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The Influence of the Public Lighting Environment on Local Residents' Subjective Assessment

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Abstract: Sustainable development and energy savings are crucial to the significant worldwide trend in smart city-related research and projects. In this regard, public lighting systems have great energy-saving potential. Nevertheless, while citizen engagement is a key element of most conceptualisations of smart cities, many smart lighting projects and systems fail to take account of the citizen's viewpoint. Applying a citizen-centric lighting design model, the objective of this study is to examine the affective impressions of local residents of the luminous environments in their areas, taking account of the activities they carry out there. Kansei Engineering is employed to connect luminous design elements with citizens' affective responses. Lighting environments in 18 urban spaces were evaluated by 310 local residents. The results show that subjective assessments in the evaluation of urban lighting environments can be explained by the following dimensions: *Expressive-interesting*, *Innovative-efficient*, *Defined-sufficient*, *Formal-uniform* and *Glaring*. The relationship of these dimensions to urban social activities shows that public lighting should generate, in local residents, sensations consistent with the nature of the activities. Urban lighting must create in the citizen a feeling of innovation (being up-to-date and contemporary) if it is to be seen as energy-saving and caring for the environment. These findings may be valuable for governments, architects, engineers, and lighting designers when developing strategies to ensure their designs are evaluated as being efficient, sustainable, and environmentally friendly.

Keywords: lighting; subjective response; urban design; Kansei engineering; residents; public lighting environment

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1. Introduction

The world's population is continually growing [1]. Cities across the globe are being confronted with a rapid increase in population; thus, energy management has become a fundamental sustainable development demand [2]. In fact, in recent years, energy saving has attracted global interest due to the rapid exhaustion of energy resources [3], rising energy prices [4,5], increasing energy consumption [6], environmental concerns [7], and environmental concerns. Thus, energy saving is one of the crucial factors in the achievement of sustainability in cities and societies [8], and new efficient technologies for generating and distributing energy need to be developed and integrated [9]. Unsurprisingly, the improvement of energy efficiency is an essential part of the development of smart city research and projects [10,11].

Transforming cities into smart cities is a fundamental solution to improve the efficiency, sustainability, and living conditions of their inhabitants. Nevertheless, in building smart cities, the focus is often put solely on innovative technological aspects [9]. This may lead to issues when implementing the smart city concept [12]. One of these problems is that citizens can feel discontented [13]. Therefore, the current concept of "smart city" begins to take into account the preferences and needs of those living in the city [14]. Winkowska et al. [15] argued that the future of smart cities lies in developing a planning methodology in which citizens are both co-creators and users. In this concept, inhabitants are the focus, and technical solutions must be developed to serve their interests. This approach is essential to ensuring that citizens engage in the design and development of smart cities [16]. It has been argued that the key to developing sustainable cities and societies is to understand people-environment-infrastructure relationships [17]. Hence, there is an urgent requirement to develop new ways of planning, developing, and constructing infrastructure that interacts with people and the environment [18].

Energy efficiency measurements are fundamental to the smart city model [19]. Public lighting systems have attracted significant attention because lighting networks are an important part of energy consumption in smart cities [20]. The International Energy Agency (IEA) has established that public space lighting has great energy-saving potential, given that it consumes 2.3% of global electricity [21]. Public lighting systems offer significant technological advancements to reduce energy consumption and operating costs. These advancements include the use of energy-efficient lighting systems such as LED (Light-Emitting Diode) technology [22], advanced luminaire designs with durable materials [23], and solar-powered lighting [24]. Compared to traditional lighting products, these developments can reduce electricity consumption by over 50% [4,25]. Additionally, smart lighting systems for remote monitoring and control enable real-time adjustment of brightness levels, scheduling, power factor correction, and fault detection, thereby reducing unnecessary energy consumption and improving efficiency [26]. Public lighting systems also offer an opportunity to integrate data analytics [27], IoT (Internet of Things) [28], and interconnected lighting systems [29], leading to proactive maintenance, minimal downtime, and reduced overall maintenance costs [30]. As a result, public lighting systems can contribute to building a more integrated and efficient urban environment [31].

Reducing public lighting costs can offer a range of benefits for a community. In the first place, by incorporating smart lighting solutions, communities can reduce expenses while enhancing the functionality and adaptability of their lighting infrastructure [32], allowing local governments to use the saved funds for other vital services and, ultimately, improving the financial stability of the community [30]. In addition, this reduction in public lighting costs promotes ecological sustainability and contributes towards a cleaner, more sustainable environment [14]. Finally, lowering public lighting costs signifies a commitment to responsible resource management and can contribute to the community's overall well-being [33]. This explains the growing interest of policymakers, urban planners, and industry leaders in energy efficiency and in how to use green energy in public lighting systems [34]. In response to this interest, a large number of researchers have analysed lighting systems in order to assist governments in the search for optimal public lighting solutions that can contribute to urban lighting design, energy conservation, and sustainable development and help create opportunities for innovation [35–37]. Nevertheless, the public lighting environment (PLE) is about more than energy efficiency and consumption reduction. PLEs are a crucial design factor in urban areas [38].

Lighting is often described as encompassing art and science [39]. Light at night affects human life [40], health [41,42] and work [43]. Light influences the way humans see and feel [44], and when designing lighting systems, it is necessary to reconcile physical, physiological, and psychological requirements [45]. These effects/issues must be taken into account when designing the PLE of urban spaces. Appropriate PLE enhances visibility [46], comfort [47], safety [33], and crime prevention [48], and instills a sense of security among citizens [49]. PLE is a multifaceted tool that can also enhance the quality of urban life during the night. This part is essential for urban nightlife, where individuals congregate in public spaces, parks, and entertainment districts. In this sense, PLE also has a crucial aesthetic component [50]. The aesthetic aspect of lighting has a key role to play in improving the overall ambience and the visual attractiveness of an urban area [51]. PLE can contribute to the creation of an exciting and attractive night-time environment. Light makes it possible to create spaces through which observers can view the city, which allow them to develop personal feelings based on the experience [52]. If the lighting design of an urban space meets the expectations and needs of citizens, illumination can become a source of inspiration, admiration, and emotion [53] by providing experiential information [54]. Thoughtful planning, energy-efficient technologies, and consideration for aesthetics and inclusivity play a fundamental role in creating a positive and sustainable urban environment for nightlife.

