poorly directed, but unnecessary could generate a special discussion, especially in context of façade lighting. The paradigm of this paper consists in the acceptance of hypothesis that the light is necessary for the beautification of the façade, with non-excessive level and perfectly directed, but the light pollution level could be different. This aspect could optimize through the Optical utilization factor (OUF). A supplementary example about the necessity of this study one find in [7], where light pollution is seen only like obtrusive lighting, sky glow, disability glare and trespass lighting are mentioned.

Optical Utilization Factor (OUF) demonstrates his relevance also in [8], where the real dimension of the problem can be found: "the dominant part of the light source luminous flux (70%–80%) misses the building and is emitted towards the sky. This fact is much more important in determining light pollution than the light reflected from even a too brightly illuminated façade" [8]. This estimation enhances the importance of OUF, more than traditional approach [9], where utilization factor (UF) was used as an indicator for energy efficiency of road lighting. From [10] one could take more similarity between façade lighting and road lighting, considering "the road lighting energy efficiency evaluation based on the normalized power density including the impacts of the applied lighting equipment, the reflection properties of the road surface (façade!) and the maintenance factor. The road lighting energy efficiency evaluation based on the installed power density permits including, in addition, any oversizing of lighting arising from too high (irrational) levels of road surface luminance compared to the required levels (or façade !)".

2 The Relevance of Optical Utilization Factor (OUF)

OUF is a classical indicator in designing interior artificial lighting or street lighting. OUF is still used in recent papers [6],

OUF is the ratio of the lumens actually received by a particular surface to the total lumens emitted by a luminous source.

A specific definition, adapted to floodlighting is given below:

$$FUF = \frac{\emptyset_u}{\emptyset_t} \tag{1}$$

where:

FUF – floodlighting utilization factor, similar to OUF,

$\emptyset_u$ – useful luminous flux

$\emptyset_t$ – rated luminous flux of the light source

The light output ratio (*LOR*) of luminaire is also very important parameter as the total loss of light energy including transmission through fittings is also taken into account.

The following expression is used.

$$LOR = \frac{Output\ of\ Luminaire}{Output\ of\ luminous\ source} \tag{2}$$

This convention could be accepted (FUF is equivalent to OUF), but the next affirmation, in equation (3) from [10], must be analyzed carefully:

$$FUF \leq LOR \tag{3}$$

Any attempt to deny equation (3) seems to deny energy conservation law. Contrary this, one demonstrate that equation (3) is not true. The argument is based on interreflections (The illumination of an object by reflected light from other objects that are not light sources), which generates an effect of "multiplying" the luminous flux. After the demonstration of this, one uses the results to obtain the maximum visual effect with minimum luminous flux, equivalent with a reduction of light pollution.

A discussion is necessary, because $\emptyset_u$ (useful luminous flux) is not a theoretical parameter. Also in [10] is determined using the luminance measurement of the façade, which includes, finally, the interreflections!

Following the same author, in [11] discovered details about how useful luminous flux is measured, based on field luminance measurements: "When the average level of luminance of the facade, its surface S and reflectance factor ρ of its materials are known, it is possible to calculate the useful luminous flux …. (assuming that there are no interreflections)". But this last hypothesis was not studied at all in [10], and for a large number of façades (different from a flat surface) it is difficult to be accepted that the interreflections are absent.

3 The Flux Amplification Factor of Concave Interreflections

The idea of flux amplification factor is based on the well-known expression of illuminance in an integrating sphere [12]:

$$E_{fin} = E_1 \frac{\rho}{1-\rho} \tag{4}$$

where

E_{fin} – final (after interreflections) illumination in interior of the sphere,

E_1 - initial (direct) illumination in interior of the sphere (lux),

ρ - reflectance factor of the interior surface.

Obvious, affecting the equation (4) with the interior surface of the sphere (S), one obtains the expression of useful luminous flux:

$$\emptyset_u = \emptyset_t \frac{\rho}{1-\rho} \tag{5}$$

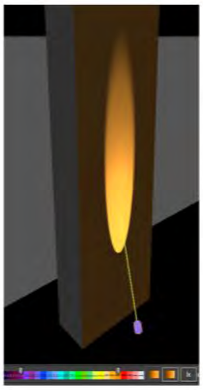
and

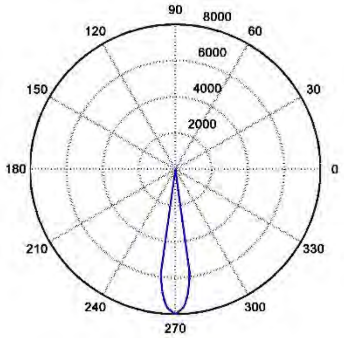
$$OUF = \frac{\emptyset_u}{\emptyset_t} \cdot 100\ \% = \frac{\rho}{1-\rho} \cdot 100\% > 100\ \% \tag{6}$$

Off course, OUF is greater than one for an integrating sphere, due to a maximum interreflections phenomena. It can be concluded that for other façade configurations the OUF will be in different proportion. To observe this, one should start from simple hypothesis to more complexes one.

3.1 The perfect planar façade

This is the most common situation, considered to represent a reference for the next configurations.





a) b)

Fig. 1 (a) The DIALux model for a planar façade and (b) the polar curves for light intensity *(cd/1000lm)* of the luminaire

The DIALux model is based on a vertical façade, dimensions 1.2*m* x 4 *m* (surface area) implemented with a cuboid with 0.5 *m* thickness, positioned at (0, 4, 0) and rotation (0°, 0°, 180°). The dimensions give the possibility to replicate the model in DIALux. A floodlight is orientated from a distance of 0.3 *m* to the façade, respectively from the point in DIALux coordinates (0; 3.4; 0.1) and an angle of 165° from horizontal, respectively (0°; 165°; -90°). The floodlight has a source of 2700 *lm*, with *LOR* = 46.7%. This extremely low value is calculated in LDT Editor Software (by DIAL), after the original file of the luminaire was modified, in order to eliminate the luminous intensity emitted over 9° from optical axis. The purpose of this constraint is to impose an OUF equal with 100%, based on a total control of light. Considering a punctual rotational-symmetrical lighting fixture, the values imposed for this luminous intensity are presented in Table 1:

Table 1. Luminous intensity for the lighting fixture used in DIALux model, Fig.1

Angle	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
cd/1000 lm	8000	7900	7800	7700	7500	7200	6800	6300	5700	0

The results (of Table 2) are predictable, but useful for the next considerations:

Table 2. The results obtained from DIALux simulation (see Fig.1.)

	Entry				Results		
Symbol	$\emptyset_t$	S_{facade}	M_f	*LOR*	E_{med}	$\emptyset_u$	*OUF*
Units	*lm*	m^2	-	%	*lx*	*lm*	%
Values	2700	1.2x4	0.85	46.7	223	2696	99.8

Where $S_{façade}$ is the target surface, M_f is maintenance factor, and E_{med} is average illuminance.
Notice: the value for *OUF* is practically 100% but its calculated value is 99.8. It is due to error as there is lack of sufficient decimals in DIALux.

We anticipate that *OUF* equal with 100% is not the ideal situation, in the sense that no spilling light is generated by the luminaire. A fast estimation can be done with (5), considering a white painting ($\rho = 0.86$) for that the flux amplification value results greater than six!

3.2 The Useful Flux Amplification from a Complete Cylinder

The interreflections on the usual façades are generated by cylindrical shape, in a small scale (window framing) or in a larger scale (on soffit or arches). In order to estimate the possible values, the limit of the useful flux amplification will be generated by a close cylinder by similarity with the integrating sphere as shown in Fig.2.

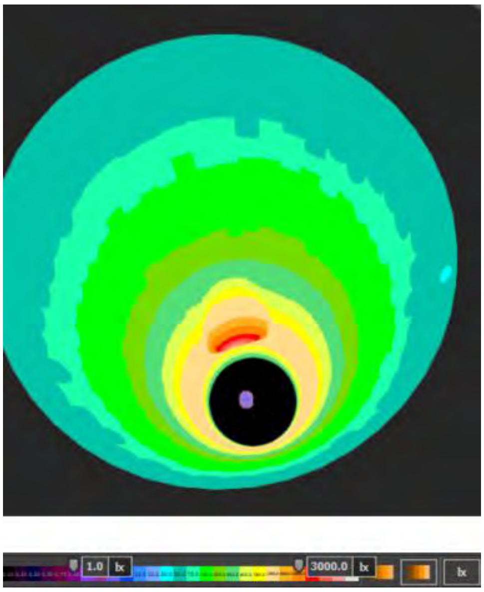


Fig. 2 The interreflections in an interior of a cylinder.

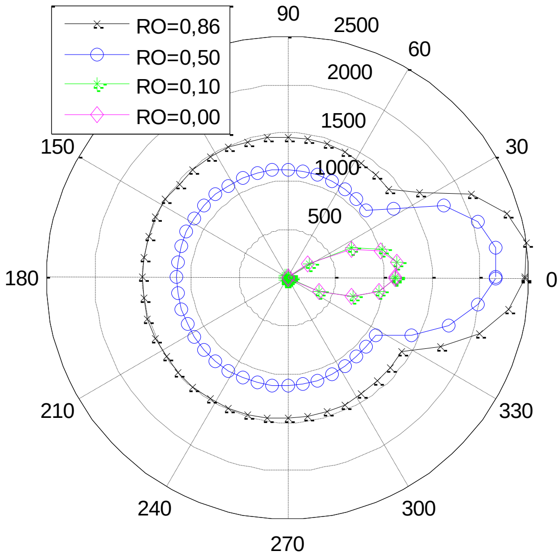


Fig. 3 The average illumination (*lx*) in the interior of the cylinder, for different reflection factor RO (***ρ***).

For a better understanding, Fig.2 was obtained by maintaining the lamp in the same position as in Fig.1.The wall is replaced by a cylinder with 0.3 m radius and positioned at (0, 3.4; 0.1). The height of the cylinder is the same 4 m, and the number of elementary surfaces used to approximate the cylinder was 44 (dimensions 42.84 mm x 4 m, equivalent to surface = 0.17136 m^2). For every individual surface in Fig.3, an average illumination (lx) was calculated, giving the possibility to compare the direct illumination (available for reflection factor $\rho = 0.0$) with the other situation, where interreflections are present with $\rho = 0.10$; $\rho = 0.50$ and $\rho = 0.86$. Results show $\rho = 0.10$ is very close to direct illumination and $\rho = 0.86$ gives maximum interreflections.

A technical observation is necessary: due to specific export of the results from DIALux, all the data must be extracted individually, especially because in DIALux the cylinder is solved like a collection of disconnected elements with particular values, not as a specific vector. Even with those difficulties, one obtains the balance between total flux of the lamp $\emptyset_t$ and useful luminous flux $\emptyset_u$ on the cylindrical wall:

Table 3. Optical Utilization Factor for the cylinder used in DIALux model, Fig.2

Wall reflectance	*0.0*	*0.10*	*0.50*	*0.86*
$\emptyset_u$ – *useful luminous flux (lm)*	*2715*	*3110*	*23885*	*30340*
$\emptyset_t$ – *total luminous flux (lm)*	*2700*	*2700*	*2700*	*2700*
OUF	*1*	*1.152*	*8.846*	*11.237*

Once again, *OUF* indicates that the total luminous flux will be amplified by the interreflections. Due to the specific method of computing of DIALux (Photon method) and the difficulties in setting the calculus points for the cylindrical elements, a certain uncertainty over the results from Table 3 must be avoided. The main source of uncertainty is the comparison with the integrating sphere, where the *OUF* has a well-known value, calculated starting from the constant of the sphere $\rho/(1-\rho)$ in addition with one (the direct illumination from the source), as in Table 4:

Table 4. The OUF for an integrating sphere.

Wall reflectance factor (ρ)	0.0	0.10	0.50	0.86
$OUF = \frac{\rho}{1-\rho} + 1$	1	1.11	2.0	7.14

This correction is possible using the exact calculus of the interreflections, developed in MATLAB by the authors.

3.3 The MATLAB Calculation for OUF for a Complete Cylinder

The interior of a similar cylinder as in Fig. 2, with diameter of 0.6 m and length of 4 m was generated in MATLAB. A direct illumination was imposed for a central region, with a constant level of 100 lx. This hypothesis could simplify the analysis of the reflected flux, with contribution to the final value of OUF. The advantage of MATLAB calculation consists in successive evaluation of every reflected flux.

Mesh generation for this cylinder is presented below:

```
R=0.3m;        % Radius of the cylinder used for interior inter-reflections
for j=1:59    % Number of elements on the generatrix
for i=1:36     % Number of elements on the diretrix of the cylinder
   XCIL(j,i)=R*cos((i-1)*2*pi/35);% domain (-0.5 to 0.4) in Fig.4
   YCIL(j,i)=2-(j-1)*4/58; % domain (-2 to 2) in Fig.4
   ZCIL(j,i)=.30-R*sin((i-1)*2*pi/35); % domain (0 to 0.6) in Fig.4
     end
   end
```

After the imposing of the direct (initial) illumination level equal with 100 lx (yellow color in Fig.4), the initial model for interreflections in MATLAB was obtained:

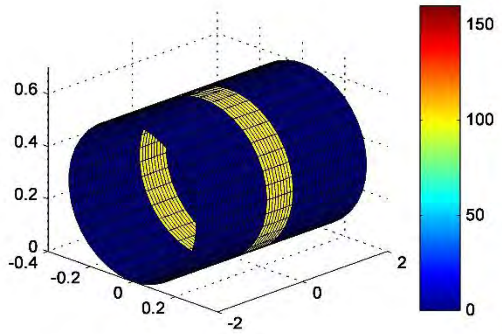


Fig. 4 The MATLAB model for interreflections in a close cylinder (initial illuminance,100 *lux*)

The interreflections in the deep interior of the cylinder ***follows the model of the integrating sphere*** as in Table 4. It is due the fact that the luminous flux spill through the extremity of the cylinder could be neglected (as it is 4 *m* long). In this way a fast confirmation of the precision of our calculation is obtained.

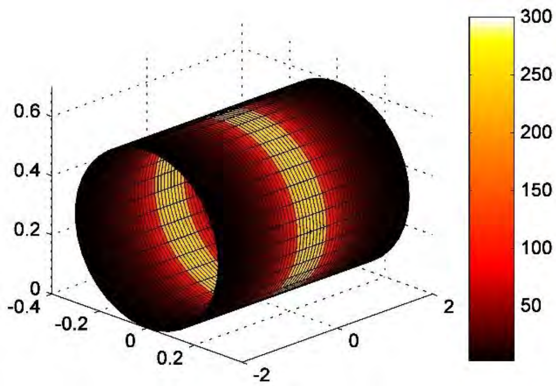


Fig. 5 The interior illuminance *(lux)* after six interreflections

A visual examination indicates that luminous flux, *after six Lambertian reflections*, is located in the central region of the cylinder also, as shown in Fig.5.

3.4 The OUF of a Cylindrical Concavity of a Façade

After the previous validation of the MATLAB model, a general situation of a cylindrical concavity with a central illuminated zone could be evaluated. This hypothesis is based on the small or medium size concavity in façades, and the purpose is not the calculation of the OUF, because it depends by random factors. OUF is greater than 100%, just to illustrate that OUF is not a good indicator for light pollution.

In Fig. 6 the initial configuration is presented with 36x56 cylindrical elements, illuminated with 100 lx (from element 9 to 28 on the diretrix and from element 9 to 49 on the generatrix):

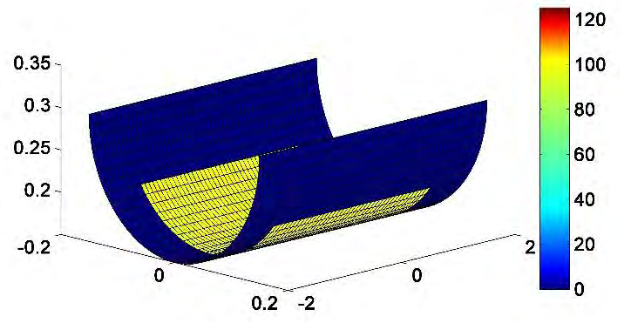


Fig. 6 The cylindrical concavity, with initial direct illumination (lux)

In Fig.7 the total reflected flux, after six steps can be visualized.

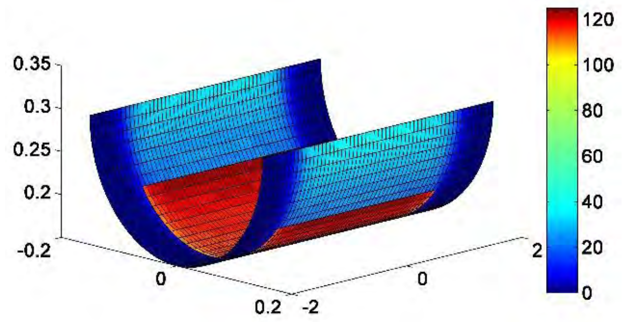


Fig. 7 The cylindrical concavity, with final reflected illumination after six steps

After qualitative assessment, a quantitative assessment is available in Table 5, where the reflected luminous flux is evaluated at every step.

