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The Basic Process of Lighting as Key Factor in the Transition towards More Sustainable Urban Environments

Antonio Peña-García [1,*], Agustín Castillo-Martínez [2] and Sebastian Ernst [3]

[1] Department of Civil Engineering, University of Granada, 18071 Granada, Spain
[2] Department of Mechanical and Mining Engineering, University of Jaén, 23700 Linares, Spain; acmartin@ujaen.es
[3] Department of Applied Computer Science, AGH University of Krakow, 30-059 Krakow, Poland; ernst@agh.edu.pl
* Correspondence: pgarcia@ugr.es

Abstract: The design of lighting installations on roads and urban infrastructure has strictly followed the regulatory requirements of each country for a long time. Based on the traffic intensity, the presence of pedestrians and the nature of activities within the area, these regulations have been used to establish the luminance or illuminance levels from or on the pavement, the minimum average uniformity, the maximum glare and the minimum energy efficiency. Accurate values of these static parameters are supposed to ensure safety, security, and efficacy, and have traditionally been considered as the main targets of lighting installations. Therefore, compliance with these regulations indicates whether an installation is legal or not. Although this philosophy is operative, the reality is different due to two main issues. First, the progressive ageing of populations, mainly in North America and Europe, the changing circumstances of traffic flow and modalities and the presence of groves or socioeconomic factors, might have a strong impact on the safety, security and sustainability of cities. Secondly, the current regulations leave out perceived safety and security issues, as well as the well-being of people; that is, how people feel about the city independently of real danger. In this research, the Basic Process of Lighting (BPL) is formulated including, for the first time, the human factors involved when people develop their activities under public lighting. Using this framework, the potential factors influencing human wellbeing and feelings are summarized after being rated by people in a survey distributed among 133 participants. The results highlight a higher perceived impact of social factors compared to physical and visual ones.

Keywords: urban lighting; sustainable cities; safety; security; well-being

Citation: Peña-García, A.; Castillo-Martínez, A.; Ernst, S. The Basic Process of Lighting as Key Factor in the Transition towards More Sustainable Urban Environments. *Sustainability* **2024**, *16*, 4028. https://doi.org/10.3390/su16104028

Academic Editor: Cinzia Buratti

Received: 13 March 2024
Revised: 6 May 2024
Accepted: 9 May 2024
Published: 11 May 2024

1. Introduction

The objective of public lighting has been classically defined as ensuring the safety and security of people and goods [1–3]. With this target, different regulations for lighting have been developed in different countries, regions and municipalities.

In general terms, these regulations tend to determine whether a lighting installation is legal or not, by defining the requirements of parameters such as "illuminance on the ground" (luminous flux received on the visual plane per unit of surface) or "luminance from the ground" (luminous flux generally reflected by the visual plane per unit of surface and the solid angle in one given direction), average uniformity, glare, light pollution and energy efficiency [4,5]. These required parameters depend on the lighting class assigned to a given street. This assignment is based on several factors. For instance, the criteria defined by the European EN-13201 standard include, among others [6]:

- Vehicle speed;
- Traffic volume and composition;
- The presence of parked vehicles;

- The difficulty of navigational tasks;
- Ambient luminosity.

However, nowadays, this approach presents several shortcomings, such as the following:

1. The advances in our understanding of the non-visual effects of light have highlighted their impact on people's performance [7–10], health [11,12] and physical and physiological wellbeing [13–16]. This has made illumination a much more complex challenge than simply achieving the requirements of some guidelines. The changes in human output due to lighting conditions are becoming so extensive and better understood that they cannot be neglected anymore.
2. Many aspects are left out of the criteria, including both non-physical factors (such as the reputation, levels of criminality or accident rates in a given area) and physical ones like urban furniture and other elements.
3. The social profile and individual characteristics or preferences of the users, such as their age, gender, cultural and socioeconomic level or vulnerability, are not taken into account in the regulations nor the plans of local administrations.
4. Ideological and political factors could prevail over strictly technical criteria, especially during electoral periods.
5. The shortcomings above, being rather general, leave a significant part of the decision making to the discretion of designers and politicians. This may lead to inequalities among different cities and even neighborhoods or streets within the same city [17].

Regarding point 2 above, as an example, let us consider the case of bollards: short pillars that are often used to separate vehicle traffic from pedestrians. On the one hand, they present an obvious improvement in safety, but on the other hand, they can also be a danger, due to their height and limited visibility [18]. One could, therefore, argue that their presence actually increases the demands for lighting. However, the aforementioned standards do not give designers many opportunities to influence these requirements: while the criteria for motorized roads (class M) include the "navigational task difficulty" criterion (albeit with limited impact on the lighting class which generally pertains to driving rather than walking), the criteria for pedestrian and low-speed areas (class P, which is applicable in such situations) are not applicable in this specific case [19]. The same happens with the coexistence of public lighting and groves in urban environments [20–22], and also with different kinds of traffic signals [23,24]. Both are systematically ignored by rulemaking bodies and, rather frequently, by designers.

The result is a rigid project subjected to a limited set of fixed parameters that are exclusively focused on objective safety and security. The preferences, feelings, fears, psychological factors and perceived safety and security are not matters of concern within the current regulations.