PLE has undoubtedly improved the quality of life in urban areas, but the downside of increased urbanisation and industrialization is the alarming rise of light pollution. This phenomenon occurs when artificial light is excessively used, leading to obtrusive light that interferes with the natural darkness of the night sky [55]. Unfortunately, over 50% of the world's population is affected by light pollution [56], with urban areas being the most affected due to the overuse of artificial lighting. Light pollution has become a significant environmental issue, affecting astronomical observations [57] and the well-being of ecosystems [58], wildlife [59], and human health [60]. The potential health impacts of light pollution have widened [61], with concerns ranging from sleep disorders [62] to severe illnesses such as obesity [63], mental disorders [64], and cancers [65]. Given the considerable concern about the impact of PLEs on human health and activities [57] and the influence of energy expenditure on sustainable urban development, quantifying the impact of PLEs on public perceptions has become crucial [36]. Thus, the connection between PLE and citizens' perceptions has become a centre of interest [33,66,67]. In order to establish the interconnections between PLE and citizens' perceptions, research have usually employed a combination of data obtained in evaluations made by citizens and in surveys. In these studies, evidence has been collected about the relationship between public evaluations and the physical measurements of lighting attributes, such as brightness [33,67–72], uniformity of spectral power distribution, colour temperature [73], and glare [74,75].

Moreover, when designing PLE, it is essential to contemplate the influence of individual characteristics and the personality dimension of having confidence in one's physical environment [76]. The utilisation of urban spaces at night varies significantly among different segments of society, which are distinguished by various parameters, such as cultural background [51], age [77], gender [78], and mobility/disability [76]. An additional challenge is the identification of users' impressions about lighting. Most of the studies that have analysed the responses of citizens to PLEs have been in the fields of psychology and engineering [79,80]. The experts who carried out these studies used questionnaires, tests, and/or rating scales, which did not take into account the parameters of luminous design that address the needs of local inhabitants. In these studies, the lighting evaluation attributes were determined in advance by researchers/experts, and the participants were mostly non-experts in lighting. This procedure has a significant limitation: the mental schemes of the non-experts/users are not considered in the questionnaires. Boyce and Cuttle [81] found that participants employed terms mainly related to brightness and clarity to describe the lighting in rooms, and concepts such as pleasantness and colourfulness were mentioned only rarely. The concepts defined by lighting experts may not be fully understood by non-experts, such as local residents, in the case of PLE. Participants' uncertainty about the meaning of concepts may cause incorrect results or an increase in the variance of responses [82]. Furthermore, non-experts may never have the opportunity to rate certain attributes that they value highly because experts filter the rating information.

In addressing this issue, Kansei Engineering (KE), also known as Affective Engineering [83], a technique capable of translating users' feelings into concrete design elements, can be very effective. Its main advantage over other preference analysis techniques (QFD, Conjoint Analysis, etc.) is that KE provides a framework for operating with users' symbolic attributes and perceptions communicated in their own words. The KE methodology develops questionnaires based on concepts understood by users, not those understood solely by experts. In order to define these concepts, KE uses the Semantic Differential (SD), which was elaborated by Osgood et al. [84]. This technique involves selecting attributes or adjectives and establishing relationships between those attributes and design parameters. SD analyses the correlation matrices of scores assigned to different terms across a given set of products. By demonstrating that only a small number of dimensions or factors are enough to distinguish between the meanings of the whole set of concepts, these dimensions form a semantic basis for describing any product. This semantic basis is called a semantic space, and each concept is represented as a semantic axis. SD is a reliable and valid quantitative research method used to assess the affective connotations associated with concepts [85]. In KE research, SD is widely used to evaluate product perception [86–90]. KE operates on the premise that people's evaluations are influenced by stimuli, which consist of both objective and subjective parameters, as well as the conceptual schema of particular user groups (semantic space). This need has been evidenced in many areas of product design, where it has been shown that concepts can be perceived differently by different groups. These perceptions vary depending on the way of life, cultural background, and personal needs of the participants. This conceptual scheme features a collection of independent concepts (semantic axis or affective impressions) used by the users in describing their impressions of a product.

KE has many applications, especially in product development [89,91–93], including in the assessment of lighting equipment and uses [94–96]. In the field of environmental evaluation [97], it has been used to examine acoustic and sound perception [98], thermal [99], and classroom environments [100]. Nonetheless, to the best of the authors' knowledge, while KE has been applied in many contexts, it has not been applied to PLE to measure residents' responses. In this sense, it should be noted that Calvillo Cortés and Falcón Morales [51] analysed observers' emotional responses to urban lighting and made subsequent design recommendations.

Some studies on PLE have focused on only one or two variables of light [73,101,102], often within laboratory conditions [103,104], or virtual environments [105]. Nonetheless, when examining the way citizens perceive light in urban settings, conducting on-site experiments can greatly enhance the authenticity, relevance, and applicability of research [70]. Real-life research affords a comprehensive understanding of urban dynamics and citizens' appraisal, encourages stakeholder participation, and generates insights that can directly contribute to positive urban planning and policy implementation changes [106].

Taking these considerations into account, this study aims to analyse the affective responses of the local residents to the luminous environments in their town, considering the activities they perform there. The objective is to establish how the PLE of an urban area can transmit to citizens the feeling that it is sustainable lighting, respects the environment, and saves energy. To achieve this, the KE methodology is used to extract a set of affective impressions and examine their relationship with the activities carried out by the residents in their urban areas.

2. Materials and Methods

A field survey was conducted in L'Alcúdia, Valencia (Spain), a medium-sized town (12,107 inhabitants in 2020). A sample of local residents assessed "in situ" the luminous environments (in the absence of natural lighting) of a set of urban spaces and the appropriateness of the environment to the activities they carry out in those areas. Following the KE technique, the neighbours had to be habitual users of the areas to be analysed. This town was chosen because it had the right population size, and its lighting typologies and urban areas were sufficiently varied and representative.

2.1. Subjects

The participants were 310 local residents. The sample size was determined based on Comrey and Lee [107]. Their average age was 36.74 years, with a standard deviation of 4.71 (Table 1).

Table 1. Subjects' data.