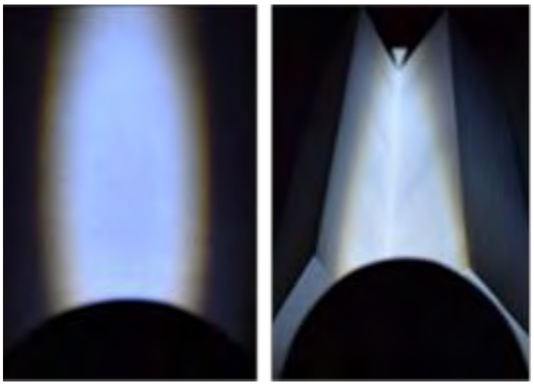
Table 5. The OUF calculation, after every reflection in the cylindrical concavity.

No.. of reflection	*1*	*2*	*3*	*4*	*5*	*6*
Transmitted Flux (lm)	*5679*	*1587*	*512*	*159*	*50.2*	*15.7*
Attenuation	*-*	*0.279*	*0.323*	*0.312*	*0.314*	*0.313*
Total flux (lm)	*5679*	*7267*	*7779*	*7939*	*7990*	*8005*
OUF	*1.000*	*1.279*	*1.370*	*1.398*	*1.407*	*1.409*

A fast comment is very important, because after sixth interreflections, the luminous flux has decreased significantly and may be neglected. Even in this particular situation, value of OUF changes very fast and becomes bigger than 1 (or 100 %), indicating that light pollution could not be used for OUF as a quality indicator.

4 Measuring the OUF Augmentation

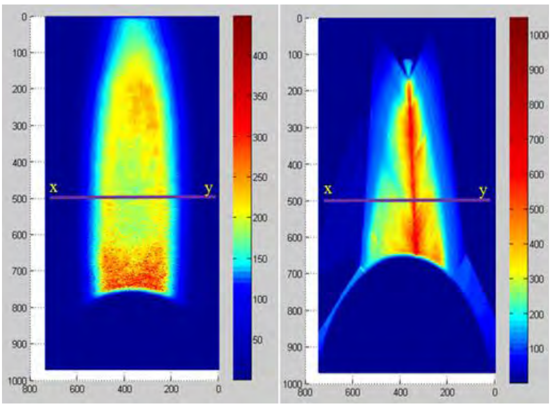
A higher OUF represents a good objective for designing to obtain low light pollution, even if it will not be an objective criterion. Using interreflections, where the façade gives the possibility to increase the luminance of the façade, with the same luminous flux emitted by the luminaires. An experimental demonstration will bring the scale of benefit when interreflections on façade are involved. A simple test bench was used, consisting in a floodlight working tangential on a planar surface. This initial configuration serves like a referential for the situation when the planar surface is replaced with a decorative prismatic profile surfaces of 3cm at an angle of 80°. The field luminance was measured, using a photo camera with the same parameters of exposure and particular transformation from RGB to luminance [13, 14]. In Fig.8 the visual aspect of the bench and in Fig.9 the luminance (*cd/m*^{2}) are presented.



a) b)

Fig. 8 The image for luminance measurement for (a) the planar surface and (b) prismatic concavity

The initial results for Fig.9 (a) are presented in Fig.10, where it can be noticed that the



a) b)

Fig. 9 The luminance (cd/m^2) for the planar surface (a) and prismatic concavity (b)

luminance in the central illuminated region is cvasi constant, with RGB level close to the value

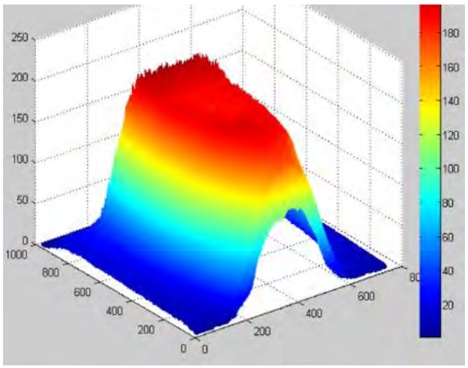


Fig. 10 The RGB values for the flat illuminated surface of the façade, as in Fig.9, a.

of 180.

After the introduction in the luminous field of a small prismatic concavity (without any other change), the luminance field generates different results, as shown in Fig. 11.

In Fig. 11 it is illustrated that the data from Fig.9 (b), and the luminance in the central field has an obvious increase with maximum RGB values close to 230. The interior dihedral angle has a higher luminance, which is a positive effect considering the accent on the façade. It is worth mentioning that this effect is obtained with the same lighting configuration as in Fig.8.

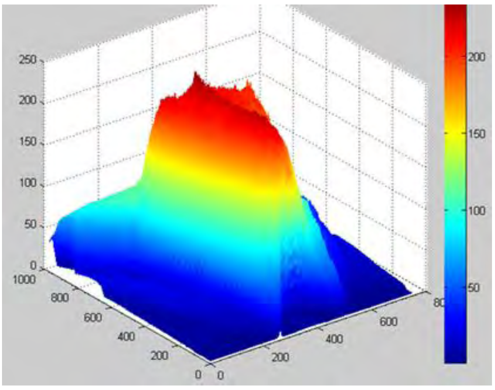


Fig. 11 The RGB values for the prismatic concavity illuminated in the same condition as in Fig. 10.

Even after a qualitative conclusion obtained from Fig. 10 as compared with Fig.11, a quantitative assessment of the luminance is necessary, based on the fact that the CCD sensor (used for this work is NIKON D5300 photo camera) has not linear characteristics [13 , Fig.1] and introduces a saturation effect for higher values of luminance. Using an experimental OECF (opto-electronic conversion function) obtained for our photo camera and considering the particular settings (exposure time 1/20s, diaphragm F8 and ISO100), luminance (cd/m^2) for those two different hypothesis is presented.

In Fig.11 the luminance field has different color map as compared to Fig.10, but it can be noticed that the effective differences are very high. To obtain the increase in intensity, the luminance values from the direction x-y (the horizontal line in Fig. 9) are extracted and presented on the same plot and the same axis, for a better comparison, as in Fig. 12.

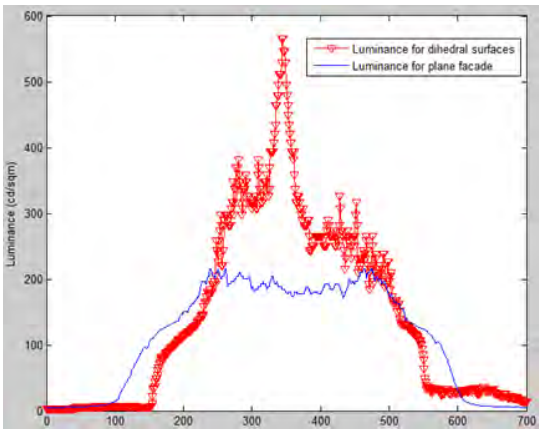
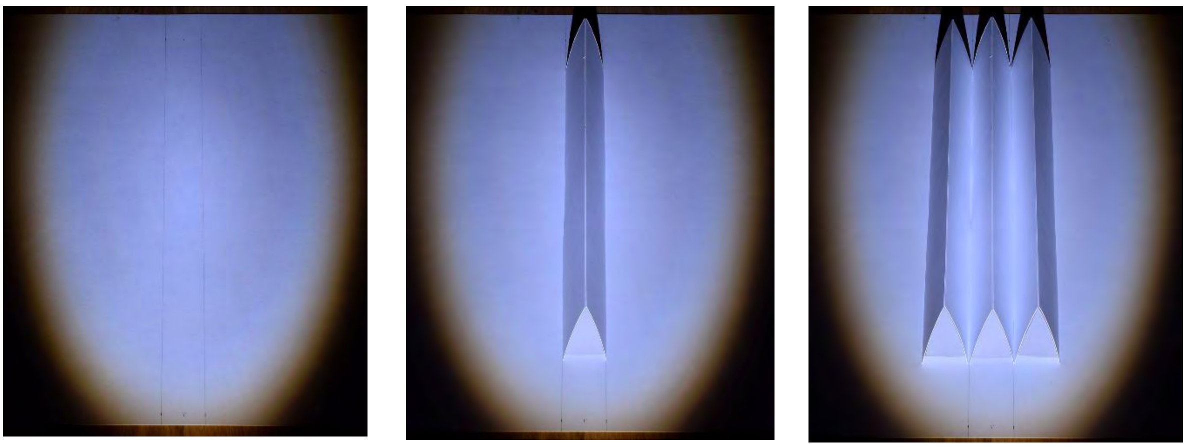


Fig. 12 Luminance comparison (cd/m^2) for central field of the images from Fig.8, with specification x-y in Fig. 9.

In absolute values, the amplification effect of the luminance is greater than double, and this is another interesting effect, giving the possibility to obtain the same visual effect with less luminous flux and less light pollution. A supplementary comment is necessaries for the level of the luminance from Fig. 12, chosen at high value due to the small scale of the model.

5 Luminance gain on multi longitudinal profiles

For architectural details, the luminance gain generated by the longitudinal profiles could be useful to decrease the floodlighting level, due the increasing of luminance contrast on some window frames, for example. The decreasing of the general floodlighting represents the method to reduce the light pollution. To demonstrate how the luminance gain occurs, one study not a prismatic concavity as in Fig.8, but one compare the luminance obtained from a flat façade (Fig.13, a) with a façade with one longitudinal (triangular) profile (Fig.13.,b), respectively three longitudinal profiles (Fig.13. c):



a) The flate façade b) Façade with one profile c) Façade with three profiles

Fig. 13 Luminance gain on longitudinal triangular profiles

The transversal luminance, for the midle of the scene, will demonstrate the luminance gain, as in Fig.14:

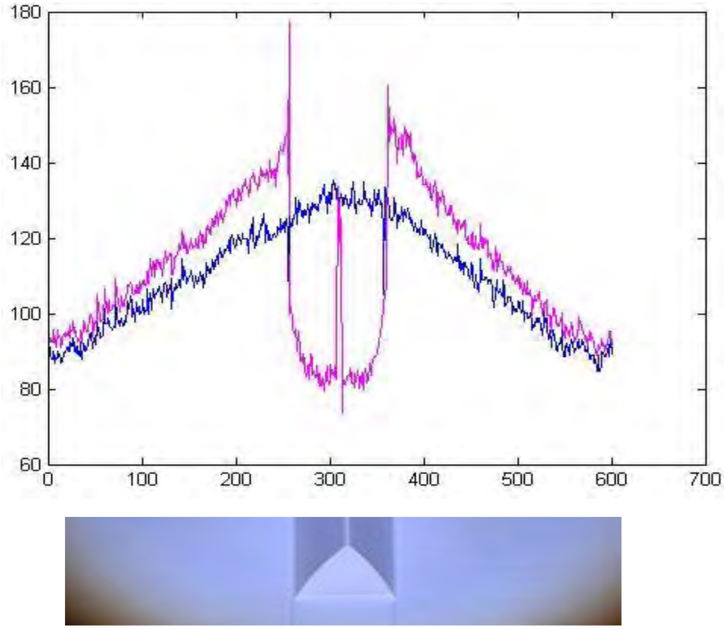


Fig. 14 Luminance gain (cd/m^2) from one longitudinal profile (magenta) compared with the flat façade luminance (blue)

Finally, introducing three longitudinal profiles, one can compare all three scenes:

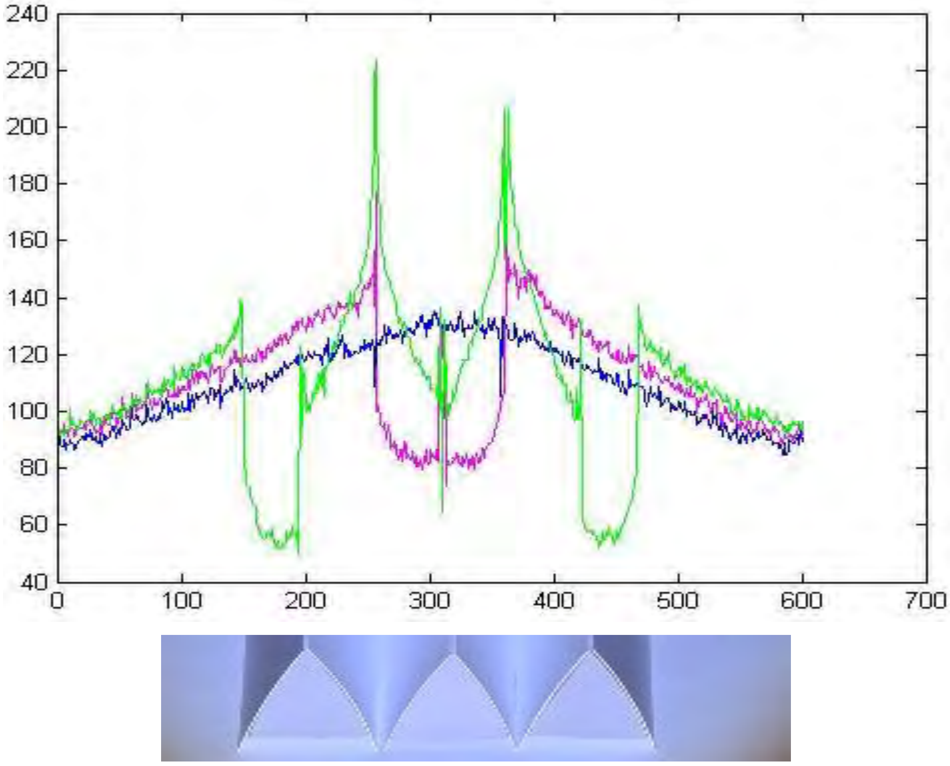


Fig. **15** Luminance gain (cd/m^2) from three longitudinal profiles (green) compared with the single profile luminance (magenta) and flat façade luminance (blue) as reference.

The profiles dimensions are 25 mm at the base and 48 mm in high, and the material is bright white paint. The geometry and the electrical parameters was constant for all the scenes.

A single profile don't produce a significant luminance gain (magenta, Fig.15), but multiplying the profiles, the effect will be more intens in the concavity, where the interreflections will be present (green, Fig.15), producing 160 to maximum 200 cd/m^2 compared with 120 cd/m^2 as initial value, for flat façade. The luminance gain of 50% is very important, especially for the close observer. This could encourage the lighting designer to reduce the general (average) illuminance level, knowing that some details on the façade will generate increased luminance levels.

6 Conclusions

OUF augmentation (calculated and measured) shows that a greater OUF don't represent a criterion for lower light pollution. The OUF is one important criterion, but only in the early steps of the designing process, giving some information about the direct light spill to the sky.

If the interreflections are considered, the situation is different. Using the small scale profiles existing on the facades, some important luminance gain could be obtained. Due this, the design process could decrease the general floodlighting, with an important effect for light pollution reduction. Starting from luminance gain of 50%, this could be the reduction ratio for the floodlighting, a very interesting challenge.

Reducing the light pollution is possible maintaining the beautification of the façades. This is possible if the façade details could be involved in a creative way, changing the philosophy of the "wall of light" with one of "beauty of the details". The details will be more visible due the luminance contrast as in Fig.15, obtained not by using the shadows, but through luminance gain.

Acknowledgements

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Measurement of Reflectance Properties of Asphalt using Photographical Methods

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Abstract— Measurement of reflectance properties of asphalt is an insufficiently addressed problem, although this parameter is involved in three major directions in which the development of roads and lighting takes place: new technologies for materials, including solar energy harvesting, energy efficiency of road lighting and light pollution reduction. For each of these directions, concerns for improving performance have been identified, in which for each percentage gained, significant efforts and costs are registered. It is thus shown that although the reflectance properties of asphalt can change the results to a large extent (even 47%), this parameter is considered as a material constant and is not measured, although it is variable over time. After evaluating some landmarks regarding the geometric domain for which this parameter must be measured, a photographic method is presented and exemplified by which the desired values can be obtained in-situ conditions.

Keywords—EN 13201, Reduced Luminance Coefficient, Asphalt albedo, Luminance map, Reflectance uncertainty, street lighting, light pollution

I. Introduction

The paper identified a parameter that underlies the calculation of the luminance of a street lighting system, the reflectance qualities of the asphalt. Usually predetermined data are used, defined for large categories of asphalt (Europe or USA), with few possibilities to estimate the real state of the materials. It is a challenge that while looking for highly accurate results in terms of calculation, for example, the reflectance factor is responsible for a high degree of approximations.

II. Different Motifs for Reflectance Measurement

The problem of asphalt, as a solution for roads, is beginning to be questioned. In this very recent article [1] we are challenged with the vision that the asphalt, as we know it, will be replaced by entirely other material, with various reasons (solar energy with photovoltaic or thermoelectric conversion, reuse of waste material). For these new materials, for which their behavior over time is not known, it is all the more important to measure the reflection factor.

A. Harvesting Solar Energy and Reflectance Factor

One of the most promising directions of road evolution is the production of electricity through photovoltaic conversion [2]. Obviously, the main objective will be the transparency and durability of the surface, so measuring reflexivity is a need. But there is also the possibility of harvesting solar energy through thermal or thermoelectric conversion [3]. Even if the amplitude of this method is less developed compared with PV conversion, the main objective becomes to obtain as high absorption coefficient as possible (albedo as low as possible), which needles contradict the requirement to obtain high luminances during night time, for good visibility.