In this complex framework, there is a clear research gap that must be urgently attended with the target of achieving more sustainable cities where people are not only objectively safer, but also feel safer and better. In particular, it is necessary to carry out the following:

(1) Establish a new conceptual framework;
(2) List all the potential factors that have an influence on public lighting;
(3) Survey people's feelings about these factors;
(4) Assess the quality of the regulations and score them according to the results of the survey;
(5) Develop methods aimed at improving the perceived quality, and;
(6) Extend or amend the current legislation to include the main factors identified and the well-being of the users, a key point for Sustainable Development when considered from a more general perspective [25].

The objective of this work is to focus on items (1) to (4). We suggest "starting from zero" and researching the potential extension of the classical criteria considered for public lighting to date, as well as the classical objectives of regulatory bodies. The achievement of these objectives is sequential, going from the concept of how public lighting works in

practice to considering how people feel. Items (5) and (6) must be approached in future research once all the factors have been properly identified.

Regarding the framework in which public lighting takes place, the current philosophy is partially supported by what will be called here "the Basic Process of Lighting" (BPL). This process, although partially defined in the in the framework of indoor lighting some years ago [26], has not taken into account the individual characteristics nor the psychological dimensions of the street users. These factors have a remarkable impact on well-being and their performance can also influence real safety and due to fear, and so far, the attention has been focused on irrelevant visual planes and other eventualities.

Hence, a deeper understanding of the BPL and its extension to a human-centered perspective are the starting points for reaching a global perspective on the perception and performance of public lighting that conforms the so-called Total Lighting concept [27–29]. But, to achieve this, and to decide how to design and redesign the installations, it is necessary to know what people really feel when carrying out their activities under public lighting. The method chosen in this work is directly asking people through a survey.

The next section undertakes the abovementioned extension of the BPL to a human-centered perspective, which has not been performed in the literature until now, and Section 3 describes and presents the results of the survey that was distributed among 133 participants with the target of evaluating their perception of the impact of certain variables that influence their life when public lighting is working.

2. Materials and Methods

Given the double objective of this research (summary and extension of the BPL, and survey to determine the main factors in BPL), the methodology is not homogeneous.

With regard to the BPL, an exhaustive search of the existing literature on lighting, visual perception, and psychophysics was carried out. Databases like Scopus, Science Direct and ResearchGate provided a high number of references, some of them already known by the authors. The main keywords used were "Lighting", "Lighting Design", "Public Lighting", "Urban Lighting", "Perceived Safety", "Visual Perception" and "Wellbeing".

Concerning the second objective, a survey with 38 questions was designed with the target of gaining information about citizens' feelings about the impact of each factor that might influence their activities under public lighting. It was distributed among 133 participants. These 38 items were divided into two consecutive rounds of 19 basic questions with each one being asked from two different perspectives.

The survey was preceded by the following instructions: "Imagine that you are walking alone during the night along one given street. Please rate the relevance (influence) of the following factors referred to that street (1 = irrelevant, 5 = very important). Keep in mind that we are looking for relevance, either it is a positive or negative one".

The original language of the survey was Spanish but they have been translated into English; the questions used were the following (see also Supplementary Materials Annex S1):

1. How relevant for your feeling of SAFETY AND SECURITY is the WEATHER?
2. How relevant for your feeling of SAFETY AND SECURITY is the presence of TREES?
3. How relevant for your feeling of SAFETY AND SECURITY is the presence of TRAFFIC?
4. How relevant for your feeling of SAFETY AND SECURITY is the COLOUR OF THE LIGHT emitted by the public lighting systems?
5. How relevant for your feeling of SAFETY AND SECURITY is the SOCIOECONOMIC LEVEL OF THE NEIGHBOURHOOD?
6. How relevant for your feeling of SAFETY AND SECURITY is the presence of SHADOWS (cast by trees, buildings, obstacles, etc.)?
7. How relevant for your feeling of SAFETY AND SECURITY is the happening of RECENT INCIDENTS in the area?
8. How relevant for your feeling of SAFETY AND SECURITY is the presence of PEOPLE?
9. How relevant for your feeling of SAFETY AND SECURITY is the presence of PARKED CARS?

10. How relevant for your feeling of SAFETY AND SECURITY is the presence of OBSTACLES (bollards, etc)?
11. How relevant for your feeling of SAFETY AND SECURITY is the level of NOISE in the street?
12. How relevant for your feeling of SAFETY AND SECURITY is the PAVEMENT materials and its maintenance status?
13. How relevant for your feeling of SAFETY AND SECURITY is the MORPHOLOGY OF THE STREET (open, surrounded by buildings, wide, narrow, etc)?
14. How relevant for your feeling of SAFETY AND SECURITY is the HOUR OF THE DAY?
15. How relevant for your feeling of SAFETY AND SECURITY is the REPUTATION OF THE NEIGHBOURHOOD?
16. How relevant for your feeling of SAFETY AND SECURITY are YOUR OWN personal distractions (mobile phone, music, etc)?
17. How relevant for your feeling of SAFETY AND SECURITY is the CULTURAL BACKGROUND OF THE NEIGHBOURHOOD?
18. How relevant for your feeling of SAFETY AND SECURITY is the CRIMINALITY RATE of the neighbourhood?
19. How relevant for your feeling of SAFETY AND SECURITY is YOUR OWN age?

These 19 questions were asked twice: one from the perspective of Safety and Security and, in a second and consecutive round, from the perspective of Well-being, that is:

1. How each factor influences the respondent's sense of safety and security,
2. How each factor influences the respondent's well-being.