Age					Gender	
20–29	30–39	40–49	50–59	>60	Female	Male
33.2%	24.2%	23.2%	11.3%	2.9%	47.42%	52.58%

2.2. Stimuli

Extracting affective impressions, or semantic axes, requires identifying relationships among a large sample of variables, so a high number of responses are needed. It was therefore necessary for the local residents to provide their opinion on an extensive and varied sample of urban spaces and PLE. This set of features or design attributes may appear to be confounding factors that are not fully under control and can introduce bias into the results. Nevertheless, the solution adopted to reduce bias is to incorporate the set of features or attributes in a completely random manner [108]. Thus, the PLE were selected based on their representativeness and differentiation. A comprehensive catalogue of the areas of the town was compiled to select the ideal test site for the urban PLE. The urban areas of the municipality were grouped by urban typology and lighting type. In the first place, this study site selection process prioritised the inclusion of various urban spaces to ensure representative coverage, such as squares, areas with and without trees, wide and narrow streets, parks, old sections, newly built areas, heritage monuments, landmarks, and roundabouts [109]. Secondly, the PLE was characterised by luminaire and lamp type, colour temperature, chromatic reproduction index, average luminance, and other lighting variables. Using the catalogue as a reference, a thorough search was conducted across the town to identify potential locations. These site inspections were conducted to ensure these test sites were suitable. After careful consideration, the field study occurred in 18 urban spaces (among more than 40 possible). These 18 luminous environments (Figure 1) were chosen based on their ability to meet the selection criteria and exhibit appropriate variability conditions within existing urban spaces and lighting types (Table 2).

This study was conducted over these 18 outdoor locations in June and July to minimise any impact of fluctuating weather conditions on the participants' responses. The questionnaires were completed (from 10 PM to 00 AM) in the total absence of natural lighting to avoid contradictory results (Suplementary Materials). The experimenters also took measures to eliminate any interference from environmental factors such as smog, precipitation, or clouds. Therefore, measurements were only taken on clear and pollution-free nights. This study was suspended during rainfall and when the temperature exceeded a narrow range of 20 ± 3 °C to prevent any possible interference of ambient temperature with the participants' perception [110].

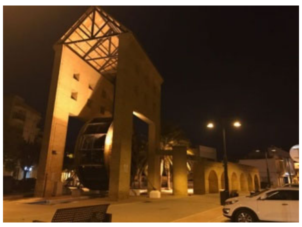
1. "Antonio Almela" avenue	**2.** "Nória" monument	**3.** "Calvari" street
		

Figure 1. *Cont.*

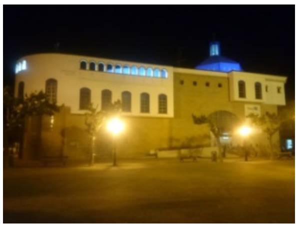
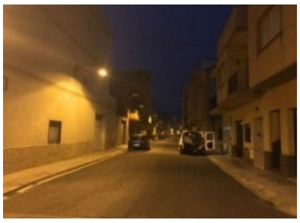
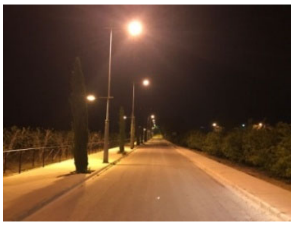
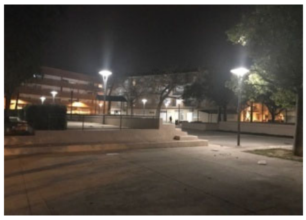
4. House of culture area	**5.** Town hall	**6.** "Les escoles" street
		
7. "Major" street	**8.** "Hernán Cortés" street	**9.** "Istobal" development
		
10. "L'Alcúdia" street	**11.** "País Valencià" square	**12.** "de l'Església" square
		
13. Skate park	**14.** "Frudesa" park	**15.** "Generalitat" park
		
16. "Second Republic" park	**17.** "Diputación" park	**18.** "Serrallo" roundabout
		

Figure 1. Urban lighting environments.

Table 2. Lighting environment characteristics.

Urban Area	Denomination	Localization	Type of Urban Area	Type of Light Sources	Average Illuminance (lx)	Correlated Colour Temperature (K)	CIE XY Colour (X-Y)
1	"Antonio Almela" avenue	39°11′30.4″ N 0°30′26.4″ W	Avenue	Led	47	3412	0.362–0.391
2	"Nória" monument	39°11′30.5″ N 0°30′28.6″ W	Monument/ Landmark	Led	22	3210	0.414–0.405
3	"Calvari" street	39°11′53.1″ N 0°30′25.1″ W	Landmark	High-Pressure Sodium Vapour	31	1740	0.565–0.396
4	House of Culture place	39°11′55.3″ N 0°30′25.0″ W	Place	Led	89	3 960	0.377–0.390
5	Town hall place	39°11′38.9″ N 0°30′25.0″ W	Place	High-Pressure Sodium Vapour	63	1820	0.534–0.417
6	"Les escoles" street	39°11′33.7″ N 0°30′18.4″ W	Pedestrian Street	Led	32	1730	0.552–0.408
7	"Major" street	39°11′46.2″ N 0°30′27.1″ W	Pedestrian Street	Led	39	1950	0.504–0.405
8	"Hernán Cortés" street	39°11′35.3″ N 0°30′05.4″ W	Street	Led	26	3522	0.371–0.384
9	"Ismael Tomás 1 Urb."	39°12′01.2″ N 0°29′54.8″ W	Street	Led	61	3481	0.366–0.401
10	"Matamons" Avenue	39°11′58.7″ N 0°30′35.6″ W	Avenue	Led	59	3507	0.411–0.512
11	"País Valencià" square	39°11′43.2″ N 0°30′25.5″ W	Square	High-Pressure Sodium Vapour	48	3152	0.391–0.421
12	"de l'Esglèsia" square	39°11′44.7″ N 0°30′24.1″ W	Square	Led	151	3040	0.417–0.414
13	"del Patinatge" park	39°11′54.4″ N 0°30′23.6″ W	Park	Metal Halide	35	5900	0.471–0.312
14	"Frudesa" park	9°12′05.2″ N 0°30′16.6″ W	Park	High-Pressure Sodium Vapour	15	2200	0.454–0.404
15	"Generalitat" square	39°12′01.9″ N 0°30′27.5″ W	Square	Led	39	3210	0.411–0.406
16	"Segona República" park	39°11′41.1″ N 0°30′41.2″ W	Park	Led	42	3714	0.412–0.498
17	"Diputació" square	39°11′50.6″ N 0°30′20.9″ W	Square	Led	125	3260	0.408–0.411
18	"Serrallo" roundabout	39°11′56.7″ N 0°30′16.7″ W	Landmark	Led	113	3315	0.402–0.498

2.3. Design and Development of This Study

This study was conducted in actual urban areas, as laboratory conditions cannot fully represent real-life locations (Figure 2). Respondents were requested to answer the questionnaires 'in situ', that is, to assess the PLE while "immersed" in the stimuli. The participants were informed of this study's objectives on an individual basis. There were clear instructions in the questionnaire on how to fill it in appropriately (questionnaire available in Supplementary Materials).