In other research concerning global warming and infrared asphalt response [4] one discover the confirmation that the various types of asphalt have responded very differently to each other, depending on composition (structure) and wear or age. An important conclusion in [4] is that "the dependence of the diffuse reflectance factor on the light spot size, in order to determine a minimum light spot size for any further optical study. By comparing the BRF (bidirectional reflectance factor) to a nearly-Lambertian Spectralon® white standard", the conclusions are that the asphalt is in general a good diffuse scatterer. This statement will be contradicted later, and we will confront it with our own measurements.

When a lower IR response is required, the asphalt with high albedo is reached, but it contradicts other very current objectives, such as lane border detection [5]. In this working hypothesis the light color is a disadvantage, because the vision requires a high luminance contrast between asphalt and markings, in order to achieve good visibility.

B. Promoting Energy Efficiency and Reflectance Factor

Another distinct direction where asphalt is involved is that of energy efficiency of lighting systems. This can be achieved through the light sources themselves (and we have seen the obvious progress of LED sources), but there may be other ways to increase energy efficiency. One of them is dimming, but not in traditional manner. Dimming that follows an original philosophy is presented in [6]. Here it is based on the finding that in the field it is not possible to ensure the constant step between the lighting poles, as is taken into account in the design phase. The distance between poles is almost nonstop reduced by several meters, due to the intersections and the access paths in the properties. These reductions can be offset with custom dim ratio for almost every pole. In relation to this strategy one can propose another factor of dimming, which takes into account that in the project calculations are carried out for new asphalt, so it is a dimming reserve that can be applied after a number of years, along with the wear of the asphalt. For this, however, we need to measure in-situ reflectance, which is also our objective.

There are also classical approaches, where the lighting system is to be modernized [7], but the problem of measuring reflectance factor is neglected, and it is mentioned only:

- Data on poles;

- Geometry arrangements.

Energy efficiency can also be achieved by precise calculations, as in [8], which is a classic and traditional approach. But if there is a purpose of reducing the

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approximations from 20% to 10% and then even to 5% and finally to 1% it is not allowed to avoid the parameter on which the luminance directly depends, i.e. reflectance factor of asphalt, as seen in [8].

Retrofit solutions can be another approach to energy efficiency. In [9] the optimization of solutions with the help of the computing power of DIALUX is used, but the reflectance answer of asphalt influence is not accessible, nor is it mentioned, which calls into question the entire optimization of [9].

Energy efficiency is also obtained by considering natural lighting during twilight, which changes the time and manner of connecting artificial lighting [10]. After finding that natural lighting is isotropic (after sunset, when the sky is still bright), it reaffirms what was actually known, that artificial lighting is anisotropic, thus contradicting the statement that asphalt is perfectly diffuse, from [4].

C. *Asphalt Reflectance and Light Pollution*

The problem of asphalt reflection can't be dissociated from that of light pollution. Even if light incident on the road is not considered light pollution, what is reflected contributes to light pollution. In [11] is found the exact study of this parameter, the reflective properties of the soil (clear spectral reflection of soil, asphalt, and concrete) and the sky glow.

In [12] this analysis is continued, by extending it to the extreme situation of summer - winter. The crowns (branches) of the trees are also clearly modeled, with or without the presence of leaves or snow. However, the arguments in [12] are also valid for street lighting, without the need for additional arguments.

Optimization of lighting systems can benefit from modern tools, such as genetic algorithm [13]. Here, however, an interesting thing can be found, because the whole optimization refers to the lighting level. Or, if the reflection factor is not considered, then the calculation depending on the lighting can generate oversizing. The approach method is even more surprising when the precise modeling of the light pollution is desired, for which the level of illumination in the areas near the road is evaluated.

There are also fewer approaches, such as [14], where ESCO-type projects are pursued several years after commissioning. It is shown that there are parameters that are not yet in current use. *Utilance* [15] is one of them, and essentially expresses the ratio between the incident luminous flux on the road and the actual luminous flux emitted by the luminaire. More interestingly, it is emphasized in [14], it is the Installation Lighting Factor, which includes the average luminance of the road and therefore reflectance of the road, with another argument for the necessity of its measurement. Global image of all these factors are presented in Fig.1.

III. The Complexity of Reflectance Measurement and the Street Lighting Performance

All the arguments so far lead us to the importance of measurement of reflectance factor of the asphalt. In such situations, as those of entrances to road tunnels [16], the contrast of luminances is important to obtain a safe visibility. In these visual scenes, the reflectance of the asphalt is evaluated in the context of the other parameters:

- The brightness of the sky (clear or cloudy);

- Road luminance (day, night);

- Reflectance and luminance of vegetation;

- Emissivity of buildings;

- The luminance of the rocks and the mountainous landscape.

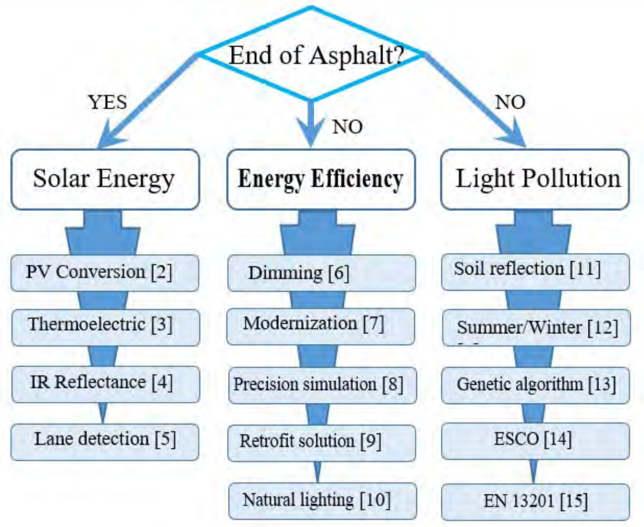

Fig. 1. Influence of reflectance factor of asphalt on other lighting connected aspects.

In contrast to [16] is [17], where there is presented a very complex system of in-situ measurement of road lighting systems, which uses a frame equipped with multiple sensors, a frame carried by a vehicle on the road. Global results of illumination and level of uniformity are obtained, but we do not find any information about luminance. However, a positive example is [18], which demonstrates the importance of analyzing the distribution of luminances, even if only illumination can be accepted for conflict areas [15]. Acceptance of illumination is justified by the fact that in conflict areas (junctions) visibility must be ensured for multiple relative driver-target configurations. The photographic method in [18] demonstrates that global (otherwise unavailable) information can be obtained that includes reflectance of asphalt, including lines or other signs.

However, about the complexity of the problem we are warned in [19], where it is stated that for certain luminance coefficients $q(\beta, r)$ [15], since specular reflection of road surface, "optimal values for luminance and illumination cannot be obtained simultaneously". This contradiction is an additional argument for measuring the reflectance factor of asphalt.

The same parameter acquires another relevance for tropical areas, where high reflectance asphalt is pursued [20]. It is interesting that the implications are analyzed only in the diurnal hypothesis, while the benefits on street lighting could be much more spectacular.

But the actual measurements of these parameters are not simple, as seen in [21], for which some aspects of the experimental program are noted:

- Measurements carried out over three years;

- Nine types of asphalt;

- Two types of wear materials;

- Asphalt concrete with particles of 11 - 16mm;

- Different ages, between 2 and 10 years;

- Different but moderate wear.

It is obvious that such a systematic approach exceeds the objective of a street lighting project, which needs to be able to achieve an optimal sizing for the situation at a given time.

The final argument for this research is found in the reference work, with monographic character [22], where the specific standards for street lighting are analyzed, in their evolution. It turns out that many of the imposed values are quite arbitrary. There are also interesting statements, namely "in-situ luminance measurement could indicate variations up to 45% from the design value". The explanation is also provided: "One contribution to this difference is uncertainty in the road surface reflectance data, for example the age and the traffic volumes".

The main situations related to reflectance measurement of the asphalt is presented in Fig.2:

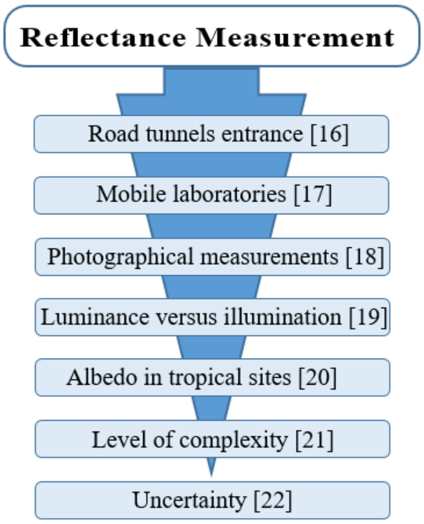

Fig. 2. The problems related to the reflectance measurement of asphalt.

Overall, the uncertainty that exist in many lighting designs due the lack of measurements of asphalt reflectance must be reduced.

IV. Reduced Luminance Coefficient Assessment for Asphalt Type C2, N1 and W4

In order to prepare the measurement program for reduced luminance coefficient *r* it is necessary to analyze in advance the range of variation of this parameter for the existing data [15], respectively for some types of asphalt. The values are analyzed for the points for which in [15] the calculation of the luminance for an observer located at a height of 1.5 m and a distance of 60 - 100 m is indicated. In Fig.3 are indicated a number of 13 calculation points, distributed with a step of 3 m along the traffic lane in the vicinity of the poles (H=10m). The values of the angles β and ε in Fig.3 for the measuring points are indicated in Table 1. It should be noted that for the following series of measuring points (towards the road axis) these values are very close, which allows us to significantly reduce the number of values for which reduced luminance coefficient *r* must be measured, without the need to complete the whole value matrix, as indicated in [15, p.17] for tgβ between 0 and 12 and ε between 0 and 180°.

This greatly limits the number of elements in the matrix with values of reduced luminance coefficient.

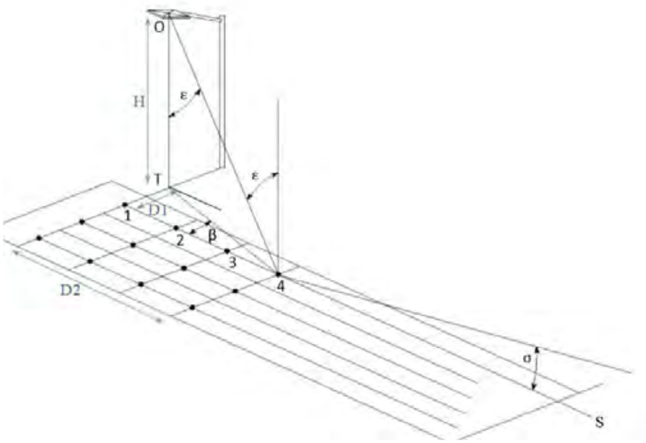

Fig. 3. Points for luminance calculation, according to [15].

In Table 1 it can be seen that after the first 3-4 calculation points near the pillar, the angle β reaches 10° ÷ 5°, and the angle ε reaches 55° ÷ 75°. These areas can reduce the amount of data that needs to be measured and analyzed.

TABLE I. Values for Angles Beta and Epsilon fot the Points from Fig.3

	D1	**D2**	**β**	**ε**
Point no.	***m***	***m***	***grades***	***grades***
1.	3	0	90.00	16.70
2.	3	3	45.00	22.99
3.	3	6	26.57	33.85
4.	3	9	18.43	43.49
5.	3	12	14.04	51.05
6.	3	15	11.31	56.83
7.	3	18	9.46	61.28
8.	3	21	8.13	64.76
9.	3	24	7.13	67.54
10.	3	27	6.34	69.79
11.	3	30	5.71	71.65
12.	3	33	5.19	73.21
13.	3	36	4.76	74.53

The next preparatory stage for the measurement program is the estimation of the range of variation of the reflectance factor, for various types of asphalt. In [15] one use another variable, namely reduced luminance coefficient, which is used to calculate the road luminance *L* for the standard observer, according to [15]:

$$L = \frac{I \times r \times \emptyset \times MF \times 10^{-4}}{H^2} \quad (1)$$

Where

I – Lighting intensity (cd/klm);

r - Reduced luminance coefficient;

Ø - Luminous flux;

MF – Maintenance factor;

H – Mounting height of the luminaire.

Equation (1) is valid for specular reflection, for which the reduced luminance coefficient r models this reflection. If we accept the hypothesis that the reflection would be perfectly diffuse, then the asphalt would be described with a material with reflectance factor ρ that would produce, for the considered angles, the same luminance L:

$$L = \frac{\rho \times E}{\pi} \tag{2}$$

Where E is the illuminance on the calculation point, produced by the same lighting intensity I:

$$E = \frac{I \times \cos\varepsilon}{l^2} \times MF \tag{3}$$

Where l is the distance between the luminaire and the calculation point.

In (2) one include (3) and we write the equality with (1):

$$\frac{I \times r \times \emptyset \times MF \times 10^{-4}}{H^2} = \frac{\rho}{\pi}\frac{I \times \cos\varepsilon}{l^2} \times MF \tag{4}$$

Making the necessary operation the reflectance factor will be:

$$\rho = \pi \frac{r \times 10^{-4}}{(\cos\varepsilon)^3} \tag{5}$$

It is necessary to specify that since reduced luminance coefficient r is not constant, neither reflectance ρ will be a constant, but a function of β and ε that is:

$$\rho(\beta, \varepsilon) = \pi \frac{r(\beta, \varepsilon) \times 10^{-4}}{(\cos\varepsilon)^3} \tag{6}$$

For the first 14 calculation points in the vicinity of the column and asphalt type C2, a variation presented in Fig. 4 is obtained. It is observed that one start from reflection coefficients of ρ = 0,15 under the column (ε = 0°) and the values increase as the angle of incidence increases to 75° - 85°.

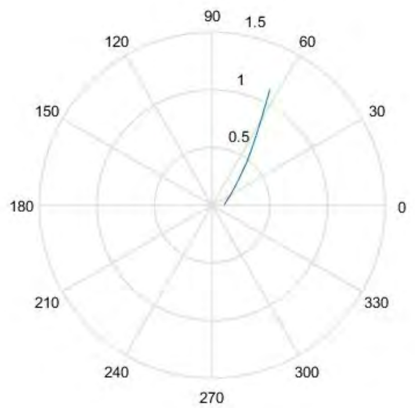

Fig. 4. Reflectance factor in polar coordinates (ε) for asphalt type C2.

Fig. 4 also forces us to analyze what happens to the reflectance factor for other types of asphalt. In Fig.5 the variation of reflectance factor for C2 asphalt together with N2 type asphalt is presented. A different range of variation is observed, but with the same tendency to increase the reflection for large, sharp incident angles. The relative brightness of N2 asphalt is much lower than that of C2 asphalt. Even if weighted average luminance coefficient (Q_0) of C2 Asphalt (CIE) is equal with weighted average luminance coefficient of N2 asphalt, respectively Q_0 =0.07, the N2 pavement (concrete) is obvious more diffusive.

With this result, the next step is to investigate what happens for the glossiest asphalt, in wet conditions: W4.

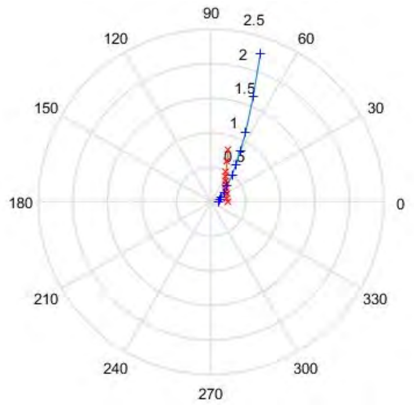

Fig. 5. Reflectance factor in polar coordinates (ε) for asphalt type C2 (blue and '+' and asphalt type N2 (red and 'x').

The results for reflectance factor for W4 asphalt is presented in Fig.6:

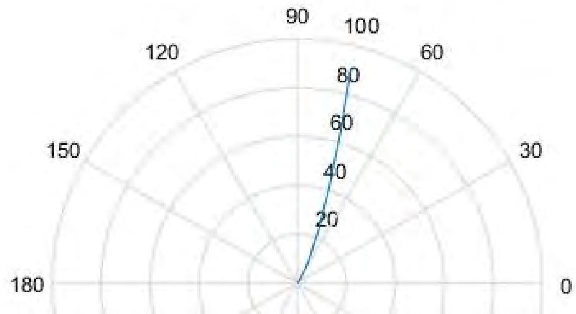

Fig. 6. Reflectance factor in polar coordinates (ε) for asphalt type W4.

The results shown in Fig.6 do not allow us to accept that it could be a reflectance factor, being visible an obvious amplification effect. Our conclusion is that the hypotheses that led us to (6) are valid for asphalt with porous structure, and lose their validity for glossy asphalt, and even more so with wet surface. For specular reflection certainly a reflectance factor as (6) does not make sense. These observations are useful in the processing and careful interpretation of data from the reflectance factor measurement.