Answers were given on a Likert scale of 1–5, where 1 denotes "insignificant" and 5 denotes "very significant" [30]. In the survey, it was made clear that the kind of influence (e.g., positive or negative) was not within the scope of the research. The questions only pertained to the significance of a given factor in the context of each question.

The following parameters have been determined for the analysis:

- $\overline{x}_T$—mean value for average answer (safety/security and well-being);
- σ_T—standard deviation for average answer;
- $\overline{x}_S$—mean value for the safety/security score;
- σ_S—standard deviation for the safety/security score;
- $\overline{x}_W$—mean value for the well-being score;
- σ_W—standard deviation for the well-being score.

The language of the survey was Spanish, and it was distributed among Spanish speakers through WhatsApp, Twitter and LinkedIn in December 2023. Twin versions in Polish and English will be released and distributed throughout 2024 among Polish speakers and an international audience, respectively. The channels of distribution will be the same.

There were no restrictions on age, gender, cultural or socioeconomic level, previous knowledge about lighting and safety or any other circumstances.

3. Results and Discussion

Departing from the aforementioned problems related to modern lighting, and following the methodology presented in Section 2, this work yielded the following two linked results:

(1) A formal definition and extension of the Basic Process of Lighting (BPL)
(2) A field study to determine the main factors influencing people under lighting installations.

The presentation of both achievements will be sequential because they are intimately connected since the second one is a consequence of the first. The open questions that arose following a deep analysis of the BPL made it necessary to carry out a survey to investigate the feelings of the users of lighting installations.

The following subsections will approach both outcomes.

3.1. The Basic Process of Lighting (BPL)

In the development of urban planning studies, little attention has been paid to the feelings and physical and psychological well-being of pedestrians, and even the few studies that do exist only started to be habitual a few years ago.

So, the BPL must be extended to the framework of human-centered installations.

Let us consider the scheme in Figure 1, in which the following five stages take place:

1. Luminaries emit luminous flux (Φ) with a given luminous intensity distribution I (α, β).
2. The pavement (visual plane) receives a given illuminance (E).
3. The pavement partially reflects the illuminance according to its physical properties in terms of the amount of reflectance in each direction (ρ) and the spectral absorptance.
4. A given luminance (L), is directed towards the eyes of each observer.
5. According to the visual input L, and other circumstances related to the situation, C, each observer will have a physical and behavioural output, O. Or, in a schematic way, $L + C \rightarrow O$.

The union of the five stages above can be referred to as the "Basic Process of Lighting" (BPL, Figure 1).

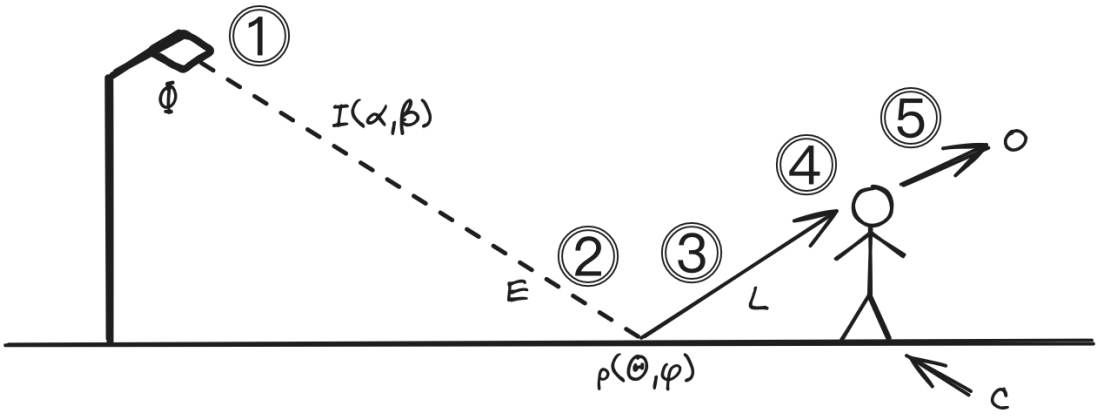

Figure 1. The Basic Process of Lighting (BPL).

Although they have not formally summarized and linked together, stages 1 to 4 in the BLP are well-known and, in general, are considered by regulations on lighting. But Nr. 5, although known in behavioral sciences, has been ignored in the field of Lighting Engineering.

In the framework of a BPL extended to a human-centered perspective, it seems clear that the broad spectrum of activities carried out in urban environments, the increasing number of not purely safety-related aspects of human activity, the need to enhance the psychological well-being of users in urban environments and the need for more sustainable cities demand a new conception.

Thus, although people's output under light stimuli has been a matter of active research for a long time [31–36], little attention has been paid to the circumstances (C) that are associated with the luminous input (L) to produce the output in both indoor and outdoor lighting situations (O) [37–40]. Thus, the path towards this new approach requires a deeper knowledge of the particular circumstances of the street users and their associations with the visual stimuli. It is necessary to give lighting a truly sustainable and human-oriented perspective [41,42].

One major target of this work is the consideration of the BPL as a central element in the design of human-centered lighting installations and, departing from this perspective, the identification of all the factors within public lighting that influence the safety, security and well-being of street users, especially pedestrians.

3.2. Factors Impacting People under Public Lighting: Identification and Classification

Once the BPL has been defined, its five stages can lead to an outline of the general scheme of factors influencing the visual tasks carried out by people in developing their activities under public lighting, as well as their effect on the performance of these activities, as shown in Figure 2.