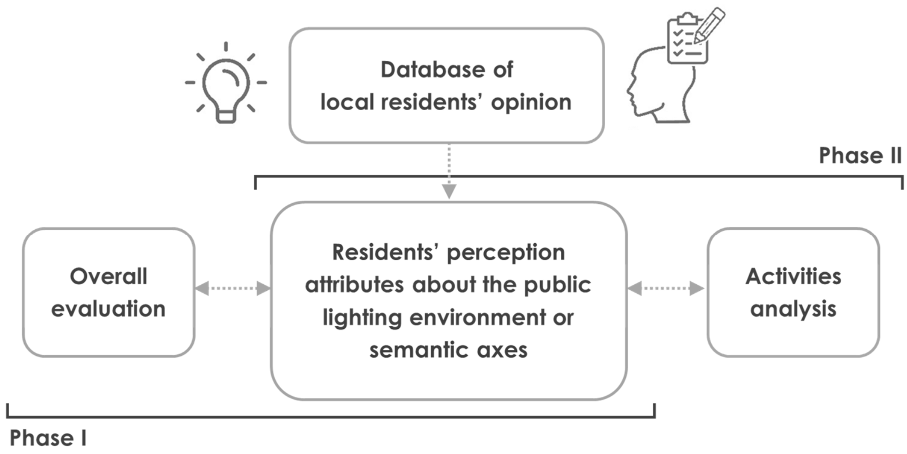


Figure 2. Research process.

The duration of completing the questionnaire ranged from 5 to 15 min. The sequence of questions was randomised, and four distinct versions of the questionnaire were designed to prevent any bias in the subjects' answers.

2.4. Data Processing

The statistical analyses were undertaken using SPSS software (https://www.ibm.com/products/spss-statistics accessed on 28 January 2024). There were two phases to the analysis:

Phase I: In this phase, the study detected the semantic axes or semantic space of participants' overall evaluations of the PLE. In the first place, the acquisition of the semantic space was mainly the result of a reduction technique [111,112]. This technique was a principal component factor analysis, which was used to detect and extract the semantic axes or groups of subjective impressions [113,114]. This factor analysis can identify uncorrelated variables that characterise perceptions of specific products, in this case, the PLE of urban areas. The semantic axes are significantly correlated with residents' responses because they consist of a set of concepts from the original group of terms. As a result, the attributes that are usually integrated into the semantic axes tend to have similar ratings and are grouped together. These axes constitute the common concepts used by residents for the assessment of the PLE of the urban areas in their town. Cronbach's alpha coefficient was employed to evaluate the internal consistency of the dimensions [115]. Thereafter, the effect of each axis on the global assessment of PLE was established using linear regression analysis.

Phase II: In this phase, the study identified the relationships between the semantic axes and the activities carried out in the urban areas. Factor analysis was also employed to recognise the groups of activities carried out in urban areas that were connected based on the PLE assessments. The relationships between these activities and the semantic axes obtained in Phase I were analysed using Spearman's correlation coefficient. Each factor or semantic axis consists of an arrangement of concepts from the original set; therefore, they are significantly correlated with the residents' responses.

3. Results

3.1. Phase I: Definition of Significant Subjective Impressions in the Global Assessment of the Public Lighting Environment

3.1.1. Determination of Semantic Axes or Semantic Space

The set of adjectives was created using factor analysis based on the residents' ratings. The adjectives were made up of groups that showed a significant correlation to the users' responses. The factor analysis reduced the 34 expressions describing the affective impressions of the luminous environment into five uncorrelated axes. These semantic factors correspond to the group of affective assessment scales adjusted to the language used by the local residents to evaluate the PLE. These factors explained 75.13% of the variance of the original variables (Table 3). To identify the adjectives or terms that the respondents associated with the axes, the contribution of the original variables was analysed.

Table 3. The total amount of variance explained.

Component	Initial Eigenvalues		Rotation Sums of Squared Loadings		
	Total	% of Variance	Total	% of Variance	Cumulative %
1	18.26	53.71	11.67	34.28	34.28
2	2.30	6.78	5.02	14.76	49.04
3	2.11	6.21	4.34	1.77	61.81
4	1.77	5.21	2.62	7.70	69.51
5	1.10	3.22	1.91	5.62	75.13

Table 4 shows the semantic axes, correlations with original terms, and percent variance explained. Table 4 presents the following semantic axes, the percentage of explained variance, and their correlations with the original terms:

- 1st axis: represents the *Expressive-interesting* impressions of the PLE of the urban areas. The Kansei words that make the greatest contribution to this axis are as follows: "expressive", "interesting", "colourful", "precious", "necessary", "cool", "clear" and "stimulating". This axis explains 34.28% of the total variance.
- 2nd axis: it can be interpreted as being *Innovative-efficiency*. The terms grouped in this factor reflect the perceptions of the PLE as "original", "reflecting", "magnificent", "joyful", "delicate", "monumental", "perfect" and "natural". It explains 14.76% of the variance.
- 3rd axis: illustrates the perceptions of the PLE as being *Defined-sufficient*. Adjectives such as "defined", "sufficient", "delicate", "safe" and "comfortable" are very significant in this factor and have a negative correlation to the terms "irritating" and "tatty". It explains 12.77% of the total variance.
- 4th axis: represents the *Formal-uniform* assessments of the PLE, featuring terms such as "formal", "uniform" and "functional". It explains 7.70% of the variance.
- 5th axis: defines the impression of the PLE as *Glaring*. The adjectives that contribute to this group are "glaring" and "brilliant". This axis explains 5.62% of the variance.

Table 4. Factor analysis.