V. Experimental Measurements

For the measurement program we started from the source-point geometry of measurement in Fig.3 [15] and with the range of values for ε and β from matrix of the reduced luminance coefficient r [15]. Especially to cover the maximum range for tgε, a distance of max. 12m of the target point with respect to the optical axis of the light source is

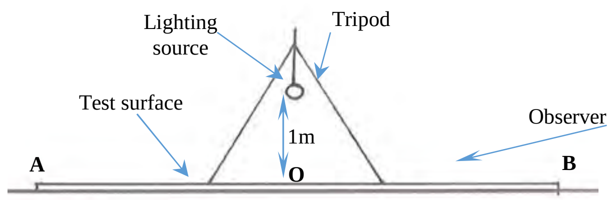

Fig. 7. The mock-up for measurements using imageing method.

necessary, if lighting source is located at a height of 1m, a configuration that generates a scale factor of 1:10. To test the measuring principle, a working surface of 5 m length was used, according to Fig.7. The digital camera calibrated for luminance measurement is placed at a height of 15 cm and a distance of 6 m, to keep the angles σ of the observer as in Fig.3 [15]. For the simplicity of the presentation, we will work only on the observer-light source direction, ie β=0° and β =180°. The obtained luminance field is presented in Fig.8:

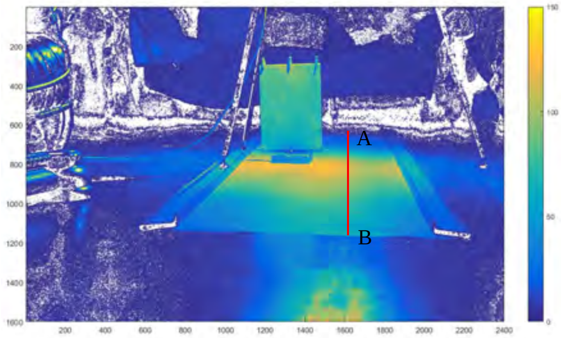

Fig. 8. Luminance map (cd/m^2) for the mock-up scene, AB is the measurement domain.

In Fig.8, the AB line is the measurement domain, corresponding to tg ε = (0 to 2.5), β = 0 and β =180. The test surface was a perfect Lambertian material (gray cardboard), with the intention of obtaining a controlled illumination (from a punctiform source), respectively the known incident intensity in each point for which the luminance is measured. The distribution of the illuminations measured and calculated on the AB direction are available in Fig.9:

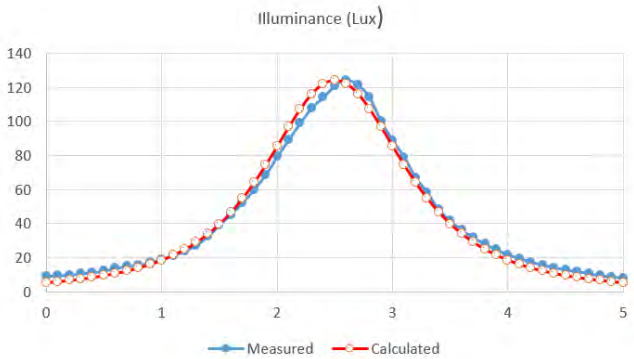

Fig. 9. The illumination level (lux) for the AB direction in Fig.8.

With this known distribution for illumination and therefore for the incident light intensity at each point, it was intended to check the diffuse reflection of the cardboard, respectively to validate the entire measuring chain. The obtained results showed, however, that the cardboard reflection is not perfectly diffuse, having a fairly obvious directional component. This aspect can also be seen in Fig. 8.

In Fig. 9 the luminance distribution (cd/m^2) is indicated for 250 elements in the vector with results (abscissa). For the 5 m long (AB), i.e. a measurement density of 2 cm. An important observation is necessary, the power of the punctiform lamp and the level of luminance on the test surface was chosen to make luminaires with two orders of magnitude higher than those in street lighting, so that measurements can be made in the presence of street lighting.

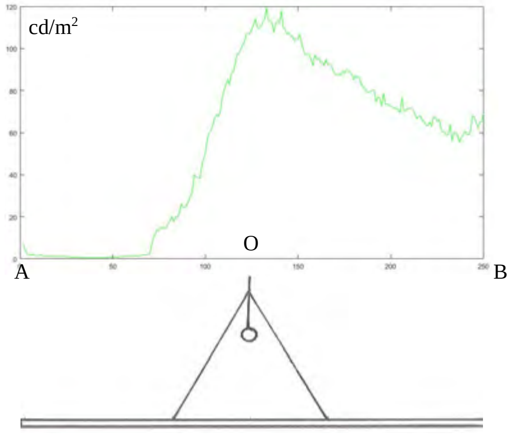

Fig. 10. Luminance distribution (cd/m^2) for AB direction from Fig.7 and Fig.8.

Fig. 10 indicates that the cardboard reflection is not perfectly diffuse. Zone AO, for which β = 180° has a much lower reflection than zone OB, for β = 0°. The results represent a demonstration of the method by which the luminance values of an area with a determined geometry can be extracted, by a single imaging measurement. From which then the reduced luminance coefficient could be calculated.

VI. CONCLUSIONS

Street lighting is well regulated and benefits from a well-defined calculation algorithm, but a special parameter, reduced luminance coefficient has been shown to be not well enough known. Even if this parameter is standardized, the fact that it changes over time is not reflected in the design and especially in the operation of lighting systems. It has been shown that there is no mathematical relationship between reflection factor for diffuse reflection and Reduced Luminance Coefficient. Specular reflection being very far from diffuse reflection, and luminances must be calculated with relations closer to the calculation of the luminance of a direct source (or reflected in a mirror). Periodic measurement of this parameter, in the field, will allow the adaptive dimming of lighting systems, lower in the case of fresh asphalt and wider as the asphalt wears out and becomes more glossy. However, measuring Reduced Luminance Coefficient is difficult, based on laboratory equipment, such as a goniophotometer. The paper proposes an in-situ method for measuring Reduced Luminance Coefficient, based on an imaging method. Using a single point lighting source, the map of the luminances in the vicinity of the respective source is obtained, and based on the known geometry of the scene, the Reduced Luminance Coefficient is finally calculated.

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Measuring the driver exposure to the light pollution

Developing experimental setup

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***Abstract* — The integrative effect of the glare will be studied in this paper, developing a non-invasive measurement system. The authors propose a measurement system based on an embedded system, Raspberry PI3, with a PI camera, but also with a GPS shield and RGB sensor, type TCS34725. The RGB sensor is used in a luminance meter configuration, in order to investigate the average luminance of the visual field.**

Keywords— glare, cumulative stress, integrative sphere, variable timelapse

I. Introduction

Light pollution is increasingly studied lately, due to the unpredictable implications discovered so far, on the delicate life's balance of pollinating insects, plankton, nocturnal beings, and even directly on people's health. Some progress has been made, but regarding the effect of light pollution on night drivers, very few studies have been registered. In the case of Romania, where the highway infrastructure is not yet well developed, this area of research is even more important. The night drivers are exposed to stress generated not only by the street lighting in the urban and rural areas, but also by the headlights of the vehicles coming from the opposite direction, by the signaling lights of the vehicles that go in the same direction and especially by the visual disturbances generated by other forms of lighting: residential, advertising, and various visual signals.

The starting idea of this research was found in [1]. In this article, an interesting connection between lighting and neuroscience was introduced. Traditionally, the only effect of light/lighting was the vision, characterized by the photopic luminous efficiency function V(λ). Today we know [1] that "V(λ) only approximates the spectral sensitivity of just two of the five photoreceptor types in the retina and, thus, does not fully characterize the spectral range of human visual (and non-visual) sensitivity to electromagnetic radiation". Another progress brought by neuroscience was the understanding of long-wavelength (red) light effect. The red light "presented to human subjects at night has been shown to significantly impact brain activity, performance and cortisol levels, biomarkers associated with alertness and stress. The spectral sensitivity of this alerting response to electromagnetic radiation has not been elucidated (at the beginning), but when neuroscience further extends our understanding of this system, those findings could be added as another type of benefit efficiency function." Consequently, the blue light was also accepted as having an effect on alertness.

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Neglecting the overall effects of the light will force us to "continue to sub-optimize the value of lighting by limiting its benefits (safety, security, health) while unnecessarily wasting electric energy and our natural resources [1]".

In the case of the present paper, the key issue is the driver's safety in connection with his fatigue.

II. The Study Of The Luminance Field Received By The Driver

The main criteria for road lighting design are found in [2]:

- average luminance (LAv)
- overall uniformity of luminance (minimum / average) (UO)
- longitudinal uniformity of luminance (minimum / maximum) (UL)
- threshold increment (TI %)
- surround ratio (SR)

One can notice that the visual disturbances generated by lighting (headlights of the vehicles coming from the opposite direction, residential, advertising, and various visual signals) are not included among the criteria proposed in [2]. Even if some comments about the calculation of veiling luminance was found in the mentioned article [2], an important limitation could be highlighted: the formula is valid only for an angle between the viewing direction and the i^{th} glare source in the range from 1.5°

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to 60°. In our opinion, this condition is not realistic: in the case of normal road lines this angle can be lower. For example, if the distance between viewing direction and the parallel passing through the oncoming headlight is 1.5 m, and the distance between vehicles is 100 m, then an angle of 0.86° is obtained. More than that, in normal conditions, taking into account the physiological glare, the viewing direction and the oncoming headlights direction could effectively superpose.

The issue of *dynamic discomfort glare* and driver fatigue, topic introduced in [3], was further studied in [4], using a special device for eye stress measurements. The approach used in [4] was to focus on the effect of the light stress, measuring the "electrical activity of the extra-ocular muscles, using two small surface electrodes positioned one below the lower eye lid (active electrode) and the other lateral to the eye (reference electrode). A third electrode, placed on the forehead served as a ground. The intensity of this activity, called the electromyogram (EMG), increases when a bright light is directed toward the eyes and this change in activity has been used as an indicator of the severity of discomfort." As for the findings of [4], "the technique described is radical, but the results are focused only for short term, flinch-type responses, whereas on roads discomfort glare is usually a cumulative process resulting in fatigue and the urge to close the eyes".

From the same series of complex systems one can mention [5], a system designed for surveying bus drivers (who confront with long and monotonous roads), for whom fatigue is monitored using "modules of head-shoulder detection, face detection, eye detection, eye openness estimation, fusion, drowsiness measure percentage of eyelid closure (PERCLOS) estimation, and fatigue level classification". The system allows to identify the fatigue installation. The interface with the driver is not difficult (an oblique orientated camera), however image processing requires significant computing power, which is a disadvantage. Surprisingly, the effect of vehicle headlights from the opposite side is neglected. In [7] one finds two digital camera and additional headlamps, used for "successfully eliminated the external lighting of both other vehicles and the road lighting luminaires", the objective being to measure the luminance of road signs. If we go back to the stressful effect of all the light sources in the visual field, we find such a research [8] looking for a relationship between headache and glare, based on a questionnaire. This questionnaire, even if it is a classic one (De Boer), maintains the subjective character of perceived sensations, and cannot be useful in monitoring the fatigue phenomenon anyway. This monitoring is seen as a system that assists the driver, similar to the system proposed in [9], where road markings are identified on the image, decoded, and provide alarms or warnings if the driver does not comply. In our case, the accumulation of visual fatigue could also generate a useful warning.

The fineness of monitoring the driver's stress-strain sources can be extended if other particular phenomena are also considered, such as high frequency flicker [10] which is generated by the LEDs from other vehicles, or by the complexity of the vehicle's interior signals [11], which has also increased due to LED instruments and signals. The most aggressive sources of blindness remain the headlights from the opposite direction, who's "effects on the adaptation state may significantly affect the mesopic luminance" [12]. This work, which studies peripheral vision, is an argument for exploring the whole visual field, with all the luminances. If all these phenomena can be understood and implemented, a contradiction is generated in [13], with an overview of "Embedding vision-based advanced driver assistance systems". The contradiction lies in the fact that the development of "computer vision, either alone or combined with other technologies such as RADAR or LIDAR, is one of the key technologies of advanced driver assistance systems (ADAS)" [13] and will reduce the need for good road lighting and the need to watch the road. Assistance systems have an even higher potential because of the possibility of "Multi-vehicle detection with identity awareness" [14], which can lead to the reconsideration of road lighting as a whole. Obviously, even in an optimistic vision, this won't happen in the short term, so the role of the driver remains important. In [15], starting from "driver decision making in response to peripheral moving targets under mesopic light levels", the driver's reactions to the vehicle's braking or accelerating in various lighting situations are studied. Such information will be interesting to explore, correlating the degree of visual fatigue of the driver with the maximum recommended speed at a given time, to reduce the risk of accident.

All of these approaches justify the development of a luminous stress monitoring system for the driver, based on the average luminance of the visual task. A luminance meter of average values and wide angle of view has been developed, associated with a digital camera, obtaining a time lapse movie with variable cadence. These devices required individualized calibration, the methods available in [15] being useful, especially for measuring luminance with digital camera.

III. The Main Components of Experimental Setup

The integrative effect of the glare will be studied in this paper, using a non-invasive measurement system. The authors propose a measurement system based on an embedded system (Fig.1), based on Raspberry PI3, with a PI camera.

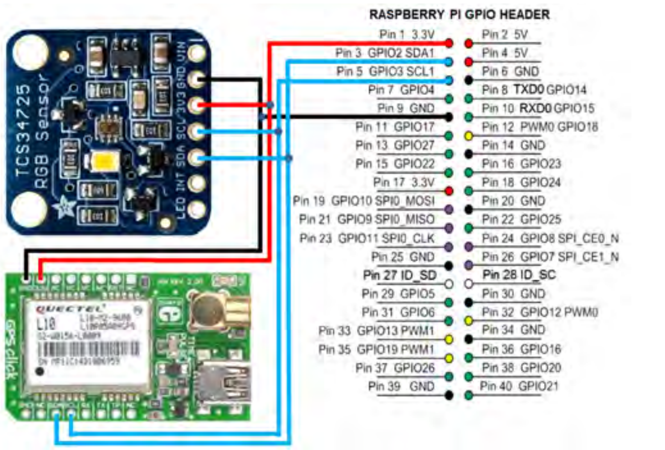

Fig. 1. The hardware configuration for measurement system based on Raspberry PI, RGB sensor TCS34725 and Quectel L10 GPS shield

The system has also a GPS shield and RGB sensor, type TCS34725. The RGB sensor is used in a luminance meter configuration (Fig.2), in order to investigate the average luminance of the visual field.

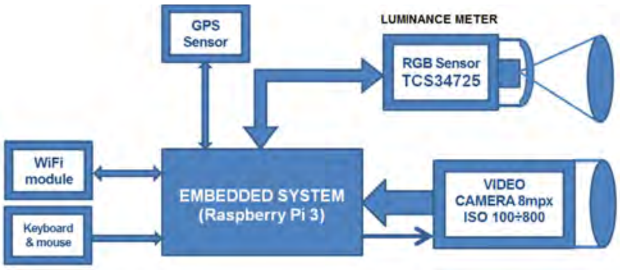

Fig. 2. Block diagram of embedded systems for variable time lapse

The block diagram indicates the main components of the system. The RGB sensor is used as a luminance meter. In contrast to other luminance meters, the advantage of this approach is the possibility to adjust the rate of data acquisition, between very high and very low rates, the latter needed in case of low traffic situations in uninhabited areas, in order to reduce the amount of data.

IV. Average Luminance Meter Simulations

The use of the luminance meter device imposes its calibration in order to include all the constructive details. For example, to obtain an average luminance and to eliminate the sensor directivity characteristic, a white partially transparent sphere was fixed in front of the sensor (Figure 3). Thus, the sensor will have the same response regardless to the area in which the sphere receives the luminance of the target visual field. Because it is difficult to assess theoretically the effect of this sphere, the whole measurement chain (lens, diaphragm, integrating sphere and the sensor) was calibrated.

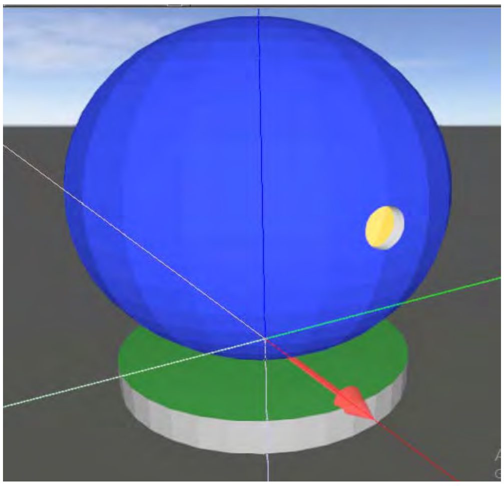

Fig. 3. The DIALux model for sensor (on Green surface) and integrative sphere (colored in Blue, for the visibility of the figure)

From the beginning, the effect of the sphere was studied, because in a classical integrative sphere a screen is placed between the lamp and the sensor, and this is not the case. For the sensor, the image focused on the exterior of the sphere represents the initial emittance. The sensor signal must not be influenced by the position of the initial emittance. To demonstrate this, a model in DIALux was developed (Fig.3).

The DIALux EVO 7.1 has the advantage to simulate transparent materials, with reflection factor, transmission factor and even refractive index. The geometry details are also available, in Figure 3 one can notice the measurement port, useful for interior "inspection" of the model. Simulation has a significant limitation due the small geometry (less than 40mm), not accepted by the DIALUX. The dimensions are accepted only in mm, and the large number of calculation points impose to use smaller dimensions. To solve this, a model in MATLAB was realized, solving the problem of successive reflections in interior of the sphere, starting from an initial emittance. The first distribution of this emittance was symmetric, as illustrated in Figure 4.