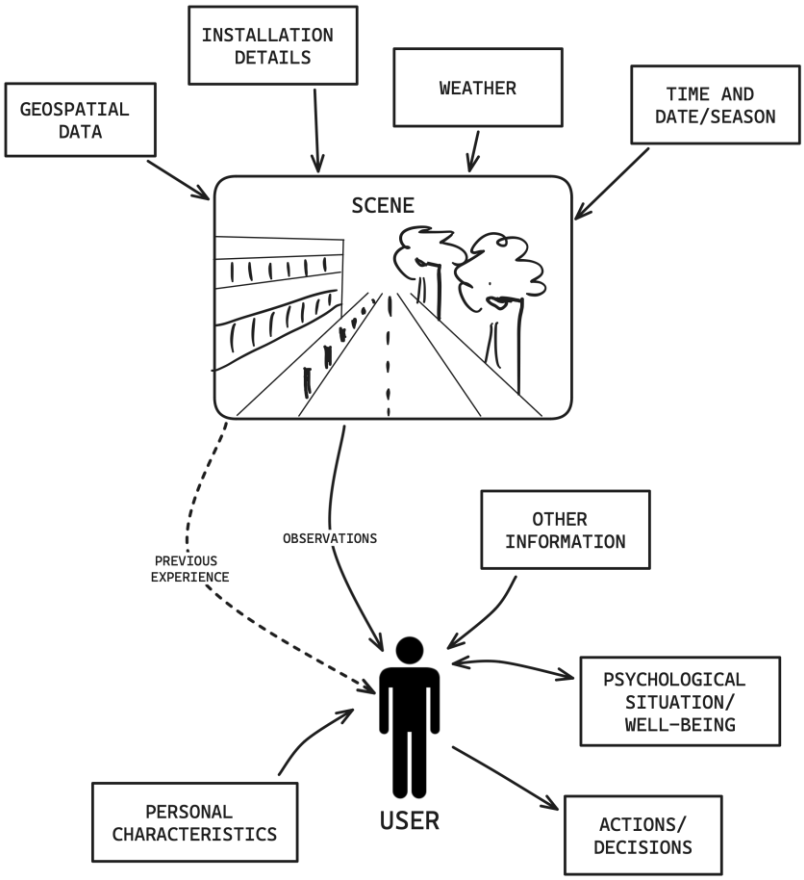

Figure 2. General scheme of the influence of street lighting on users' well-being and actions.

The central section of the figure features a scene with lighting operating in a particular mode, under specific weather conditions and at a given time and date. This scene can be considered as everything the user can observe and/or has observed in the past and uses as previous experience. The scene may, therefore, be seen as the sum of the road characteristics (e.g., width, lane structure, pavements) and the context of the road, such as the existence of buildings, greens and the character of the area (residential, industrial, commercial, etc.). The physical elements can be easily assessed by human designers on single streets and in very small areas, but some difficulties arise when moving to a larger scale. The data usually exist in GIS (Geographic Information System) datasets. Although currently existing spatial data analysis tools can be used to integrate separate GIS datasets, the process can be time-consuming and error-prone. However, graph-based methods, such as STGT (Spatially Triggered Graph Transformations), can be used to visualize the detected spatial relationships between objects, and have been successfully used to improve the energy efficiency of lighting [43].

In addition to the observable scene, other factors may influence the user's perception of lighting. Specifically, they may possess other information, either certain (e.g., statistics) or uncertain (e.g., opinions), such as knowledge of previous incidents in each area or the region's reputation, which may affect their well-being or actions.

Finally, there are personal factors, such as age, gender, health or attitude, which also contribute to the perception of lighting [44].

In relation to the Basic Process of Lighting, as described in this work, four categories can be identified and used to label the factors being investigated:

1. Light emission and propagation towards the visual working plane (A).
2. The flux that is received and processed by the surface. The reflective and colorimetric properties of the surface where the illuminance is received process the luminous flux by absorbing and reflecting some or all wavelengths and reflecting them in one spatial pattern. The luminance towards the eye of each individual will determine his perception (B).
3. Visual perception with physiological and neural processing of the luminous input received (C).
4. Psychological processing and output, resulting from the perceived scene (D).

It is important to remark that this labelling is not a reiteration of the five steps forming the BPL that have already been introduced. It rearranges them into a more convenient form allowing to be handled when trying to identify the factors. For example, from a technical point of view, it was convenient to separate the factor of the amount of luminous flux reaching the pavement (item Nr. 2 in the BPL) from the flux processing carried out by the pavement (item Nr. 3 in BPL) because the illuminance on the ground is a parameter of the highest importance in the design process. However, beyond the BPL, they can be merged when one is just trying to decide whether people give importance to the nature of the pavement.

Table 1 presents the identified factors according to the proposed labelling: A and B concern light and the street; C takes account of the physiological aspects; and D is a psychological category. As seen, due to the complex nature of the visual process in urban environments, there is an overlap between the defined categories in each factor.

Table 1. Factors and their assignment to aspects.