	1	**2**	**3**	**4**	**5**
Expressive (evocative, sentimental)	0.830				
Interesting (captivating)	0.824				
Colourful (vivid)	0.808				
Beautiful (rich, quality)	0.801				
Necessary	0.779				
Cool (cute, beautiful)	0.779				
Clear	0.776				
Stimulating (exciting, motivating)	0.775				
Agreeable	0.747		0.460		
Warm	0.736				
Correct	0.709				
Recommended	0.687	0.432			
Healthy (beneficial)	0.679				
Comfortable (convenient)	0.661		0.462		
Perfect (outstanding)	0.653	0.493			
Monumental	0.638	0.500			
Magnificent (exquisite)	0.602	0.582			
Joyful (sympathetic, amusing)	0.591	0.538			
Secure (safe)	0.580		0.468		
Sufficient (appreciable)	0.573		0.510		
Natural (simple, pure)	0.523	0.491			
Innovative (up-to-date, contemporary)		0.837			

Table 4. *Cont.*

	1	2	3	4	5
Reflecting (planned, proportionate)		0.732			
Efficient		0.627		0.472	
Delicate (subtle, fine, soft)	0.459	0.536	0.496		
Bright	0.454	0.468	0.416		
Defined (not diffuse)			0.811		
Irritating (overwhelming, suffocating)			−0.749		
Tatty (poor, dull, improvable)			−0.647		
Formal (serious, conventional)				0.846	
Uniform (constant)				0.767	
Functional				0.643	
Glaring (intense, powerful, annoying)					0.832
Resplendent (brilliant, radiant)					0.727
% Variance explained	34.28	14.76	12.77	7.70	5.62
Cronbach's alpha	0.96	0.89	0.92	0.71	0.67

A Cronbach's alpha analysis was conducted to assess the consistency of the perceptual space. Given that the coefficients for this reliability coefficient for the first five axes were between 0.67 and 0.96, it can be concluded that the scales have adequate reliability [115].

It should be noted that the ranking of the obtained axes is associated with their eigenvalues and, thus, with the quantity of variance explained. An elevated eigenvalue for a factor indicates that residents' responses varied more along that axis than along others. For instance, the residents found significant differences between the PLE of some of the urban areas, that is, the *Expressive-interesting*, *Innovative-efficient*, and *Defined-sufficient*. In addition, the axes are uncorrelated. This implies that, at a conceptual level, residents were aware that they were facing different attributes.

3.1.2. Ranking Semantic Axes based on their Importance in Residents' Global Evaluation of the Public Lighting Environment

Using linear regression analysis, the semantic axes were ranked according to their relationships with the variable of overall evaluation of the PLE of the urban areas. Five significant axes were included in the model (Table 5).

Table 5. Linear regression model of the PLE global evaluation variable.

Model	B	Standard Dev.	β	t	Sig
(Constant)	0.361	0.032		11.368	0.000
EXPRESSIVE-INTERESTING	0.802	0.032	0.669	25.193	0.000
INNOVATIVE-EFFICIENT	0.221	0.032	0.185	6.954	0.000
DEFINED-SUFFICIENT	0.613	0.032	0.511	19.249	0.000
FORMAL-UNIFORM	0.155	0.032	0.131	4.912	0.000
GLARING	0.188	0.032	0.157	5.901	0.000
		R = 0.886			

PLE global evaluation = 0.361 + 0.802 (expressive-interesting) + 0.613 (defined-sufficient) + 0.221 (innovative-efficient) + 0.188 (glaring) + 0.156 (formal-uniform).

The results showed (Figure 3) that the axes "*Expressive-interesting*" and "*Defined-sufficient*" mainly determined overall evaluations, having high, positive coefficients, β = 0.669

and β = 0.511, respectively. Succeeding in importance was the "*Innovative-efficient*" axis, with β = 0.185. The "*Glaring*" and "*Formal-uniform*" axes contributed, with small coefficients, β = 0.157 and β = 0.131. A strong linear correlation was shown by the correlation coefficient R (0.886), indicating good predictive ability for the model.

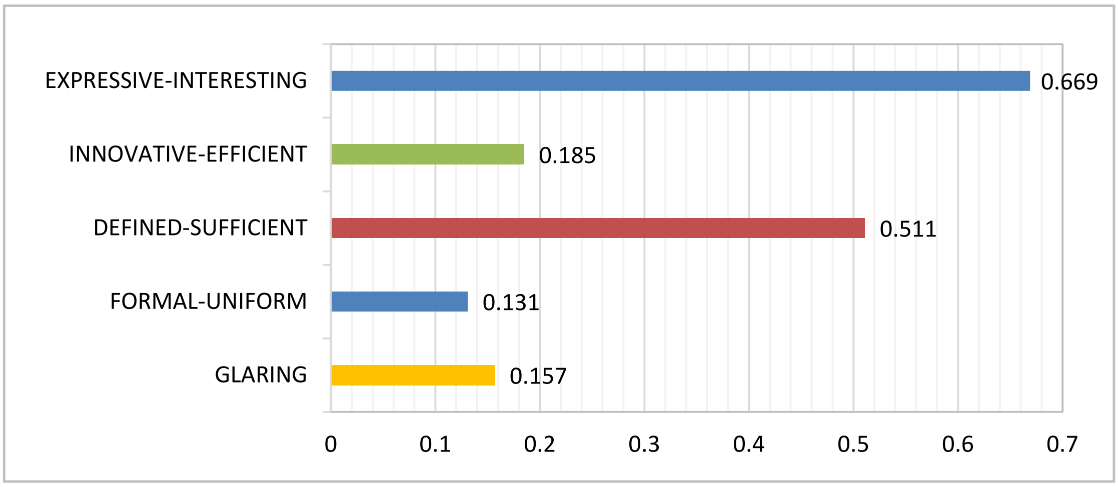


Figure 3. Relationship of the affective axes with the global evaluation variable.

3.2. Phase II: Relationships between Semantic Axes and the Activities Carried out in Urban Areas

3.2.1. Determination of the Groups of Activities

The 16 types of principal activities that the residents undertook in the urban areas were grouped by the factor analysis into four factors, or axes, based on their PLE assessments. These factors describe 83.34% of the variance (Table 6). In order to establish the concepts associated with each factor, the contributions of the original variables were examined. This process identified the next four factors:

- 1st factor: *Having fun* activities undertaken by residents in urban areas are described in this factor. The activities "having fun", "strolling", "playing", "chatting", "looking at one's telephone/tablet", "walking" and "reflecting" are associated, with a positive correlation, with this factor. It explains 32.11% of the variance.
- 2nd factor: the activities that are grouped under the heading of *Reflecting-resting* are represented by this factor. It is related to the activities "reflecting", "resting", "relaxing", "sitting", "looking" and "eating". It explains 25.58% of the original variance.
- 3rd factor: the activities of *Running-physical activity* are represented by this third factor. It contains, with a positive correlation, "running" and "cycling". It explains 16.12% of the sample variance.
- 4th factor: *Saving energy* activities are explained by this fourth factor. This factor reflects the activities "saving energy" and "caring for the environment". It explains 9.53% of the sample variance.