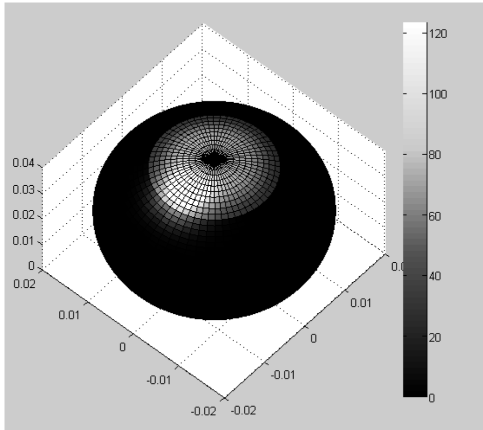

Fig. 4. The symmetrycal model for the emittence area, on 40 mm sphere (lux)

This initial hypothesis was useful to build the model, but the real situation imposes one to consider a different distribution, non-symmetrical, as shown in Figure 5:

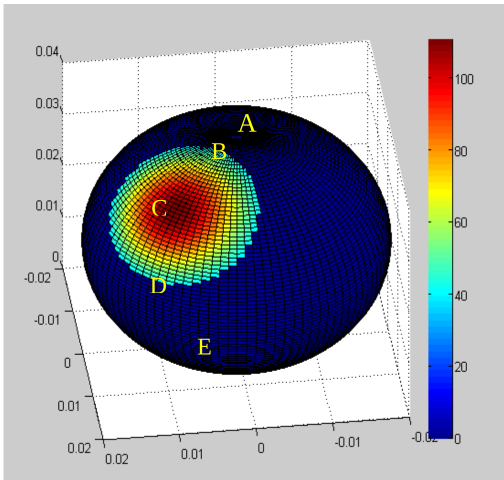

Fig. 5. The non-symmetrycal model for the emittence area (lux)

If a sensor will be mounted in the inferior zone of the sphere, the signal must not depend on the initial emittance. This was very fast to demonstrate, considering six successive inter-reflections, plus the first direct illumination from the zone with initial emittance. The result is available in Fig. 6, where data from the *"meridian"* A-B-C-D-E are plotted. The most interesting zone is D-E, which is constant and is not dependent by the initial position of emittance B-C-D. One must remember that this fact is true only for Lambertian reflective surfaces.

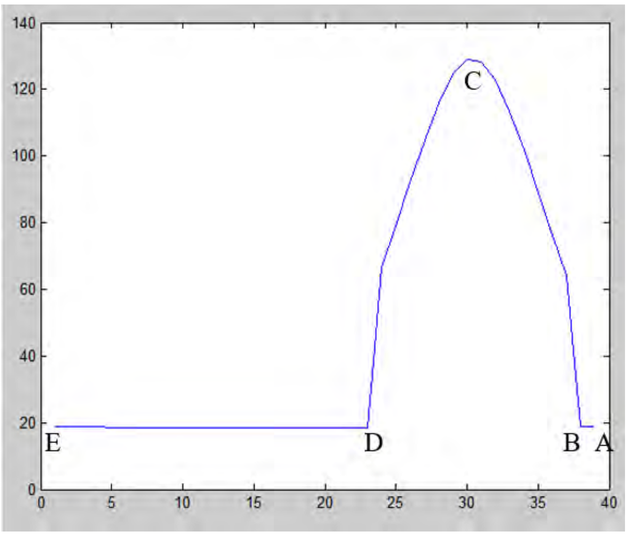

Fig. 6. The interior illuminance of the integrative sphere in front of the sensor (lux) for the *"meridian"* A-B-C-D-E as in Figure 5.

This is equivalent with the hypothesis that one could mount the sensor in any point of the inferior zone of the sphere (region D-E) and the output will be independent of the initial emittance, giving the possibility to calibrate the luminance meter.

V. PI Camera Calibration

As in [16], the glare calculation from HDR images was used for the dynamic discomfort glare assessment. The following equation [16], was used:

$$L_f = \frac{k \times F^2}{t \times S} \quad (1)$$

Where: L_f is Average field luminance; K is a camera calibration constant; t is exposure time; F is number for diaphragm opening; S is ISO number.

The issue with this equation is the use of K, the camera constant, which, in our opinion, is not correct and represents a source of errors. In this paper we adapted Equation (1) by replacing K with *Opto-Electronic Conversion Function OECF*.

The problem was solved by calibrating the PI camera based on a luminance standard as in [17, 18, 19].

A typical street analyses is present in Figure 7.

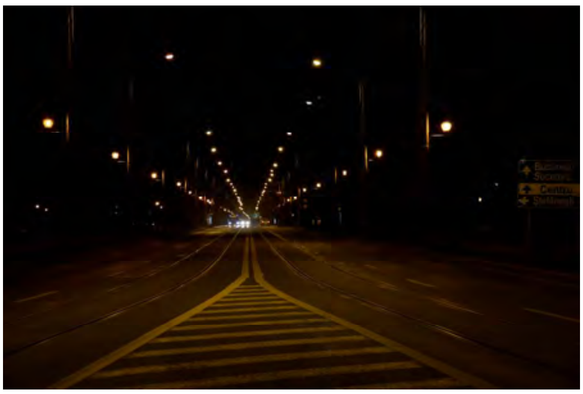

Fig. 7. The lighting system on Carol Boulevard, Iaşi City.

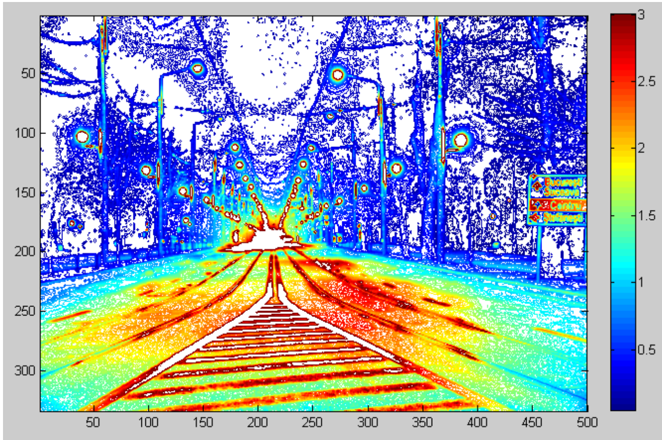

Fig. 8. The luminance field (cd/m^2)

The figure 8 is obtained using a very small increment of the iso-luminance curves, with the following MATLAB command:

contour(lum,[0:0.05:3]) (2)

where *lum* is the matrix with luminance values. From the first observation, the street is over lit and some street white lines are over 3 cd/m^2. In the center of the image, some headlights generate also a higher luminance. Changing the limits in (2) and imposing the luminances to be plotted from 0 to 100 cd/m^2, the Figure 9 is obtained:

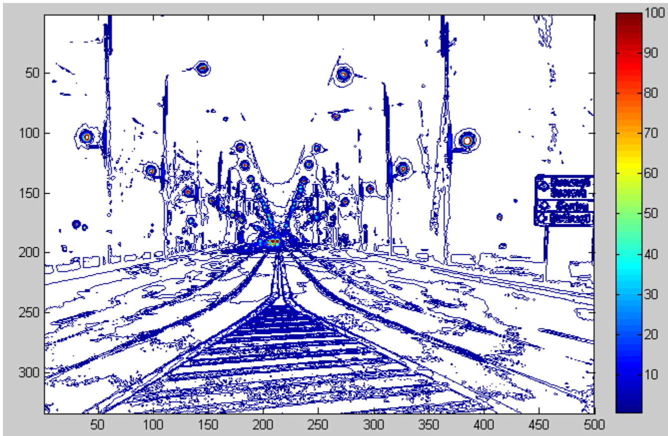

Fig. 9. The extended luminance field, from 0 to 100 cd/m^2 (the maximum is 149.2 cd/m^2)

Multiple photos were analyzed, to understand and to extract the significance of the glare sources present or not in the pictures. One notices also the fact that for higher values of the luminance, the camera saturation must be avoided, imposing shorter exposure time and higher F numbers.

In Table I one observes that average luminance has a small variation depending on the presence of the approaching headlights. Starting from this, the criterion for detecting the light pollution will be the *derivative* of the average luminance of the visual field. It can be calculated numerically or, in the case of the analogic sensor for luminance meter, using an Operational Amplifier. This will be the condition tested for variable time lapse, as one illustrates below.

TABLE I. MAXIMUM AND AVERAGE LUMINANCE OF THE VISUAL FIELD

Street category	Photo number	Exposure parameters		Glare sources	Output parameters	
		Time sec	*F number*	*YES/NO*	*Maximum Luminance cd/m²*	*Average Luminance cd/m²*
M3	468	1/8	4.8	YES	268.4	1.645
	469	1/8	4.8	NO	256.2	1.566
	477	1/15	4.8	NO	251.4	1.472
	481	1/60	4.8	YES	753.2	1.625
	482	1/60	4.8	YES	934.8	1.342
M5	519	1/10	4.8	YES	329.3	0.909
	541	1/2	4.8	NO	67.2	0.893
	549	1/30	4.8	YES	982.1	0.921
	535	2	4.8	NO	16.2	0.931
	539	1/4	4.8	YES	389.5	0.947

VI. SOFTWARE CONSIDERATIONS

The GPS shield is used to obtain GIS information (Geographic Information System) for the time lapse images, generating a map of light pollution sources. The system proposed in this paper could be more interesting when used in the public transportation sector, when it could be used as a monitoring system for light pollution sources.

During tests, in urban areas, the GSM signal was lost frequently. To compensate for this shortcoming, a supplementary function was implemented, based on speed measuring and distance calculation between two GPS coordinates (not illustrated in Figure 2).

The main problem to solve, after experimental setup, was the software for the PI camera, to generate time lapse images. The first option was *Python*, but important restrictions were discovered in connection with the camera settings. Instead, in *Linux* it is possible to impose all the quantitative parameters (exposure time, diaphragm, ISO sensibility). The software is presented with useful comments:

```
 #!/bin/bash
#video capture script with PiCamera
#command line is:
#/home/pi/Arduino_I2C/video.sh noFps time FileName
#where: noFps - number of frames per seconds (2...30)
#      time - the duration of the file to be created
#      FileName - file name, which may contain job describe
NUM=0
#init files counter
KEY=0
#init keypressed buffer
if [ "$1" != "" ]; then
#check existing of parameters command line, and if yes
 while [ $KEY -eq 0 ]
#while keypressed buffer is empty
 do
  if read -t 0 -N 0 ; then
#check if keypad was pressed, and if yes
   read -N 1 KEY
#read keypad and stored in buffer
  else
#else if not key pressed
   let NUM=NUM+1
#increment files counter
        DATE1=$(date +"%Y-%m-%d_%T.%3N")
#read current time and date
   DATE="$3_${DATE1//:/-}_${1}fps_${2}sec_${NUM}"
#generate the video file name by form
#FileName_YYYY-MM-DD_hh-mm-ss.zzz_noFps_time_NUM.h264
   raspivid -w 640 -h 480 -fps $1 -p 0,0,320,240 -o $DATE.h264 -t $(($2*1000))
#start capture video program with
#640x480 resolution video capture, %1 frames per second,
#320x240 preview resolution
#and with length by $2 seconds
  fi
 done
else
 echo "video.sh %fps %time %filename"
#warning: not enough parameters in command line
  fi
```

VII. RESULTS

The results of the present paper are focused in four directions:

- Demonstrating that the advanced driver assistance systems are in continuous development, and new criteria for improving the safety during night driving are possible
- Solving details about constructive aspects and calibration problems for average luminance meter and PI camera;
- Establishing that the average luminance of the visual field could not generate the change of time lapse, but the derivative could generate the criteria for the different night vision conditions, with more aggressive light sources;
- Developing software for variable time lapse, controlled by the measured average luminance of the scene;

The research is in continuous development, but the constructive details solved in this paper give the possibility to obtain effective results.

ACKNOWLEDGMENT

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Imaging Measurements for Public Lighting Predictive Maintenance

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Abstract- **The maintenance of lighting systems has been mentioned since 1922. Today, methods and procedures for the maintenance of public lighting are known, but they have remained of the classic, reactive type, based on periodic inspections or on the end users' reaction. Even after the LED revolution is triggered by optimizing maintenance costs, it is only meant to reduce electricity costs. Introducing tele-management systems was a new step. It meets predictive control, proactive systems, smart integrated systems, but maintenance remains of the classic, reactive type. Even the introduction of robots in this area has not brought a paradigm shift. Some limitations are, however, signaled, and imaging measurement methods are being used. These methods, however, are extensive, based on the sweeping of the entire street network for making measurements. The present paper introduces an imaging method for analyzing the degradation in time of the lighting system parameters, on the basis of which predictive maintenance works can be carried out. The method allows analysis of a section of public lighting, which makes it more efficient than other known methods.**

***Keywords*: Correlated color temperature, CCT measurement, luminance measurement, luminance map**

I. INTRODUCTION

There are about three levels in which public lighting maintenance is being approached: traditional, based on intelligent systems (Smart Cities), and the third based on periodic measurements (the area that justifies this new research).

A. *Public Lighting Traditional Maintenance*

The subject of lighting maintenance has become important with the refurbishment of light sources based on solid state technology. Investigating the methods underlying the maintenance of public lighting began with the big cities of the world, such as Los Angeles [1], where for a modernization program of 140,000 lamps, it mentions only energy savings (estimated at 40% but in the end to 57.6%). Others cities New York or Birmingham have similar approach. This surprise is confirmed by the development of the maintenance methods used in Romania, where they are empirical and poorly standardized. From the study cases, important information can be found, one example being [2], with a pilot project for an intelligent lighting systems. Here the emphasis is on command and control strategies, and nothing about necessary maintenance. Even when the subject of research is explicitly the *maintenance of exterior lighting*, as in [3], it can be demonstrated that a completely different problem is studied. Thus, in this example [3], the meaning of *operation and maintenance* only understands the part of the command, while maintenance even generates confusion. Thus, maintenance refers to the purpose for which the lighting system is used, namely the maintenance of some electrical power plant, without reference to the maintenance of the lighting system itself. Therefore, when a paper that addresses even to the *preventive maintenance of public lighting* [4] is identified, quite rarely, the expectations are very high. However, predictive maintenance is described in [4] as based on visual inspections based on end-user complaints. Even if wireless lighting control systems are implemented, there is only one parameter that is monitored for maintenance purposes, namely the lamp running time, a parameter that allows you to estimate the time when the lamps will need to be replaced. And on the whole, it results that [4] shows also the reactive maintenance. Contrary to the situation in Romania, the maintenance of public lighting is much better regulated, as in the case [5]. Being a relatively recent document and having a chapter dedicated to *Maintenance requirements*, we expect to find the solution to the problem. Even if we find some maintenance related details (such as time offsets for On-Off commands for LED as against High Pressure Sodium lamps), preventive maintenance-specific items are reduced to absence (only some intervals for replacing lamps). Another local standard [6] contains prescriptions for public lighting maintenance but also based on regular inspections or reports from the general public. It is stated that these inspections are not cost-effective, so it is recommended that the (annual) inspections could be accompanied by repair works at the same time. Continuing the study of some regulations in the field leads us to [7], which has established detailed measures for preventive maintenance. We find only regular inspections, (annuals for streets with more than 200 pillars). In order to check the pillars, indicate other intervals (four years for wood pillars or eight years for concrete pillars). However, visual inspection is very limited in terms of the pillars (it can be established that a pillar is tilted, but the structural flaws will remain hidden), but also on the parameters of light. In any case, it turns out that inspections are required both during the day (for mechanical faults visualization) and at night (with lighting in function, for visual observations or even measurements). This information is not found [7].

B. *Public Lighting Maintenance in Smart Cities*

Our expectations were that the deployment of distributed intelligent systems would bring a technological leap in

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maintenance. In [8] there is presented such a lighting system, with predictive control, in the sense that there is the possibility of establishing different ways of variation of the road traffic, while elaborating dimming programs with anticipation. There are no mentions regarding the anticipation of maintenance measures (predictive).

A new concept is the *proactive* maintenance [9]. This concept includes diagnosing defects and remotely resolving without the presence of the technician. Although the principle seems very advanced and would be extremely useful for some applications (nuclear power, for example), in the case of intelligent public lighting it only refers to the possibility of "bypassing" a communication block or replacing the data transfer through using cloud technology, very reliable. The issue of maintenance of the light sources, their evolution over time is not addressed.

Other study case [10] provide us with important technical details where defects are localized by extensive use of the GPS system. Presentations of planning of maintenance works are presented based on the energy consumption, ie the intensity and duration of the lamps. The only additional maintenance function is signaling and locating the absence of supply voltage. However, this feature can hardly overcome the speed and accuracy (geographic) of the classic signaling system, based on end-user complaints.

The possibilities of smart lighting systems, however, have unlimited reserves for maintenance strategy. Such research is available in [11], where the lighting system is assisted by flood sensors for areas prone to this natural phenomenon. Of course this is a particular case, but the incorporation of smart devices in the luminaires allows for such achievements. The entire functioning of the lighting system responds to flood alarms: the dimming is reset, moving from the economic level to the maximum level of illumination, for interventions. LED display panels will give explicit warnings about the hazard, the duration, the location, and the bypass routes. This example illustrates that the lamps themselves could be the subject of a predictive maintenance feed-back, following the depreciation of the output luminous flux. To demonstrate that this light flux depreciation is a real problem, it is enough to analyze a calculation method for light loss factors [12]. The method desires to be precise, taking into account many variables. However, the degree of uncertainty also increases because the difference between estimates and the time evolution of on-site conditions may be different. Hence, for us, the time measurement of the light loss factor is very useful for predictive maintenance of light sources.