Factor	Category
Criminality (Real)	D
Cultural background	C, D
Personal distractions (music, messaging)	C, D
Fame of area	C, D
Hour	C, D
Morphology of zone	A, B, D
Nature and status of pavement	B
Noise	C
Other obstacles	A, B, D
Parked cars	A, B, D
Presence of people	A, B, C, D
Recent incidents	C, D
Shadows	A, B, C, D
Socioeconomic level area	D
Spectral Power Distribution	A, B, C
Traffic	A, B, C, D
Trees	A, B, D
Weather	A, B, C, D

3.3. Scoring of Factors according to People Perception and Feelings

Once the survey was completed, the collected data were analyzed with the primary aim of detecting patterns that could be studied in subsequent research. They are shown in Tables 2 and 3.

Table 2 presents the statistical parameters corresponding to the answers about each factor when: (1) considering the questions in the sections related to safety and security together with those related to wellbeing (columns 1 and 2); (2) those related to safety and security alone (columns 3 and 4); and those related to (3) wellbeing alone (columns 5 and 6). The following parameters were obtained:

Table 2. Distribution of answers: total (T), safety/security (S), well-being (W).

Factor	$\bar{x}_T$	σ_T	$\bar{x}_S$	σ_S	$\bar{x}_W$	σ_W
Criminality rate of neighborhood	4.45	0.76	4.53	0.77	4.37	0.87
Hour of the day	4.18	0.82	4.50	0.81	3.87	1.15
Recent incidents	4.13	0.90	4.26	0.95	3.99	1.09
Reputation of neighborhood	4.11	0.82	4.23	0.87	3.99	0.93
Socioeconomic level of neighborhood	3.98	0.85	4.22	0.89	3.75	1.08
Other people	3.89	0.82	4.02	0.93	3.75	0.93
Morphology of the street	3.78	0.82	3.94	0.89	3.62	1.00
Pavement materials and state	3.71	0.97	3.74	1.07	3.68	1.09
Color of light	3.68	0.91	3.59	1.07	3.77	0.99
Noise	3.63	0.81	3.49	0.93	3.77	1.10
Cultural background of neighborhood	3.59	0.94	3.61	1.05	3.56	1.05
Traffic	3.56	0.92	3.82	1.04	3.31	1.23
Trees	3.49	0.87	3.18	1.09	3.80	1.09
Weather	3.44	0.83	3.26	1.01	3.61	1.04
Own age	3.44	1.02	3.49	1.10	3.39	1.19
Personal distractions	3.41	1.04	3.48	1.16	3.35	1.12
Shadows	3.31	0.98	3.44	1.12	3.18	1.15
Parked cars	3.06	0.85	3.17	0.96	2.95	1.06
Obstacles	3.05	1.07	3.04	1.15	3.07	1.23

A detailed analysis of Table 2 reveals several remarkable facts:

1. The surveyed people are mainly concerned with criminality and threats from people.
2. The six top factors have an exclusively social, sociological or economic nature, making up 31.6 per cent of the total. Fear of threats from other people is not an isolated high-ranked item, but a clear fact that arises from all of the perspectives and the modality of the questions.
3. Only one factor of this nature (cultural background of the neighborhood) is surpassed by other factors of more technical or urban nature.
4. The relevance of technical factors directly related to sight and visual performance is, by far, much lower than the relevance of social factors. This seems to be a clear indication of the initial hypothesis of this work: regulations on lighting should consider people's feelings, even if it is not easy.

Once the prevalence of these factors had been identified, the target was to eliminate factors that, according to this survey, do not seem to be essential. For this reason, a simple filter was defined. It consisted of considering the fact that respondents who wanted to express "do not know" often selected three as their answer.

Therefore, we decided to transform the values using the following formula:

$$a_N = \max(0,\ a_R - 2)$$

where:

- a_N is the normalized answer;
- a_R is the raw answer.

In this way, the value emphasizes answers where the respondent actually found the given factor significant. As a result, the normalized answers are in the range 0–2.

The values of the normalized results are presented in Table 3.

As seen, the presence of parked cars, one factor that has clear visual impact due to the shadows on the pavement caused in some configurations (especially on narrow sidewalks), is perceived to be four times less relevant than the criminality rate of the neighborhood or the hour of the day. Even the explicit item "presence of shadows", directly related to a mandatory parameter in regulations around the world (average uniformity), is far away from the social and socioeconomic factors.

An explanation for these results is the high plasticity of the human visual system and hence, our capability to adapt to a wide range of luminance. This range goes from less than one tenth to one hundred candelas per square meter. In other words, since people easily adapt (or think that they have adapted) to different visual conditions, they do not seem to give a high importance to them.

Table 3. Normalized answers ordered by factor of significance.

Factor	Total	Safety and Security	Well-Being
Criminality rate of neighborhood	1.47	1.56	1.41
Hour of the day	1.23	1.54	1.05
Recent incidents	1.20	1.35	1.14
Reputation of neighborhood	1.16	1.27	1.08
Socioeconomic level of neighborhood	1.04	1.27	0.92
Other people	0.97	1.11	0.86
Pavement materials and state	0.88	0.92	0.88
Morphology of the street	0.86	1.02	0.79
Color of light	0.80	0.79	0.89
Cultural background of neighborhood	0.74	0.80	0.77
Noise	0.73	0.64	0.95
Traffic	0.72	0.95	0.67
Own age	0.67	0.73	0.68
Personal distractions	0.65	0.75	0.62
Trees	0.64	0.50	0.95
Weather	0.58	0.53	0.79
Shadows	0.56	0.68	0.53
Obstacles	0.46	0.45	0.53
Parked cars	0.35	0.43	0.35

As discussed, the results above show a stronger influence of socioeconomic and cultural factors, even above that of the other technical items directly related to the design of the lighting installation.