Table 6. Factor analysis of activities.

	1	2	3	4
Having fun	0.797			
Strolling	0.775		0.421	
Playing	0.768			
Chatting	0.752			
Looking at one's telephone, tablet	0.667		0.432	
Walking	0.667		0.484	
Reflecting (considering)		0.847		
Resting		0.830		

Table 6. *Cont.*

	1	2	3	4
Relaxing	0.504	0.744		
Sitting	0.594	0.640		
Looking	0.611	0.626		
Eating	0.505	0.611		
Running			0.824	
Cycling			0.818	
Saving energy				0.939
Caring for the environment	0.477			0.712
% Variance explained	32.11	25.58	16.12	9.53
Cronbach's alpha	0.95	0.94	0.92	0.70

For all dimensions, Cronbach's alpha values were determined. The reliability coefficient values for the first four factors ranged from 0.70 to 0.95. Therefore, it can be concluded that these scales are highly reliable [115].

3.2.2. Relationship between Semantic Axes and Groups of Activities

A non-parametric Spearman correlation coefficient was used to determine the correlation between the semantic axes of the PLE and the groups of activities (Figure 4).

Figure 4 shows that local residents associate the various sensations evoked by the PLE with the diverse activities they carry out in urban areas.

Thus, the activity factor *Having fun* is significantly correlated with all affective impressions. The sense that the PLE is *Expressive-interesting* and *Formal-uniform* is the most salient of all the affective impressions.

Of the set of affective impressions, the sense that the PLE is *Expressive-interesting* and *Formal-uniform* is the most salient. The perceptions are ranked in order of importance based on their correlation: *Defined-sufficient*, *Glaring* and *Innovative-efficient.*

The activity factor *Reflecting-resting* was strongly related to the luminous environments that generate *Expressive-interesting* and *Defined-sufficient* sensations. There was no significant correlation between the impressions of the PLE as *Glaring*, *Formal-uniform* and *Innovative-efficient* and this factor.

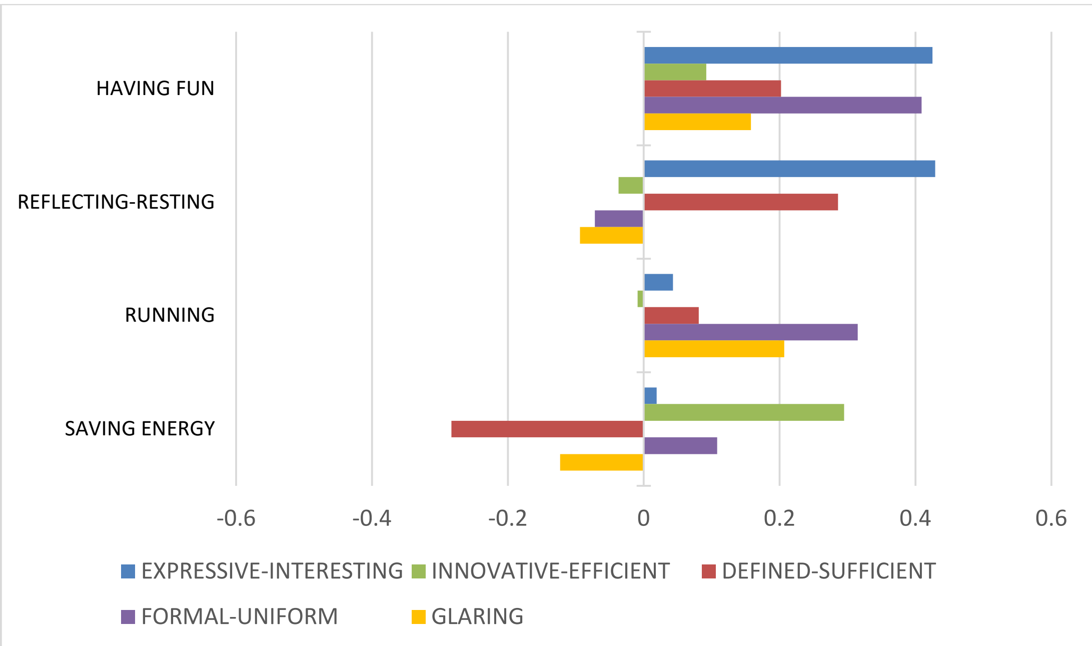


Figure 4. Relationship affective impressions and groups of activities.

The group of activities *Running-physical activity* was significantly correlated with the sensation that the luminous environments are *Formal-uniform* and *Glaring*. The impressions *Expressive-interesting*, *Defined-sufficient* and *Innovative-efficient* had no significant correlations with this factor.

Finally, the activity factor *Saving energy* was associated with luminous environments that produced the sensation of being *Innovative-efficient* and not *Defined-sufficient* and *Gla*ring. The impressions *Expressive-interesting* and *Formal-uniform* had no significant correlations with this factor.

4. Discussion

This study aims to analyse the subjective responses of local residents to the luminous environment concerning the activities they carry out in their urban areas. The objective is to establish which aspects of the PLE of urban areas provide their citizens with the feeling that they are associated with sustainable lighting, taking care of the environment, and saving energy. To this end, the KE methodology is used to identify the set of affective impressions of residents on their PLE and examine the relationship with the activities they perform habitually in their urban areas. The findings provide significant contributions from a methodological and practical point of view.

From a methodological perspective, the main contribution of this study is the use of SD within the framework of KE to assess residents' emotional responses to the PLE in their urban areas. In the field of PLE, SD is of utmost importance as it helps to analyse user perceptions and their correlation with lighting characteristics. It is widely accepted that different demographic groups hold distinct perceptions of identical products [111,116]. Through the use of the KE methodology on the basis of SD, the terms applied to identify the relationships between the PLE and the activities performed in urban areas were defined not by experts but by local residents. Using SD in this study provided subjective rating scales adjusted to local residents' languages without expert intervention. This approach ensures that the perceptions of the PLE being assessed are the ones that are valued by the citizens and can be expressed by them.