An additional argument is obtained in the case that maintenance works (lens cleaning, poles paintings) are performed by specialized robots [13]. Apparently this will be the solution for the future, turning maintenance into a routine activity. And yet there are unwanted implications, and the safety of pedestrians and vehicles is one of them. Therefore, even in the case of robotic maintenance, determining the optimal moment of intervention can be made not by arbitrary planning but by periodic measurements.

C. *Measurements for Maintenance Works in Public Lighting*

After we highlighted some maintenance limitations, even in intelligent lighting systems, it is our turn to show that in-situ measurements can provide better data than expected. A modern system that operates on the basis of isoflux control [14] raises such issues. The central problem is the speed of aging of the semiconductor, of the optical parts, which depends on the operating regime and outdoor temperature. No matter how precise the models that estimate this phenomenon are, they will leave some approximations. Temperature will be a permanent variable, without necessarily having to comply with multiannual statistics. Even more important are the conclusions from [14], where the use of the isoflux method can extend the life of LED lamps from 16 years to 21 years! We notice that the point in question is five years. Whether the question of when to intervene to replace the lamps, plus or minus one year, can be too long, easily induced due to the inherent differences between the estimate and the reality. Again, in-situ measurement could generates precious information, predictive ones, but the nature of measurements is not easy to determine.

A real problem related to maintenance is the failure of dimming drivers. In [15] it is stated that this type of defect is not detectable by visual inspections. Obviously, LED luminaires have a very large luminance even in the dimming regime. Consequently, non-dimming operation is undetectable, with unpredictable results saving energy of the lighting system. The solution proposed in [15] consists in precision measuring the energy consumed to detect defects of dimming. Hence the possibility of measuring the luminance of the luminaire in operation, in order to detect dim errors. For this, a global imaging method could be the solution, as will be shown below.

The fact that imaging measurements can provide information on the state of the lighting system is demonstrated in [16]. Here, aerial airways images are obtained from a fixed platform (Milad Tower, Tehran, 380 m high, which obviously generates major restrictions for other locations). The images are used, discouraging, only to detect blackout lamps (faded lamps). This is possible due to the use of 2x400W sodium lamps and obviously with a high ULOR (Upper Light Output Ratio) that are unacceptable today, especially for LEDs. This method, even if perfected, is affected by random errors. When measuring the road luminance (as in imaging methods), this is dependent on air pollution, wet / dry condition of the asphalt, asphalt ageing, and the presence of vehicles.

The principle of carrying out measurements to determine the maintenance program in public lighting is available in [17], where the idea is to produce illuminance maps of roadway by measurements from a moving vehicle. Maps are obtained for the entire road network, and by following the evolution of these parameters (level of illumination), it is possible to establish the depreciation of optical parts (not necessarily major defects) and thus the necessity of cleaning interventions, for example. It is claimed that the method has a low cost, but we have reservations in this regard. A medium / small city can have many hundreds of km of streets that has to go, whose multiple scroll (for bilateral poles, for example) means both time and money.

The same idea is being developed in a more recent research [18], in which the same illumination maps are made, with GIS data indexed using GPS receivers. This system was used by authors for measurements in Iasi, Romania, with the observation that in order to obtain street lighting values, measurements are needed in late night hours, when the traffic is null or very low, allowing the sensor to be located close to the asphalt level. In [18] it is proposed to use public transport to continuously monitor the level of illumination. Our observation is that the level of illumination in the useful plane will not be measured, but at a height of about 3m. However, the evolution of these illumination values may be the basis for determining the depreciation of the luminous flux emitted by some luminaires, and hence the planning of their maintenance.

There are also opposing opinions, as it is [19], where it is stated that if the planned interventions are realized, respecting the prescribed periods of time, then “no measurements are necessary”. The argument is not consistent because the purpose of measurements is to establish that interventions must be made earlier, or even at longer intervals, with obvious economic effects.

II. Luminance Measurements For Street Lighting Luminaires

The use of a digital camera for the measurement of luminance is available in [20]. Measuring the usual luminance (encountered in architectural lighting) does not pose any particular problems. In order to diagnose the condition of a luminaire, it is necessary to measure the luminance that reaches very high values. In the case of discharge lamps, a special restriction is the frequency at which these lamps operate, so that the exposure time should be relatively high, in order not to sample a half-period. In order to integrate the variable luminance of the discharge lamps, the exposure must be higher than 20ms, which results in saturation of the sensor (RGB = 255) and the impossibility of measurement.

For LEDs powered at high frequencies switching (about 100 kHz), this time can be shortened to the maximum available values (1/4000 s). The maximum luminance values will be the following, corresponding for the parameters below:

- Exposure time = 1/4000 s
- F number : 29
- ISO: 100;

Depending by the maximum RGB values obtained in the JPG file, the maximum luminance will be as in Table 1, corresponding to NIKON D5300:

TABLE I
Maximum Luminance Values Measured By Digital Camera

No	Average RGB Values	Maximum luminance (cd/m2)
1	125	$6.148 * 10^4$
2	175	$2.3625*10^5$
3	220	$1.1700*10^6$
4	245	$3.2209*10^6$
5	253	$4.3696*10^6$

The results are based on equation (4) and (5) from [20] and obvious are nonlinear. Considering these, a night scene is analyzed, as in Fig.1:

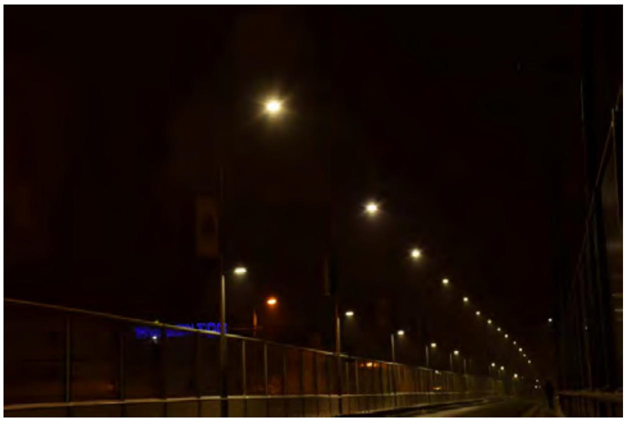

Fig. 1. The night scene of O.Bancila Street

According SR EN 13201, the luminance of the street must be measured, and using calibrated camera the luminance map is available:

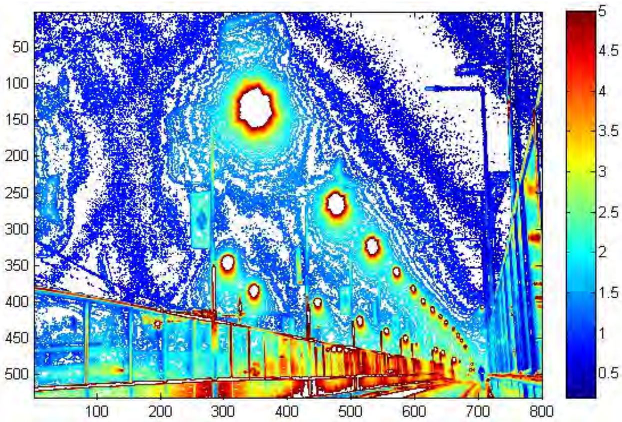

Fig. 2. The luminance map (cd/m^2) for the night scene of O.Bancila Street

It is noted that asphalt luminance is between 1.5 and 2.5 cd/m^2, due to the wet condition of the road. These values cannot be used as a reference, as they will vary continuously. Totally different is the situation if the brightness of the luminaires is measured. Using the particular settings for the digital camera (exposure time=1/1000s, F=29, ISO=100) the luminaire luminance was measured, as in Fig.3:

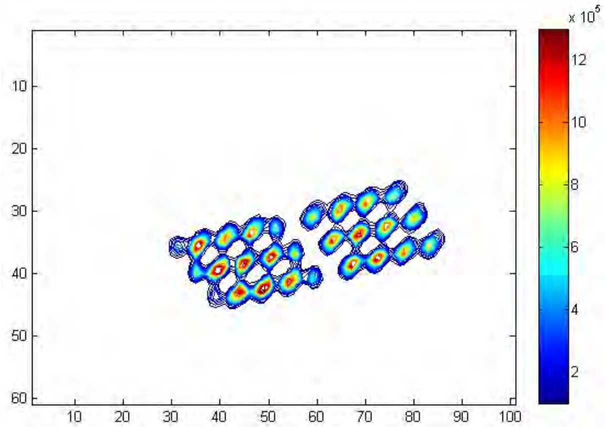

Fig. 3. The luminance map (cd/m^2) for LED luminaire

The luminance map from Fig.3 could serve as the basis for monitoring over time. The luminous map offers especially qualitative assessment. For quantitative analysis, the distribution of luminance on certain axes of the luminaire is much more useful. For the different location of the luminaire and the digital camera, some geometrical considerations are necessary, according to [21]. For the longitudinal (geometrical) axis of the luminaire the variation of the luminance is available in Fig.4. It is possible to individualize

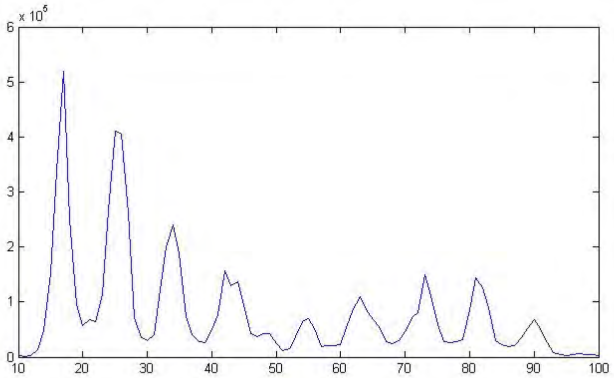

Fig. 4. The luminance profile (cd/m^2 x 10^5) for the longitudinal (geometrical) axes of LED luminaire

the eight high power LEDs (out of 24) and the comparisons of the parameters or the evolution of the values over time are much easier to achieve.

The luminance inequalities that are highlighted in Fig. 4 are not necessarily interpreted. Much more important are time changes (depreciation), obtained with the preservation of the station point and the calibration / setting of the digital apparatus.

III. Correlated Color Temperature Measurements For Street Lighting

Calculation of CCT is still a topical subject when pursuing the characterization of a wide range of light sources [22]. For lighting maintenance, the CCT range is much lower, between 2500K and 10000K. The primary RGB sensor values are used to obtain CIE XYZ color space, using a linear transformation. After that, XYZ color space is device independent, could be used to calculate x and y, the coordinates of chromaticity diagrams and after that the CCT. First step rises some problems, regarding the calibration of the digital camera:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

The matrix of linear coefficients b_{11} to b_{33} gives in literature for different white reference (D65 or D50) don't match with the standard measurement performed with a Konika Minolta CS-100A Luminance and Color Meter. The solution was to calculate the linear coefficients, using three different measurements for three different light sources, with CCT covering the domain between 2700K and 6000K. The first measurement, for the lighting source S_1 of 2700K, we obtained the values R^1, G^1, B^1 from the digital camera and X^1, Y^1, Z^1 from CS-100A Luminance and Color Meter. In a similar manner, other two sets of data was generated.

One write three times equations for the first line X from (1), obtaining:

$$\begin{bmatrix} X^1 \\ X^2 \\ X^3 \end{bmatrix} = \begin{bmatrix} R^1 & G^1 & B^1 \\ R^2 & G^2 & B^2 \\ R^3 & G^3 & B^3 \end{bmatrix} \times \begin{bmatrix} b_{11} \\ b_{12} \\ b_{13} \end{bmatrix} \tag{2}$$

Where b_{11}, b_{12}, b_{13} could be calculated.
Again, for the third line in Z:

$$\begin{bmatrix} Z^1 \\ Z^2 \\ Z^3 \end{bmatrix} = \begin{bmatrix} R^1 & G^1 & B^1 \\ R^2 & G^2 & B^2 \\ R^3 & G^3 & B^3 \end{bmatrix} \times \begin{bmatrix} b_{31} \\ b_{32} \\ b_{33} \end{bmatrix} \tag{3}$$

Where b_{31}, b_{32}, b_{33} could be calculated.
In the final, all the coefficients are determined:

$$\begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} = \begin{bmatrix} 0.5074 & 8.8116 & -0.1947 \\ 0.2973 & 0.6273 & 0.0752 \\ -0.0477 & 0.0809 & 1.0748 \end{bmatrix} \tag{4}$$

In these manner the particular calibration of any digital camera could be used to obtain RGB to XYZ transformation, and after that CCT could be calculated. A supplementary comment is necessary, for the Y line, with its coefficients b_{21}, b_{22}, b_{23}. These coefficients are involved in luminance calibration and must be kept as initial.

IV. Conclusions

The paper demonstrates that predictive maintenance is very rare used for public lighting. Decreasing of the performance of lighting systems over time is estimated only by calculation, and no systematic measurements over long periods of time, especially for LEDs, are known. A cause of lack of measurement is the complexity of specialized measuring instruments for luminance or CCT measurement. By using a customized calibrated digital camera, one obtain an affordable device that can be used for global imaging measurements for an entire road section. On the basis of periodic observations and time evolution of parameters, predictive maintenance strategies can be determined, maximizing financial efficiency.

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Luminance field of the façades:

from aggressive to attractive lighting

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***Abstract*— The paper represents the methodology used to support a Light Pollution initiative, inside the STARS4ALL program. The purpose of this initiative is to involve a large number of participants in a qualitative but also quantitative assessment of lighting solutions for façades. The purpose is to discover the light pollution sources. The method is based on digital camera calibration, to obtain the luminance map of the visual field. Details about absolute values for luminance, illuminance of facades and also contrast of luminance are available.**

***Keywords*— Light pollution, camera calibration, luminance measurement;**

I. INTRODUCTION

The paper is focused on the architectural lighting of the façade. This topic represents an important source of light pollution. In our days, the beautification of the city increase the level of architectural lighting, applied to the number of the façades but also in light level. A large scale of this light is spill to the sky, generating all negative effects of light pollution.

The approach is based on photographic method to measure the luminance of the façades. Using qualitative assessment, pictures will be indexed with a qualitative criterion (aggressive or attractive), but most important, with a quantitative criterion (measured luminance). The luminance is not a common physical value used to characterize the lighting (as illumination in lux or luminous flux in lumen), because the measurements are not so easy or cheap. Despite of this, the luminance is the most important factor for vision. Using luminance, one can characterize a satisfactory vision, but with minimum light pollution.

Raising the awareness is realized through the involvement of the students in engineering (civil engineering) and architecture. For this, a MATLAB function was realized, giving the possibility to compute a large number of photos, by any non-specialized person. In this function, the calibration of the camera is included, with details for further calibration.

The qualitative criterion is not sufficient for light pollution reduction. Qualitative assessment is based on visual observation, on site or using images. One notice that even specialists could be influenced by subjective judgement, due the eye adaptation.

II. THE LUMINANCE MAPS

In the context of the intensification of light pollution, the situation of architectural lighting was poorly understood and even misunderstood. An example is [1], where the problem is approached similarly to visual comfort in general, for various visual tasks. Thus, ... " as a result of responders' individual aesthetic preferences set of average luminance of respective facade zones were obtained. During statistical analysis of the results, elements of interval estimation were used to assess an average value of the luminance levels of illuminated facade zones, with a probability equal to a confidence coefficient. The results of statistical studies enabled the determination of the most preferred illumination levels of respective facade zones as well as the average luminance levels of those areas". We cannot agree, because for architectural lighting the problem must be formulated differently: *how can a maximum visual effect (not visibility) be achieved with a minimum light flux*? Because if we leave the eye and the subjective impression to impose the solutions, it is clear that a tendency to increase the level of illumination and, implicitly, of the light pollution will be imposed.

An argument for the reduced possibilities of using the eye as a "tool" for the qualitative assessment of the luminous environment can be found in [2], where subjectivism is replaced by the digital image. Moreover, the method is applied to the luminous environment during the day, when the high values of

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the contrasts (façades, vegetation, sky) can be studied. At night, more information can be revealed, and that's why we opted for this approach.

The fact that façade lighting has been neglected is demonstrated in [3], which is a design guide for vertical surfaces illumination, but has a very limited use area. And then what happens if architectural lighting only develops based on subjective inspiration?

An alarm signal is drawn in [4] because "atmospheric optics and lighting technology are among the primary sources of uncertainty in predicting the collective optical effects that all city lights can have on the diffuse light of a night sky... the cumulative light emission from all structures in a heterogeneous light-emitting and blocking urban environment is difficult to obtain, and still remains inadequately quantified." Obviously, there are attempts to describe the effect of all light sources in the urban environment, and it is demonstrated [5] that the façade lighting presents an increasing trend. Of course, architectural lighting is not denied, especially since it was used in antiquity [6]. In the same paper, the authors specify the risk of committing mistakes, but also the way of succeeding. One of these successful methods is to model façades in detail and to analyze HDR (High Dynamic Range) images, as proposed in [7].

Compared to [7], where indoor facades are being studied, in the present paper, HDR images will be used for outdoor facades analysis. The same methods based on High Resolution Luminance Images are available in [8], also applied for outdoor visual comfort. Obviously, the benefits of HDR images will be extended for the case of monitoring the façade luminance. The validity of the use of luminance maps is underlined in [9], where one highlights details that that the direct, visual observation cannot detect.