It is necessary to remark upon the fact that some of the items in this survey have been the focus of other research on lighting, but they have always been isolated; that is, they have not been part ff such a wide set of factors. This is the case for the color of the light, which was the focus of another survey [3], but only in combination with strictly technical parameters like the illuminance levels.

According to the current state-of-the-art, the problem of an taking integral approach towards the design of urban lighting systems has only been partially addressed. From a technical point of view, some contributions have been related to the internet of things and telecommunications [45], specifically oriented to SDGs [46], or have been civil engineering focused [47], centered around power savings [48], or specifically oriented towards better maintenance protocols [49]. Transversal approaches have been studied in the past [50], although they are outdated and specifically addressed the tourism economy.

However, there have been no formal proposals summarizing and explaining, in detail, the process of lighting from a truly human-centered perspective, including, as a basic step, the function of human processing of the surrounding circumstances and the consequent output. This research aimed to lay the foundations for a new, integral, human-oriented design process for urban lighting.

4. Conclusions

Departing from the current perspectives of existing regulations, design standards and policies for public lighting in urban environments, this works had the following targets:

1. Defining the Basic Process of Lighting (BPL) as a chain of core stages going from the physical installation to the human output.

2. Taking the classic BPL as a departing point and extending it to a human-centered perspective that can become a reference and guide for the design of lighting installations where the global dimensions of people and sustainable development really matter.
3. Identifying all of the aspects that participate in the BPL with a survey, and finding their real weights in the perceived safety, security and well-being of the people developing their activities under the public lighting to suggest that the authorities implement these factors in future standards.

After achieving these milestones, a deep analysis of the results allowed us to come to the following conclusions:

1. The BPL is the central element in public lighting. It has been extended to a human-centered perspective, which allowed us to identify several questions that could be answered by street users.
2. The number and variety of factors determining the feelings of safety and security and the well-being of the users of public lighting is much wider and more complex than considered in the design of cities and neighborhoods to date.
3. According to the results obtained from the 133 survey participants, the fear of crime and potential offenses from other people, are, by far, the main concerns of people walking on the street at night. This feeling of safety is strongly attached to well-being; that is, feeling good, optimistic, and free of worries when walking along the street at night.
4. Some factors objectively impacting the work of public lighting and hence, the visual perception of people, are perceived as less important. These are the presence of parked cars, obstacles, shadows, the weather and trees, which occupy the last positions almost exclusively. This result is surprising because of the lack of uniformity and visibility introduced by parked cars, trees and even the explicit presence of shadows impairing vision, but the respondents did not seem to worry very much about these factors.
5. The high capacity of the human visual system to adapt to a very wide range of luminance can explain why the visual factors are below the social and socioeconomic ones in this survey. The results show that people are not very concerned about how they see when compared to conflict with other people.
6. The conclusions above highlight the deep gap between objective visual circumstances and people's preferences. It can be due to cultural or ideological background, personal experiences or other factors. No doubt, it is necessary to carry out more research in this field.
7. In summary, the disagreement between the expectations from engineering and behavioral perspectives must lead designers, researchers, rulemaking bodies and public administrations to answer the one question of the highest importance: when defining installations of public lighting, must we consider just the classical parameters or take into account people's preferences and intimate feelings of safety, security and well-being? According to the results obtained in this work, it seems clear that the correct choice is the second one.

There are two main limitations of this study. They are summarized together with the corrective actions that may be the focus of future research.

1. Potential biases due to national and cultural peculiarities of the surveyed people. This potential limitation will be checked and corrected if applicable, by distributing the translated version of the survey among people in other countries. Future research will focus on a multinational survey and the analysis of the data.
2. Distractions or a lack of defined opinions among respondents while filling out the survey. Other strategies like professional survey takers asking people face to face and alleviating any doubts that might arise should be used in future research to collect subjective comments and other impressions from the people.

Departing from the limitations and corrective actions above, and once the factors have been strongly established and the national features analyzed, future research should

also approach ways to decide and propose how to introduce the new human-centered framework of lighting into the technical regulations. This task could be matter of ad hoc working groups in which public administration bodies, designers and researchers participate. Future works will incorporate proposals in this direction.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16104028/s1.