In the present work, SD was employed as the first step of the KE methodology. This approach to product design considers user feedback and translates it into quantifiable metrics that can be used to improve the product's design. By analysing customer perceptions and relating them to objective design elements, it is possible to identify design principles that can successfully enhance the product. In the KE technique, this first phase is essential because it is complicated to determine statistical evidence of relationships between affective responses and overall evaluations of PLE when rating scales are created on attributes that are not understood by local residents or on concepts that present overlapping information. Studies based on subjective evaluations of lighting in public spaces tend to focus on concepts/attributes specified by experts in the field [36]. In this process, respondents may not fully understand the concepts used in the evaluation process, which might provide inaccurate results [117]. Previous research [117] has shown that inexperienced observers' judgments of luminance parameters vary based on whether the terms used in the assessments have been defined beforehand. Moreover, analysing individual semantic profiles offers insight into how citizens perceive a PLE, enabling informed decisions about which axes should be modified by the lighting design. Comparing semantic profiles permits urban and lighting designers to make design changes that align with citizens' expectations and preferences.

After this first step of KE, established in this study, where residents' affective dimensions are obtained, further research could establish which design elements of PLEs generate them. Statistical models such as neural networks [118], fuzzy logic [119], or linear regression [120] could establish this correlation between specific lighting design elements and semantic attributes. Thus, this correlation could help to incorporate the preferences and needs of citizens into lighting design specifications to ensure the final product meets their requirements. Additionally, it would also be useful to explore the affective responses of lighting designers, architects, and urban planners. This would help identify any differences in perception between them and the citizens. This second step is fundamental, as, for example, assessing the sustainability of a PLE involves careful consideration of technical, environmental, and social factors [121], which often require expertise in specific domains [38]. While citizens may offer subjective impressions, relying solely on such assessments can lead to inaccuracies and overlook critical aspects of sustainability. To ensure a more comprehensive evaluation and avoid inefficient solutions, qualified professionals must establish clear criteria for designing PLEs that effectively connect citizens with technical requirements.

In addition, it is crucial to determine the significance and relative weight of each attribute of PLE during product development. By doing so, the impact of any potential improvements on customer satisfaction can be accurately measured. To accomplish this, an approach has been developed to assess the connections between the evaluations of each semantic axis and the global evaluation of the different PLEs.

This study's results provide significant practical contributions.

First, a series of concepts were defined that captured local residents' perceptions', in their own words, of local urban luminous environments. Five axes, which explained 75.13% of the variance (Table 4), were identified: *Expressive-interesting*; *Innovative-efficient*; *Defined-sufficient*; *Formal-uniform* and *Glaring*. These axes describe the conceptual structure that local residents employ to differentiate the luminous environments of their urban areas. Comparing the results of this study with other works is challenging because few studies have been undertaken into luminous environments in urban areas in the framework of KE [51]. The application of KE in urban environments has focused mainly on the design of outdoor lighting appliances [95,122]. Moreover, in general, most studies on PLE have evaluated one or two variables of light [73,101,102], frequently in laboratory conditions [103,104], but scarcely the overall perceptions that luminous environments evoke, simultaneously examining the effects of all relevant variables.

Nevertheless, it is worth contrasting some of the findings with other research. The axis *Expressive-interesting* in this study is identified as the capacity of the PLE to create expressive-interesting sensations. Other studies have also employed this attribute in a comparable manner, utilising terms such as "fascination", "entertainment" [51], "stimulating" [81], and "interesting" [123]. Many of the adjectives that constitute this axis (Table 4) were used by Flynn et al. [124], with the term "evaluative". The axis *Innovative-efficient* represents the union of the adjectives "innovative, up-to-date, contemporary", "reflecting", and "efficient". It is noteworthy that, in this case, in the semantic space of the local residents, these concepts were linked. In fact, many studies have connected these concepts [35,125]. This is a significant contribution, because if lighting is to be perceived by citizens as efficient, it must give the impression of being innovative. The *Defined-sufficient* axis represents the combination of the adjectives "defined" and "sufficient". Flynn et al. [79] also employed this concept under the adjective "distinct". The axis *Formal-uniform* is formed by the union of the adjectives "formal", "uniform" and "functional". Flynn et al. [79] placed this concept within the category "spatial modifiers". These affective impressions can also be associated with other works that used the adjectives/terms "uniform" [81], "uniformity" [126], and the expression "complexity" used by Veitch and Newsham (1998). *Glaring* is associated with the concepts "glaring" and "resplendent". This factor describes adjectives analysed in other studies, such as "dazzling" [127] and "brilliant" [76]. It is worth emphasising that local residents perceive this concept as an independent factor, as do experts. Glare has received notable research consideration as an important attribute of lighting quality [128–130].

It should be noted that the terms " bright" and "clear" were integrated into the residents' semantic space. These two adjectives, linked to the concept of visibility or visual comfort, are important themes for lighting research experts [131]. The sensation of "brightness" [132,133]/brightness" [134] is a widely used concept. In the present study, brightness appears on almost all axes with the same value, except for *Formal-uniform*. Experts have also often used the words "clear" [135] or "clarity" [136], which appear in this case only on the *Expressive-interesting* axis. Although experts clearly differentiate between "bright" and "clear", the residents' responses grouped the two terms in the *Expressive-interesting* axis. Fotios and Atli [117] found that these concepts were rated similarly by non-experts. Flynn et al. [79] also observed that the terms bright-dim and clear-hazy were treated in analogous ways and grouped them under "visual clarity".

Second, after the acquisition of the residents' semantic space or the set of adjectives, regression analysis results were used to quantify the importance of these perceptions/emotional responses in their overall evaluations. In this way, the impact of each attribute on their overall assessments of their urban luminous environments was established. The outcomes suggest efforts to improve the PLE in urban areas. The outcomes suggest that efforts to improve the PLE of urban areas should focus on two main points: PLE must generate sensations of being *Expressive-interesting* and *Defined-sufficient* in the residents. An essential dimension is the axis *Expressive-interesting* given that it groups the adjectives "expressive", "interesting", "colourful" and "beautiful". This is a significant outcome, given that some authors [137] have argued that preferences and aesthetic judgments are specific qualitative lighting design criteria (along with mood states, happiness, alertness, and satisfaction). In this sense, the findings of this study are a clear indication of the importance that citizens assign to the qualitative aspects of lighting. Some authors have already noted that light has an identifiable affective importance for observers [138], and emotional terms or affective adjectives are often used when people express an aesthetic or preference evaluation of a place [124]. Other authors have highlighted the importance of using engaging urban lighting to attract visitors [40,139] and attention. The *Defined-sufficient* axis describes the luminous environment as "defined", "sufficient", "bright" and "delicate" (and not "irritating" or "tatty"). The importance of these two axes in overall assessments is consistent with the conclusions drawn by Hawkes, Loe, and Rowlands [140]. These authors indicated that spaces assessed as more attractive were also evaluated as brighter and more interesting. These results show that people describe how they feel about light in a space in terms of brightness and interest.