Similarly, as one can find in [10], if we extend the study of daytime reflexivity façades to night-time, we can expect some very serious consequences, namely the luminous flux emitted to the sky.

This criterion is also important in the context of floodlighting, and interesting conclusions can be found in [11], where it is demonstrated that a good from *bottom to top* direction of reflectors working on a facade may be a better solution than the *top to bottom* solution. The latter solution could reflect an enormous luminous flux to the sky through the reflective effect of the pavement. For our research, this kind of effect can be highlighted through luminance maps.

III. Methodology

These luminance maps could not be available without calibrating the digital cameras. There are also specialized digital cameras, standard, but their price makes them inappropriate for use on a large scale, by a large number of specialists. Calibration of digital cameras is mentioned in many papers, but most works elude the essential steps of calibration. In this paper, the calibration principles described in [12, 13, and 14] have been used. This calibration details are available in [15], for the particular camera used (NIKON D5300).

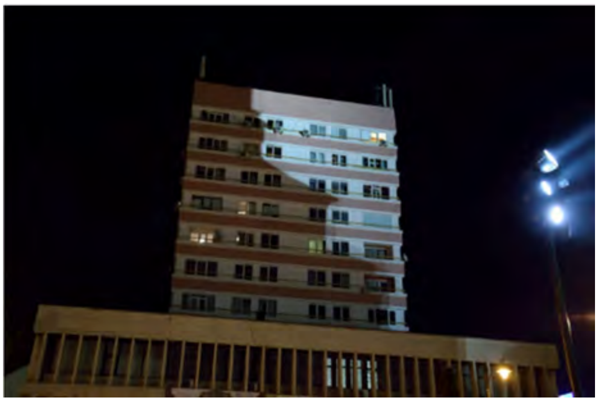

Fig. 1. Obtrusive light

The quantitative criterion proposed will be luminance of the façades, and also luminance contrast. This parameter (Luminance contrast - LC) it is not used in present for façades, but is well known that the visibility depends LC. It gives the possibility to obtain a better visibility of the façade with lower illumination.

Some luminance meter are used, in a specialized team. These measurements generates an important data base, describing the sources of light pollution.

The method is based on a successive image processing, to transform RGB information in luminance map. The optoelectronic function of the camera is used, also the exposure time, F-number and ISO sensibility. To illustrate this, some study case are presented, with available comments and relevant issues.

In Figure 1 is presented an obvious example with a façade which is target for a obtrusive lighting system (one notice the shadow of a church, illuminated from the pillars situated in four corners, one could be seen in fig.1). The surprise consists in the values of the luminance of the façade, as in fig.2:

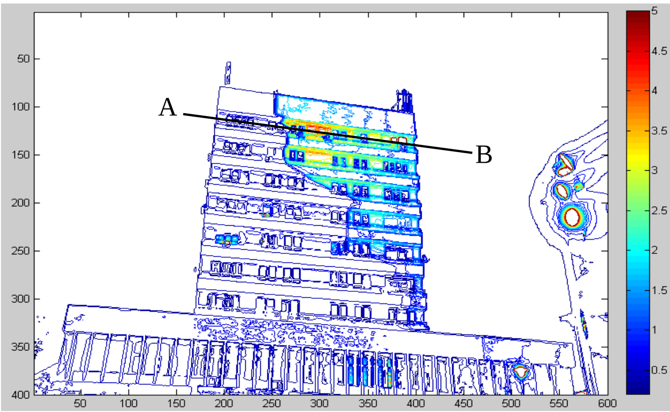

Fig. 2. The luminance map for façade with obtrusive light

Knowing the connection between illuminance E and luminance L for perfect diffuse reflection:

$$L = \frac{\rho}{\pi} E \quad (1)$$

on find an illuminance close to 15 ÷ 17 lx, a totally unacceptable value. For tenants, the discomfort generated by the obtrusive light (indoor) is accentuated by the loss of the night sky and also the night vision on the city landscape.

Extracting the values from a particularly region (A-B in Figure 2), the supplementary information are available:

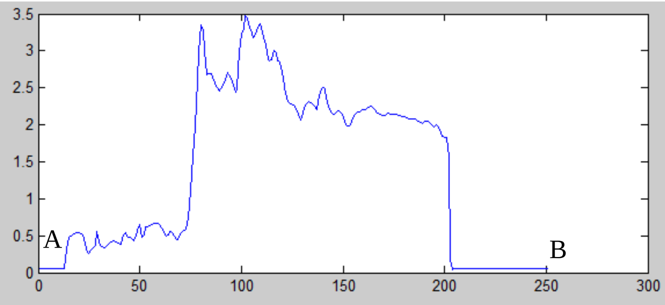

Fig. 3. The luminance variance on the façade from Figure 2, zone A – B.

The difference between the left region (relative shadow) and the right one is obvious, and even the shadow part has a relative high luminance.

A different scene is presented in Figure 4, where the subject is an airplane exposed and illuminated in front of a façade:

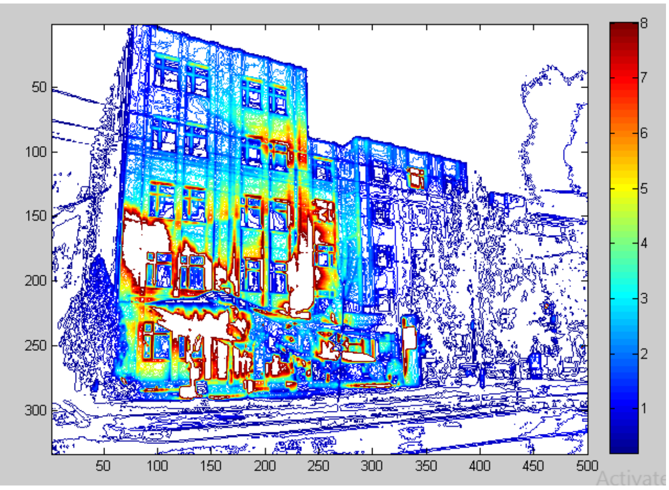

Fig. 4. A Fight jet exposed in front of a façade

For the beginning, one notice that the dynamic range is not sufficient to reveal all the luminance field. A different photo was taken, extending the dynamic range of the image, as in Figure 5. The absolute values for illuminance are greater than in the first case, one discover more than 50 lx on some regions of the façade! More interesting is the poor visual effect obtained for the fighter jet itself, due the smooth surface and dark painting!

To underline obtrusive light is one objective, but the façades could also be studied, searching to quantify the importance of the luminance level but also the contrast of luminance, as in the next example.

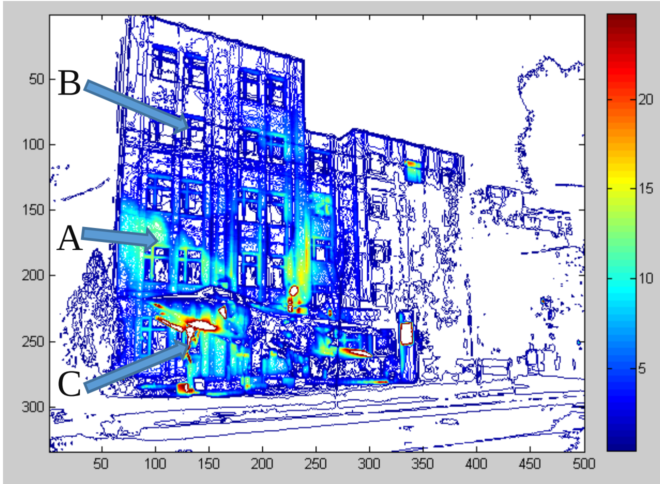

Fig. 5. The immage from Figure 4, with HDR, and luminance for obrusive lighting (zone “A”), shadow of the plane (zone “B”) and the position of the plane (zone “C”).

The next study case is The Municipal Museum, Iasi City as Figure 6. Situated in a relative dark area, residential houses with small streets, the first aspect indicate a pleasant atmosphere, quite attractive. The luminance values represent a surprise, so a supplementary picture was necessary, due to higher luminance as in Figure 7:

Fig. 6. The Municipal Museum Façade, Iaşi City

Fig. 7. Shorter time of exposure, for High Dynamic Range

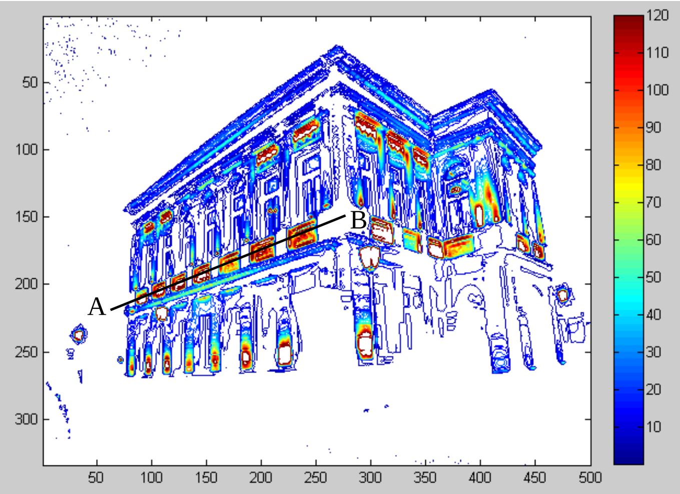

Fig. 8. The luminance map for the Municipal Museum Façade, cd/m^2

Some details are interesting, such as the line A-B, from where the profile of luminance distribution is presented in Figure 9:

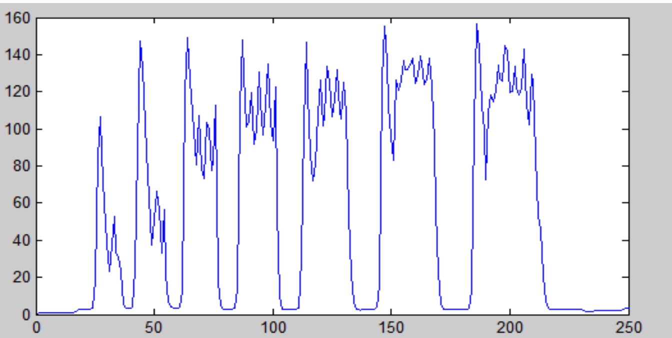

Fig. 9. The illustration of contrast of luminances, on the line A-B, Figure 8 (cd/m^2)

In Figure 9 one notice the existence of the contrast of luminance, and the architectural details could be accentuated at much lower values of luminance, in any case not so aggressive.

A lower level of contrast is generated by the floodlighting solution, as in Figure 10:

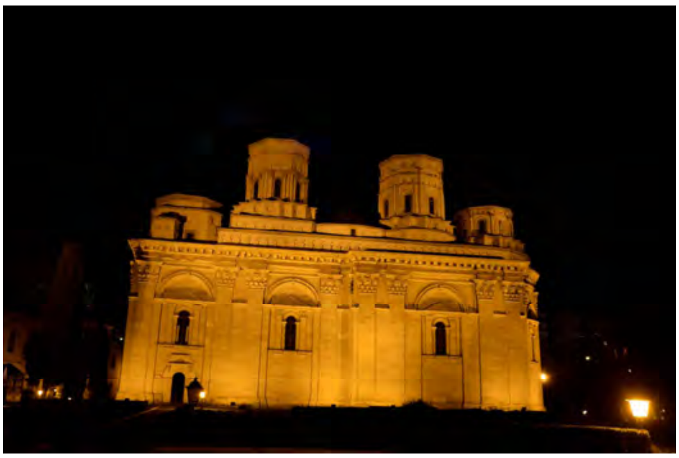

Fig. 10. Sf.Golia Church with low luminance contrast

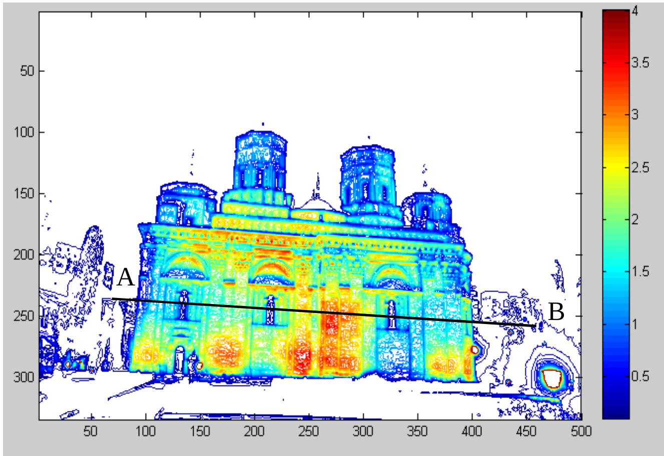

Fig. 11. Luminance map (cd/m^2) for Sf. Golia Church

The average luminance is less aggressive than in Figure 6, but even here the values are too high, and the poor uniformity is generated by non-optimization of optical lens of luminaires! This affirmation is much obvious studying the profile of luminance on the line of windows, A-B in Figure 12:

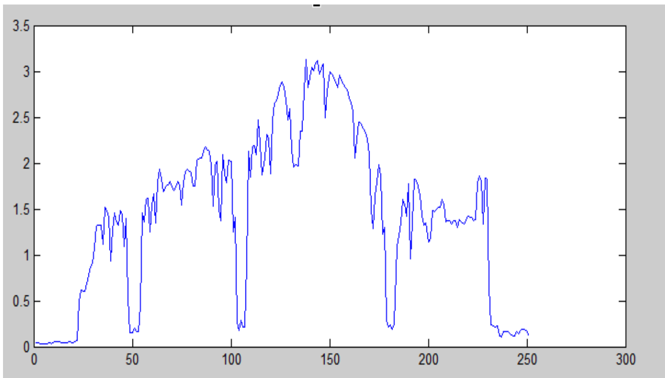

Fig. 12. The luminance profile on line A-B from Figure 11, with non-uniformity for the central zone of the churc, and dark windows.

The method will serve as a base for a guide with practical comments and solution for the improvement of façades attractiveness and light pollution reduction.

IV. Conclusions

The luminance field gives important information about the lighting solution of façades. This information will remain unknown without a luminance map. Using DSRL camera calibrated for luminance, it is possible to involve a large number of observers, and it is possible to cover a large area of a city, giving important information about the level of the luminance on façades. This information is transparent for public, increasing awareness facing light pollution. The proposed method will indicate, for every illuminated façade, some interesting details:

- The level of luminance, uniformity
- Extreme values of illuminance
- The light pollution sources

- Details with luminance contrast

Based on this method, a labeling systems for façades lighting could be propose, including not only the beautification aspects, but also light pollution problem.

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Light Pollution Assessment Using Photographical Methods

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***Abstract*— Light pollution is a phenomenon that has been reported since a long time, but the specialist's reaction is still modest. There are some attempts for specific regulations. Using photographic tools can be a solution, especially because of the possibilities to achieve global measurements of the lighting field. The purpose of this paper is to substantiate a work in which the general public aware of the phenomenon, based on qualitative evaluations and quantitative assessments. Moving from photography at night, for which there are sufficient quantitative information, towards the assessing of light pollution (not even benefit from an operational definition) is another important goal. And this is not only about street lighting (for which there is a description of the specific efficiency) but also for architectural lighting and advertising. The outcome sought by the author is finding a way to better observe early forms of light pollution and also to promptly report the serious situations or the exaggerate levels of the phenomenon. The method is based on low level aerial photography, and data processing to make the difference between useful light (on the street, on the facades etc.) and light pollution. Computing the global fields of light, received at different altitudes, it is possible to identify the pollution, even the source of it. In other case, there is no feedback mechanism to perform the self-limitation of the negative effects of light pollution. This could represent a main contribution to the designing of lighting systems.**

Keywords: Light pollution; pollution factor

I. INTRODUCTION

From [1]: "Sky glow occurs when artificial light from cities interacts with the constituents of the atmosphere, aerosols and water molecules located basically at the troposphere level."

In [1] it is presented a microcontroller-based system for automated and continuous sky glow measurements with the use of digital single-lens reflex cameras. Relevant details about hardware, software, camera calibration and testing are available. In figure 1 [2], the zenithal night-sky brightness was measured, but no information was obtained about air pollution.

In [3] we found a confirmation of this influence. A study about small particle Rayleigh scattering, about large particle Mie scattering, is presented, but the subject of releasing aerosols phenomenon which is coupled with light pollution, is avoided.

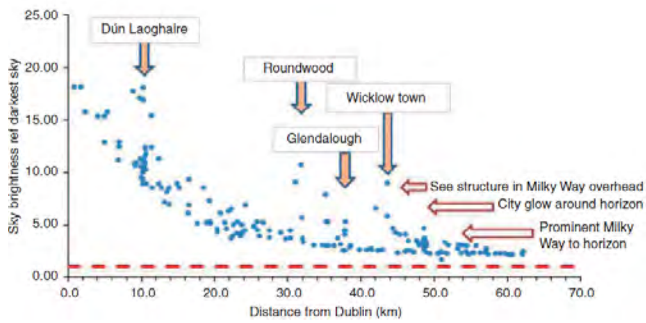

Figure 1. Measurements of the zenithal night-sky brightness obtained in clear-sky moonless conditions in surveys southward of Dublin city centre [2]

II. EVOLUTION OF LIGHT POLLUTION ASSESSMENT

Light pollution is already a classical subject, but no relevant progress is available in present:

a) CIE Report 126 (1997): methods of measuring, and recommendations for minimizing, sky glow.Night-time photographs of the sky are made while using a consistent lens type, F-stop, exposure time and film type.