Author Contributions: Conceptualization, A.P.-G., A.C.-M. and S.E.; methodology, A.P.-G.; software, A.C.-M. and S.E.; validation, A.P.-G., A.C.-M. and S.E.; formal analysis, A.P.-G.; investigation, A.P.-G. and A.C.-M.; data curation, A.C.-M. and S.E.; writing—original draft preparation, A.P.-G., A.C.-M. and S.E.; writing—review and editing, A.P.-G., A.C.-M. and S.E.; visualization, S.E.; supervision, A.P.-G.; funding acquisition, S.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded in part by AGH University of Science and Technology, grant number IDUB D2/5157.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Survey data are available by request made to the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Painter, K. The impact of street lighting on crime, fear, and pedestrian street use. *Secur. J.* **1994**, *5*, 116–124.
2. Boyce, P.R.; Eklund, N.H.; Hamilton, B.J.; Bruno, L.D. Perceptions of safety at night in different lighting conditions. *Light. Res. Technol.* **2000**, *32*, 79–91. [CrossRef]
3. Chalfin, A.; Hansen, B.; Lerner, J.; Parker, L. Reducing Crime Through Environmental Design: Evidence from a Randomized Experiment of Street Lighting in New York City. *J. Quant. Criminol.* **2022**, *38*, 127–157. [CrossRef]
4. Svechkina, A.; Trop, T.; Portnov, B.A. How Much Lighting is Required to Feel Safe When Walking Through the Streets at Night? *Sustainability* **2020**, *12*, 3133. [CrossRef]
5. Portnov, B.A.; Saad, R.; Trop, T.; Kliger, D.; Svechkina, A. Linking nighttime outdoor lighting attributes to pedestrians' feeling of safety: An interactive survey approach. *PLoS ONE* **2020**, *15*, e0242172. [CrossRef] [PubMed]
6. *CEN/TR 13201-1*; Road Lighting—Part 1: Guidelines on Selection of Lighting Classes. European Committee for Standarization: Brussels, Belgium, 2014.
7. Van Bommel, W.J.M.; Tekelenburg, J. Visibility research for road lighting based on a dynamic situation. *Light. Res. Technol.* **1986**, *18*, 37–39. [CrossRef]
8. Ödemis, K.; Yener, C.; Olguntürk, N. Effects of Different Lighting Types on Visual Performance. *Archit. Sci. Rev.* **2004**, *47*, 295–301. [CrossRef]
9. Rea, M.S.; Bullough, J.D.; Zhou, Y. A method for assessing the visibility benefits of roadway lighting. *Light. Res. Technol.* **2010**, *42*, 215–241. [CrossRef]
10. Bremond, R. Visual performance models in road lighting: A historical perspective. *Leukos* **2020**, *17*, 212–242. [CrossRef]
11. Boyce, P. Light, lighting and human health. *Light. Res. Technol.* **2022**, *54*, 101–144. [CrossRef]
12. Figueiro, M. Nonvisual Lighting Effects and Their Impact on Health and Well-Being. In *Encyclopedia of Color Science and Technology*; Springer: Cham, Switzerland, 2023; pp. 1236–1246. [CrossRef]
13. Lucas, R.J.; Peirson, S.N.; Berson, D.M.; Brown, T.M.; Cooper, H.M.; Czeisler, C.A.; Figueiro, M.G.; Gamlin, P.D.; Lockley, S.W.; O'Hagan, J.B.; et al. Measuring and using light in the melanopsin age. *Trends Neurosci.* **2013**, *37*, 1–9. [CrossRef]
14. Figueiro, M.G.; Nagare, R.; Price, L. Non-visual effects of light: How to use light to promote circadian entrainment and elicit alertness. *Light. Res. Technol.* **2018**, *50*, 38–62. [CrossRef]
15. Sahin, L.; Figueiro, M. A 24-hour lighting scheme to promote alertness and circadian entrainment in railroad dispatchers on rotating shifts: A field study. *Light. Res. Technol.* **2021**, *54*, 441–457. [CrossRef]
16. Ohashi, M.; Eto, T.; Takasu, T.; Motomura, Y.; Higuchi, S. Relationship between Circadian Phase Delay without Morning Light and Phase Advance by Bright Light Exposure the Following Morning. *Clocks Sleep* **2023**, *5*, 615–626. [CrossRef]
17. Haifler, Y.T.; Fisher-Gewirtzman, D. Spatial Parameters Determining Urban Wellbeing: A Behavioral Experiment. *Buildings* **2024**, *14*, 211. [CrossRef]
18. Nakamura, T.; Yoshioka, Y. Effectiveness of Bollards in Deterring Pedestrians from Running into the Roadway. *Hum. Factors Transp.* **2022**, *60*, 133–140. [CrossRef]