Third, this work established the relationship between the affective responses of PLE and the activities that local residents perform in urban areas. The activities associated with PLE assessments are *Having fun*, *Reflecting-resting*, *Running-physical activity*, and Saving energy. These four independent factors explained 83.34% of the variance. The most significant contribution of this correlation (Figure 4) is that luminous environments need to be adapted in different ways based on the diverse activities undertaken in cities. The results make it clear that citizens differentiate between luminous environments suitable for having fun and for undertaking physical activities. This is why it is important to separate the different activities that take place in urban areas in an assessment analysis of the PLE.

The group of activities *Having fun* predominantly demands a PLE that generates the perceptions *Expressive-interesting*, *Formal-uniform*, *Defined-sufficient* and *Glaring*. In this sense, the finding that a luminous environment producing expressive-interesting sensations is suitable for having fun, walking, or playing is consistent with the results obtained by Lester [141], who argued that attractive PLE has a positive effect on pedestrians and supports their enjoyment of the walking experience. In the same vein, the group of activities *Reflecting-resting* are associated with luminous environments described as *Expressive-interesting* and *Defined-sufficient*, but not *Innovative-efficient*, *Formal-uniform* or Glaring.

The group of activities *Running-physical* activities involve physical activities such as running, cycling, or walking. These activities are associated with luminous environments described as *Formal-uniform*, *Glaring* and *Defined-sufficient*. These results are significant in view of the importance of sport and recreational activities as part of a healthy lifestyle in today's society and the efforts of public authorities to provide a range of sports facilities to meet these needs [142]. Some authors have analysed which is the most suitable lighting for pedestrians [143–145], cycling [49,146] and sports [147]. Nonetheless, to the best of the authors' knowledge, scarce research has analysed lighting perceptions in the context of recreational activities [148], such as running, from the point of view of citizens themselves. In this sense, the results of the present study indicate that when observers describe luminous environments as *Formal-uniform*, *Glaring* and *Defined-sufficient*, they regard them as suitable for running-physical activity; this is consistent with the results found by Jorgensen et al. [149]. These authors argued that active people might become fearful when their fields of view are blocked by overgrown shrubs, meandering paths, and/or trees. In the same vein, other researchers have reported that respondents who benefit from good street lighting make more use of private playgrounds, recreational facilities, and sports fields and are more inclined to be physically active on a regular basis [150].

Finally, for a luminous environment to be considered suitable for *Saving energy* activities, it should mainly generate the sensation of being *Innovative-efficient* and not the sensations of being *Defined-sufficient* or *Glaring*. This is a very significant finding, given that it is anticipated that much effort will be put into changing and upgrading urban PLE to make it more sustainable and efficient [151]. In this regard, if public authorities wish to transmit the message that PLE is sustainable and suitable for taking care of the environment, it should provide the feeling that it is innovative and efficient. This is essential information for authorities, architects, engineers, and lighting designers because it explains what form residents believe urban luminous environments should take to make them suitable to save energy and take care of the environment. In this sense, whether lighting is seen as innovative plays a fundamental role.

This study has some limitations that open avenues for future research. One such limitation is the fact that the assessments were carried out in real urban areas. It is possible that different elements were present in the specific urban areas that could affect the observers' perceptions. In this sense, the citizens' perceptions of the PLE may be influenced by the specific urban design, infrastructure attributes, and characteristics of the route taken [152]. Nevertheless, this was not significant in the phase where the semantic axes were established because diversity is more important than uniformity. The aim of differential semantics is to identify independent semantic axes based on the evaluation of a sample of stimuli. To ensure the representativeness of the results, there must be enough individuals but also a sufficient number of stimuli that prompt respondents to propose a broad range of associated adjectives. The solution used in the present study follows the experimental control approach of Kish [108]. This approach operates on the basis that chance, when variables are introduced randomly, will create comparable distributions of units in all the analysed variables. Therefore, bias is less significant. Another limitation is that, in order to successfully implement sustainable development practises within the lighting industry, it is imperative to tailor product offerings to specific population segments and activities. To this end, the current study centred on the citizens of L'Alcúdia (Spain) and examined the semantic space of local residents. Gathering the opinions of town residents and evaluating the real PLE in situ has allowed for authentic insights to be obtained. Nonetheless, it is essential to recognise that working with diverse populations can result in significant inter-group variation, potentially impacting the structure of the semantic axis. Therefore, additional research would be needed to obtain findings for other cities or population subsets.

5. Conclusions

In order for a PLE to be considered sustainable by local residents, this study examines the emotional impressions that this PLE must produce. In this regard, this study analyses the affective impressions of local residents of the PLE in their urban areas, considering the different activities residents carry out in their town. This study identifies subjective evaluation scales adjusted to the residents of urban areas by applying a model that prioritises citizens in the urban lighting design process. The basis of this approach is KE, a technique that can connect luminous design elements with local residents' affective responses. The findings showed that PLE must provoke distinct, different sorts of sensations, adapted to the different activities undertaken in urban areas. This approach can help produce lighting environments that improve citizens' satisfaction and their experience of their urban areas, and luminous environments that generate the feeling that the lighting system is sustainable, helps care for the environment, and saves energy.

PLE is a fundamental element of urban planning, as it contributes to the safety [153], security [154], and visual attractiveness of a community [139]. These results can contribute to urban planning, energy management, and policy formulation and may be useful to engineers, architects, and lighting designers in the development of new urban lighting environments that attempt to satisfy urban residents' expectations. Citizen assessment is essential in designing public lighting solutions as it ensures that their needs, preferences, and concerns are considered, resulting in more comprehensive and inclusive lighting designs [155]. By incorporating the perspectives of those who use and reside in urban areas, planners can create public lighting that meets the diverse requirements of the community, promotes sustainability, and supports overall well-being [33].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14031234/s1, File S1: Questionnaire in English and Spanish.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. The invitation to the survey emphasizes that participation is voluntary, anonymous, and optional. The participants could leave the survey at any time during the process and were also informed that the data would only be used for academic purposes.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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