CIE Report 126 is largely silent with respect to decisions about lighting that one could make in the design of an installation. Probably this report was at the origin of SQM – Sky Quality Meter, a very useful tool for astronomers.

b) IESNA TM 11 – (2000) contains limits on the maximum illuminance (presumably on a verticalplane) along the property boundary for a lighting installation

c) CIE Report 150 (2003) provides measurement methods for characterizing the photometric parameters of a lighting installation thought to be correlated with these negative effects oflighting. The measurements are made in reference to limits on the illuminances, luminances and luminous intensity resulting from a lighting installation.

d) AFE guide [5] for nuisance lighting (2006) is a site-based system for calculating glow, but it requires knowledge of the ground reflectances in surrounding properties in order to calculate the sum of the direct and reflected upward luminous flux from each of the luminaires in a lighting installation.

e) Outdoor Site-Lighting Performance (OSP) [5] (2008).

This method is very elaborated, it operates with three main values:

Glow = all light leaving the property

Trespass = peak illuminances associated with light crossing the property boundaries

Glare = discomfort glare from luminaires (luminance)

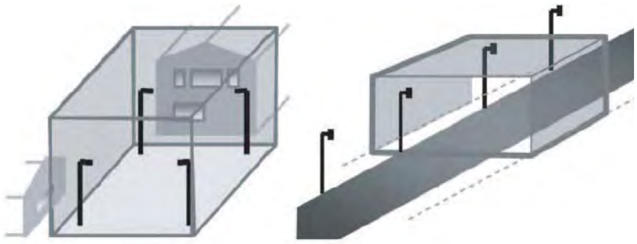

Figure 2. Calculation boxes for lighting installations [5]

III. A STUDY CASE FOR LIGHT POLLUTION ASSESSMENT

A lighting system for a sport field - training purposes - is designed (figure 3). The technical solution is not the main subject; it serves for light pollution assessment.

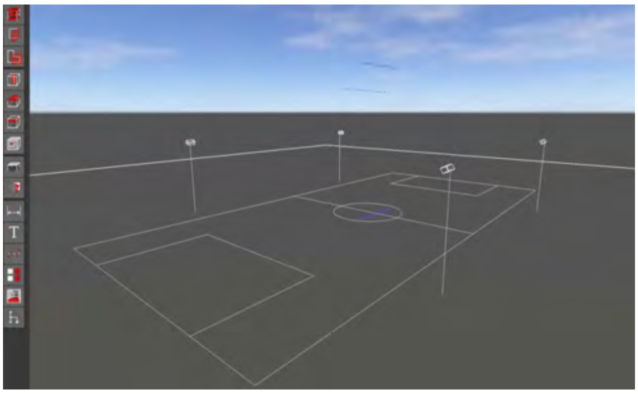

Figure 3. Sport field dimensions: 38 x 18m, assessment zone 42 x 24m, pillars height = 6m

4.a 4.b

Figure 4. The proposed luminaire PFE-1000 7X7 HPS 1000W: a- Luminaire image; b – Intensity distribution (qualitative).

PFE-1000 is a powerful floodlight that can feature up to 1000W HPS lamps (figure 4). It provides excellent illumination of extensive outdoor areas such as car parks, sports facilities, recreational areas, facades, airports, motorway junctions and intersections.

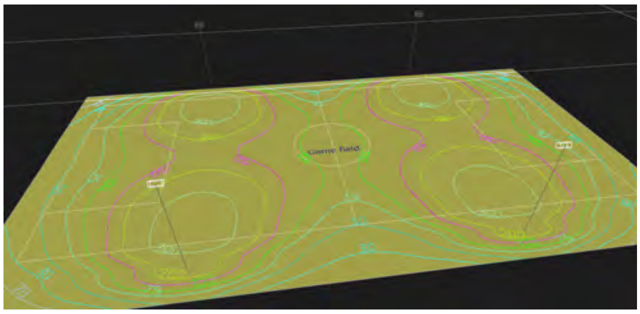

Figure 5. The results of lighting design, fast optimization

Based on this technical solution (figure 5), some quantitative considerations are possible.

$$Assessment\ zone = 42 \times 24m = 1008\ m^2 \tag{1}$$

$$Average\ illuminance\ (perpendicular) = 149\ lx \tag{2}$$

Useful luminous flux (with direct incidence on assessment zone) is relevant for light pollution assessment:

$$\emptyset U = \int_0^{Area} E(A)dA \tag{3}$$

and

$$\emptyset U = 150192\ lm \tag{4}$$

Depending on situation, the useful luminous flux could be considered grater (if vegetation or facades are interesting to underline).

Electrical power of the lamps, including ballasts:

$$P=4 \times 1085\ W = 4340\ W \tag{5}$$

Lighting Power Density is a well-known criterion:

$$LPD= 4.306\ W/m^2 \tag{6}$$

From EN 13201-5 we have SLEEC: (Street) Lighting Energy Efficiency Criterion. This is an indicator that is used in the European lighting

The formula of SLEEC is:

$$SE = \frac{P}{E \times S}, \tag{7}$$

Where P is system power, E is average horizontal illumination and S is the surface. For the study case we obtain:

$$SE = 0{,}0289\ \ W/lx/m^2\ \ \text{(C class)} \tag{8}$$

Handbook Energy Labeling for Public Lighting [8] gives a global image about efficiency of the system (Table 1). Label classification is an useful instrument, with indirect relevance for light pollution. Also, on mentioning [7] labeling for luminaires with LED sources, but again nothing about light pollution phenomenon.

TABLE I. PUBLIC LIGHTING LABELING [6]

Label	SE (W/lx/m^2)		SL (W/(cd/m^2)/m^2)
A	0.01	0.005 – 0.014	0.15
B	0.02	0.015 – 0.024	0.3
C	0.03	0.025 – 0.035	0.45
D	0.04	0.035 – 0.045	0.6
E	0.05	0.045 – 0.055	0.75
F	0.06	0.055 – 0.065	0.9
G	0.07	0.065 – 0.075	1.05

For our study case, effective emitted luminous flux makes the difference from above energy efficiency criteria:

$$\emptyset EE = \emptyset_{lamp} \times MF \times LE = 480000 \times 0{,}7 \times 0{,}68 = 228480\ lm \quad (9)$$

where:

MF =Lighting maintenance factor,

LE = Lighting Efficiency of the luminaire.

The ***pollution factor of the system*** (PFS) represents the lost luminous flux over the effective emitted luminous flux:

The definition of PFS could be:

$$PFS = \frac{\emptyset_{Lost}}{\emptyset EE} = \frac{\emptyset EE - \emptyset U}{\emptyset EE} = \frac{228.480 - 150.192}{228.480} = 0{,}34 \quad (10)$$

PFS gives a quantitative image of the light pollution source (luminaires). For our study case, this value looks inacceptable, because we expect to have a better situation using downward distribution, with direct luminous flux oriented directly to the field.

Comment: The utilization factor UF, accepted even in the recent publication [9], is the initial luminous flux reaching the (road) surface ($\emptyset_{\mathrm{uo}\,uo}\emptyset_{\mathrm{uo}}$) versus the luminous flux produced by all the light sources of the lighting installation ($\emptyset_{\mathrm{Tlamps}}$):

$$UF = \frac{\emptyset_{uo}}{\emptyset_{T\ lamps}} \quad (11)$$

The utilization factor is useful for energy efficiency criterion.

IV. HIGHLIGHTING LIGHT POLLUTION

Until this designing phase, no information about light pollution is available.

The proposal for light pollution assessment from designing phase consists in the use a series of assessment zones, in ascending positions and underside view. The method is different from Outdoor Site-Lighting Performance (OSP) [5], and it has the advantage to be fast and relevant. After the designing phase, the method could be used to evaluate the existing lighting systems, using a CCD camera.

The Underside view is realized (in DiaLUX) with the next settings for Assessment zones (figure 6).

In figure 7 is presented one assessment zone (above the luminaires) and in figure 8 all the assessment zones could be located. In figure 9 on demonstrate the illuminance components, with the contribution of light pollution (see the Legend).

Figure 6. Settings for underside assessment zone (DiaLux)

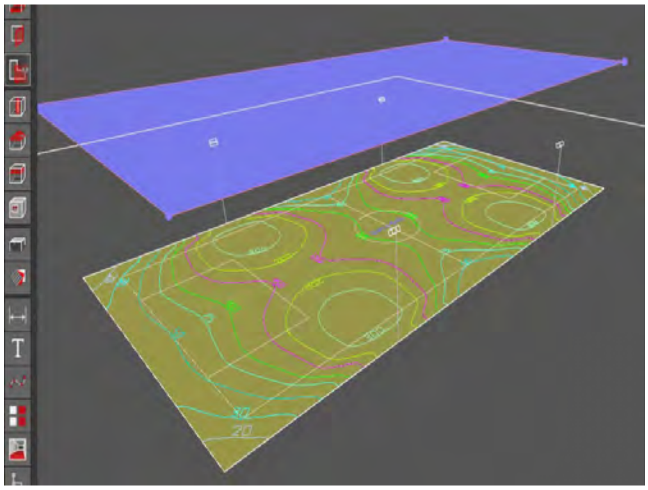

Figure 7. Geometry for one underside assessment zone (DiaLux)

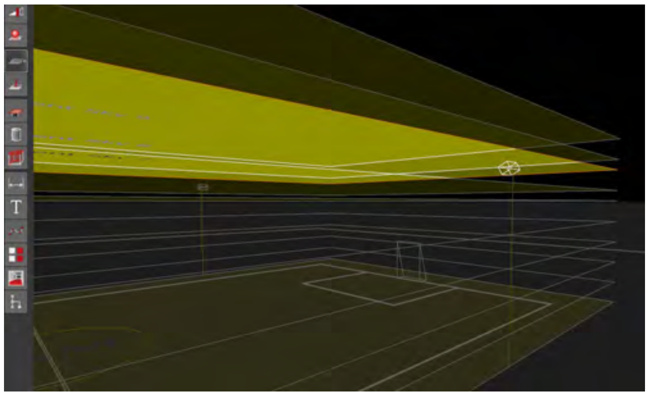

Figure 8. Geometry for a number of nine underside assessment zones (DiaLux)

V. RESULTS IN LIGHT POLLUTION ASSESSMENT

Using the series of the assessment zones, the average illuminance is calculated. For the light pollution not the absolute value is important (even if the sky glow will be influenced by the pavement reflectance), only the variance of the average illuminance. If on some altitude a jump (step from “A” point to “B”, figure 10) will occur, there it will be a light pollution source, with direct contribution on sky glow. Figure

10 presents this aspect.

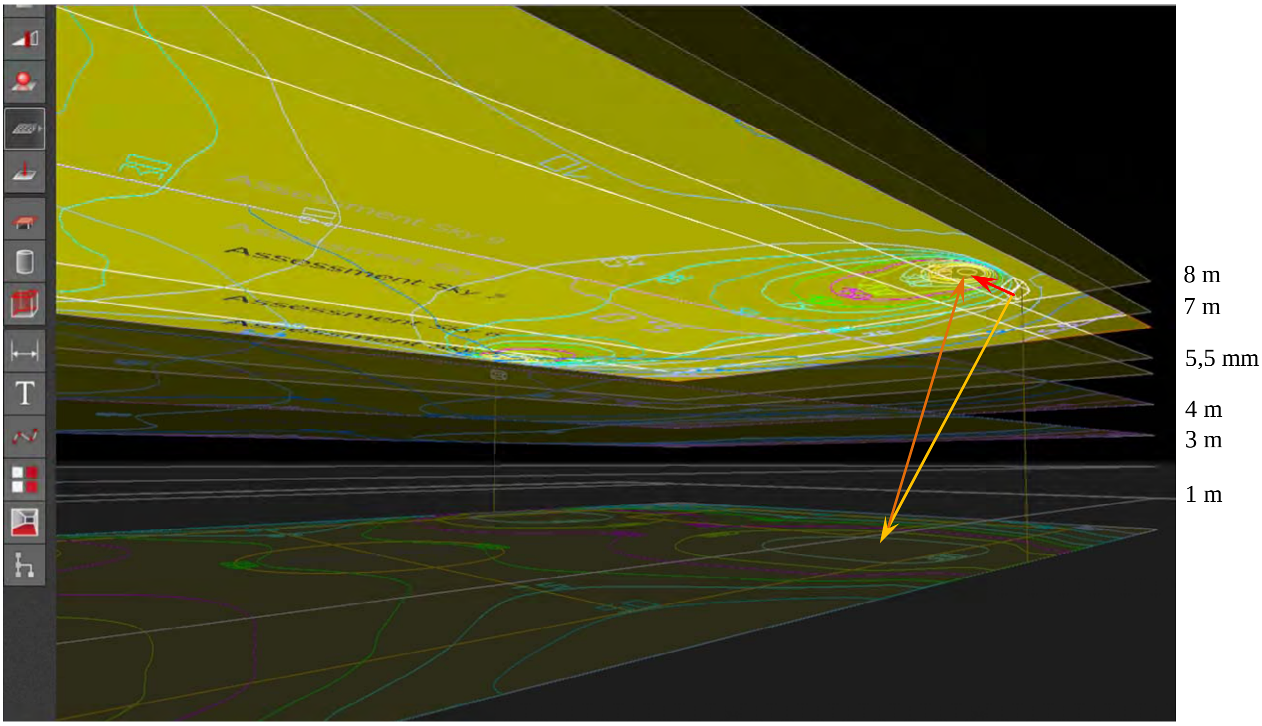

Figure 9. Illuminance of the assessment zones (DiaLux)

Legend:

= direct raytrace to working plane
= reflected raytrace to the underside assessment zone
= direct raytrace to the assessment zone (The Main light pollution)

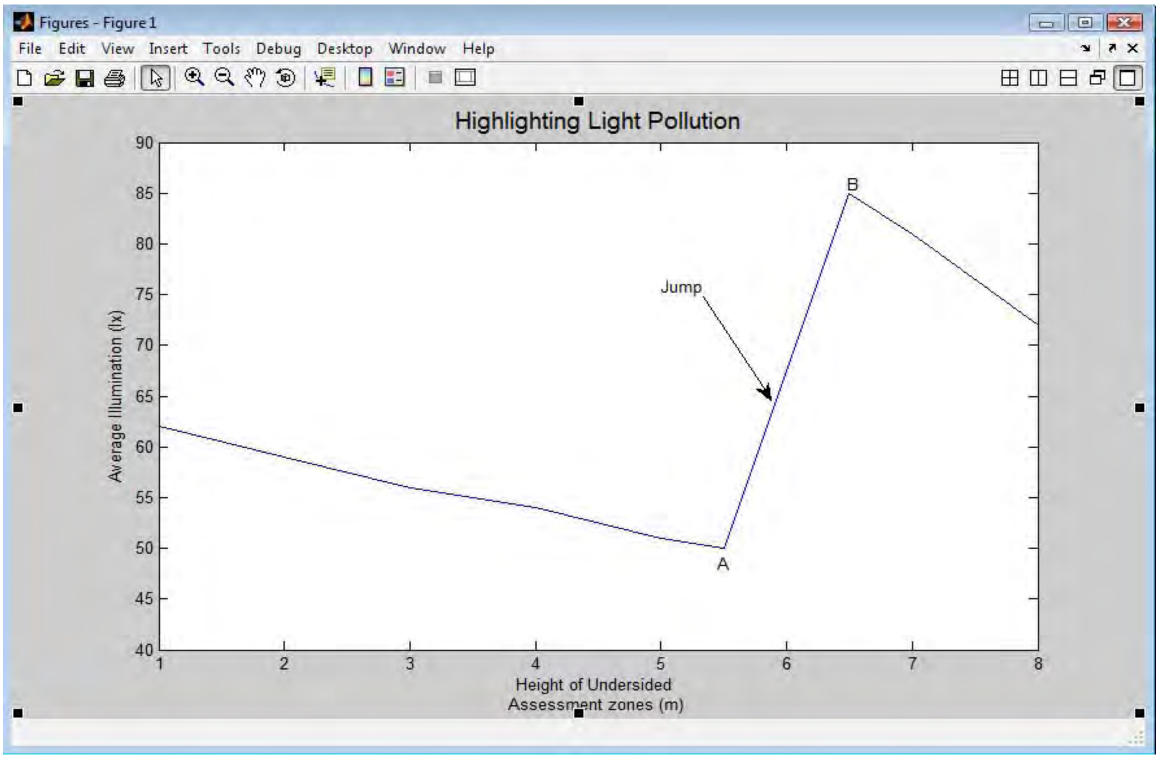

Figure 10. Highlighting light pollution using average illumination on underside assessment zones

VI. Conclusions

Similar to designing phase, light pollution sources could be identified using a CCD camera in ascending movement, from the street level to 10 m over the light sources (luminaires, commercials, advertising, decorative or festive lights), aiming the inferior view.

Integrating the luminance field, a connection with average illumination of the assessment plane is obtained. The sources of light pollution could be highlighted, knowing the altitude of the jump of average illumination.

The method is useful for light pollution assessment on existing sites, and it has the advantage to be uninfluenced by the atmospherically conditions (air pollution).

The definition of the *pollution factor of the system (PFS)* represents a criterion for the designing phase, and a practical method for light pollution reduction.

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