19. Iravani, S.N.; Sohrabi, S.A.; Gheitarani, N.; Dehghan, S. Providing a Pattern and Planning Method for Footpaths and Sidewalks to Protect Deteriorated and Vulnerable Urban Contexts. *Eur. Online J. Nat. Soc. Sci.* **2024**, *13*, 1–20.
20. Castillo-Martínez, A.; Peña-García, A. Influence of Groves on Daylight Conditions and Visual Performance of Users of Urban Civil Infrastructures. *Sustainability* **2021**, *13*, 12732. [CrossRef]
21. Mouratidis, K. The impact of urban tree cover on perceived safety. *Urban For. Urban Green.* **2019**, *44*, 126434. [CrossRef]
22. Berdejo-Espinola, V.; Zahnow, R.; Fuller, R. Physical and social disorder, but not tree cover, contribute to lower perceptions of safety in urban green spaces. *Research Square* **2024**. [CrossRef]
23. Alkhulaifi, A.; Jamal, A.; Ahmad, I. Predicting Traffic Sign Retro-Reflectivity Degradation Using Deep Neural Networks. *Appl. Sci.* **2021**, *11*, 11595. [CrossRef]
24. Jamal, A.; Reza, I.; Shafiullah, M. Modeling retroreflectivity degradation of traffic signs using artificial neural networks. *IATSS Res.* **2022**, *46*, 499–514. [CrossRef]
25. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
26. Peña-García, A.; Salata, F. Indoor Lighting Customization Based on Effective Reflectance Coefficients: A Methodology to Optimize Visual Performance and Decrease Consumption in Educative Workplaces. *Sustainability* **2021**, *13*, 119. [CrossRef]
27. Peña-García, A. Sustainability as the Key Framework of a Total Lighting. *Sustainability* **2018**, *10*, 4412. [CrossRef]
28. Peña-García, A. Towards Total Lighting: Expanding the frontiers of Sustainable Development. *Sustainability* **2019**, *11*, 6943. [CrossRef]
29. Peña-García, A.; Salata, F. The perspective of Total Lighting as a key factor to increase the Sustainability of strategic activities. *Sustainability* **2020**, *12*, 2751. [CrossRef]
30. Pierre, D. Long Live the Likert Scale: Designing survey questions. In Proceedings of the CACUSS 2023: Honour, Engage, Evolve, Niagara Falls, ON, Canada, 4–7 June 2023. [CrossRef]
31. Arduini, A.; Pinneo, L.R. Properties of the retina in response to steady illumination. *Arch. Ital. Biol.* **1962**, *100*, 425–448. [PubMed]
32. Pinneo, L.R.; Heath, R.G. Human visual system activity and perception of intermittent light stimuli. *J. Neurol. Sci.* **1967**, *5*, 303–314. [CrossRef] [PubMed]
33. Posner, M.I.; Snyder, C.R.R.; Davidson, B.J. Attention and the detection of signals. *J. Exp. Psychol. Gen.* **1980**, *109*, 160–174. [CrossRef]
34. Gale, A.G. Human Response to Visual Stimuli. In *The Perception of Visual Information*; Hendee, W.R., Wells, P.N.T., Eds.; Springer: New York, NY, USA, 1997. [CrossRef]
35. Zhang, F.; Ridder, H.; Pont, S. The influence of lighting on visual perception of material qualities. In Proceedings of the SPIE—The International Society for Optical Engineering, San Francisco, CA, USA, 17 March 2015; Volume 9394. [CrossRef]
36. Lasauskaite, R.; Cajochen, C. Influence of lighting color temperature on effort-related cardiac response. *Biol. Psychol.* **2018**, *132*, 64–70. [CrossRef]
37. Castilla, N.; Blanca-Giménez, V.; Pérez-Carramiñana, C.; Llinares, C. The Influence of the Public Lighting Environment on Local Residents' Subjective Assessment. *Appl. Sci.* **2024**, *14*, 1234. [CrossRef]
38. Siraji, M.A.; Lazar, R.R.; van Duijnhoven, J.; Schlangen, L.J.; Haque, S.; Kalavally, V.; Vetter, C.; Glickman, G.L.; Smolders, K.C.; Spitschan, M. An inventory of human light exposure behaviour. *Sci. Rep.* **2023**, *13*, 22151. [CrossRef] [PubMed]
39. Ren, M. Impulsive Buying Behaviour Factors Generalisation and How to Improve. *Lect. Notes Educ. Psychol. Public Media* **2024**, *39*, 58–64. [CrossRef]
40. Jedon, R.; Haans, A.; de Kort, Y. Pedestrians' Alertness and Perceived Environmental Safety Under Non-Uniform Urban Lighting. *Glob. Environ. Psychol.* **2024**, *in press*.
41. Jägerbrand, A.K. New framework of sustainable indicators for outdoor LED (light emitting diodes) lighting and SSL (solid state lighting). *Sustainability* **2015**, *7*, 1028–1063. [CrossRef]
42. Jägerbrand, A.K. Synergies and Trade-Offs Between Sustainable Development and Energy Performance of Exterior Lighting. *Energies* **2020**, *13*, 2245. [CrossRef]
43. Ernst, S.; Kotulski, L.; Sędziwy, A.; Wojnicki, I. Graph-Based Computational Methods for Efficient Management and Energy Conservation in Smart Cities. *Energies* **2023**, *16*, 3252. [CrossRef]
44. Wu, Y.; Liu, Q.; Hang, T.; Yang, Y.; Wang, Y.; Cao, L. Integrating restorative perception into urban street planning: A framework using street view images, deep learning, and space syntax. *Cities* **2024**, *147*, 104791. [CrossRef]
45. Sathesh Raaj, R.; Vijayprasath, S.; Ashokkumar, S.R.; Anupallavi, S.; Vijayarajan, S.M. Energy Management System of Luminosity Controlled Smart City Using IoT. *EAI Endorsed Trans. Energy Web* **2024**, *11*. [CrossRef]
46. Zielinska-Dabkowska, K.M.; Bobkowska, K. Rethinking Sustainable Cities at Night: Paradigm Shifts in Urban Design and City Lighting. *Sustainability* **2022**, *14*, 6062. [CrossRef]
47. Alnejem, M.; Rehan, G.; Taghipour, M.; Alhabsi, F. Urban Street Principles as an Effective Strategy for Improving Environmental Sustainability. In Proceedings of the Oman Conference for Environmental Sustainability, Muscat, Oman, 26–28 February 2024.
48. Shavkatov, S. Adaptive Illumination: Designing a Smart Street Lighting System for Sustainable Urban Environments. *MATRIX Acad. Int. Online J. Eng. Technol.* **2023**, *6*, 18–32. [CrossRef]

49. Deodati, A.; Petrachi, E.; Vendramin, G.; Cosma, L.; Bene, P. Urban Lighting: An Innovative Solution, Eco-Sustainable and Resistant to Corrosion. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1099*, 012016. [CrossRef]
50. Ji, W.; Wen, Y.; Chen, Z.-L. Sustainable Development of Urban Lighting Systems. *J. Cent. South Univ. Technol.* **2006**, *13*, 17–20.