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Article

The Social Light Field in Eco-Centric Outdoor Lighting

Helga Iselin Wåseth [1,*], Veronika Zaikina [1] and Sylvia Pont [2]

[1] Department of Optometry, Radiography and Lighting Design, University of South-Eastern Norway, 3616 Kongsberg, Norway; veronika.zaikina@usn.no
[2] Perceptual Intelligence Lab, Faculty of Industrial Design Engineering, Delft University of Technology, 2628 CD Delft, The Netherlands; s.c.pont@tudelft.nl
* Correspondence: helga.i.waseth@usn.no

Abstract

This study examined how different lighting characteristics of conventional and eco-friendly lighting and environmental conditions, particularly snow cover, influenced the luminous environment and, in relation to that, pedestrian perception of faces on footpaths. The analysis was based on a dataset comprising both subjective evaluations and objective measurements. The spatial and directional light field above a footpath was measured for the two types of road lighting, of which the "eco-centric" luminaire had a lumen output of 4820 lm and reduced blue-light component (correlated color temperature (CCT) of 2200 K) compared to the conventional luminaire with 14,000 lm and 4000 K. The luminaires were analyzed under snowy and non-snowy conditions. Snow cover significantly increased light diffuseness and density (directionally averaged illuminance at a point), resulting in more uniform light and higher subjective ratings. Also, face visibility ratings were generally higher and more uniform, while non-snowy conditions led to more pronounced differences between positions and luminaire types. Regression analysis revealed that vertical illuminance at eye height was the strongest predictor of perceived facial friendliness and well-lighted-ness and contributed to more favorable ratings for the environment lighting too. The eco-centric luminaire was found to positively influence face lighting ratings but received lower ratings for environmental visibility. Increased horizontal illuminance did not consistently result in enhanced subjective evaluations, which points to limitations of traditional illuminance-based lighting standards, often considering horizontal illuminance at ground level as one of the main metrics. The "social light field" concept emphasizes a holistic approach to urban lighting design that integrates social perception and environmental sustainability by considering the distribution of the actual, resulting light throughout the urban space, especially vertical illuminance at the face and its effects on visual appearance, as well as contributing interactions with the environment and materials in it.

Keywords: light field; cubic light measurements; light modelling; social light field; footpath lighting

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1. Introduction

A wide range of studies show the negative impact on nature from Artificial Light at Night (ALAN) [1–4]. As awareness of these impacts increases, lighting designers and lighting engineers are challenged to develop solutions to minimize the negative effects on nature while sustaining the beneficial effects associated with artificial light [5]. ALAN facilitates our urban mobility by fostering a sense of security, thereby encouraging walking and cycling [6]. Notably, the appearance and visibility of the faces of other pedestrians is an important cue for the experienced sense of security. Edensor [7] also points to the importance of creating atmosphere by a balanced relation between light and dark.

We studied how two real road lighting setups shape the 3d light field on footpaths and their effect on faces' appearance. Measurements in snowy and non-snowy conditions (winter vs. autumn) were compared. We analyzed optical, image, and subjective data for the standard and eco-centric lighting, to assess its impact on light field structure, face visibility, and perception of face and environment appearance. By integrating optical measurements, image analyses, and subjective evaluations, this transdisciplinary research aims to assess how lighting design and environmental context affect perceived face illumination and the overall pedestrian experience.

2. Background

2.1. Nighttime Walks

Humans are a diurnal species, which entails that our sensory system is adapted to move around under daylight conditions. Our visual system also allows us to see in dim or dark conditions, yet with restricted visual acuity and color discrimination, resulting in a less detailed perception of the environment. In the context of walking on footpaths at night, our visual perception operates under suboptimal conditions due to low illuminance levels, and this can create a sense of unease when walking at night. The sense of safety is an internal physiological state, regulated by the autonomic nervous system, assessed on a subconscious level through neuroception [8]. It is the unconscious assessment of safety versus danger [9]. Optimizing the visual conditions with the help of artificial light at night can relieve an alerted nervous system and enhance our conscious sense of security. Lighting also contributes to obstacle detection and visual orientation and enables interpersonal judgement and social security [10–15]. Bille and Sørensen [16] argue that light socially illuminates places, people and things and hence affects experiences and materiality. The spatial distribution of the light is important when judging three-dimensional targets [17], like faces. Likewise, the formation of shadows and face-to-background contrast varies between two light poles [12]. The quality of the light and its distribution impact how the surroundings and objects in them appear [17]. With "quality of the light", we refer to its spatial and form-giving effects on the appearance of environment, objects and people in it, via the interplay between the light distribution and the materials, creating a visual experience of a certain quality. In this paper, we are not referring to the luminaire's standard Luminous Intensity Distribution (LID) concept, widely used in lighting technology, but instead to the resulting light field [17,18] (the finally resulting light or luminous environment, capturing the spatially and directionally varying light including the effects of primary and secondary lighting of reflections, interreflections, and so forth, throughout the space—so the actual light in the space instead of the light emitted from the luminaires) and perception-based, qualitative lighting design approach [19]. Certain light qualities, like its diffuseness, light vector direction, and vertical illumination, were in a previous study found to influence judgments of how friendly a face looked [20]. In the present study, we address the relationship between the actual light (optics and photometric light field metrics), the appearance of the environment (luminance-based metrics), and how this affects human observers (perceived luminous environment and faces in it), using a framework we call "the social light field".

2.2. The Social Light Field

In the book "Cities for People", architect Jan Gehl addresses the concept of "the social field of vision", which refers to the visual perception of a person at varying distances and how this relates to social interaction [21]. Gehl's work is based on daylight conditions, but the "social field of vision" will naturally change at night when electric street lighting becomes the main light source. The characteristics of light influence the appearance of other persons [22–25], thereby affecting social interactions, a concept we termed "the social light field". The social light field derives from the light field concept, which was originated by Gershun [18] and further developed into a practical framework by [17,26–28] and describes the luminance as a function of position and direction. The light field of a perceived scene, whether indoor or outdoor, in daylight or artificial light, depends on the light source, but also the certain characteristics of the scene—the geometry of the space and the objects in it, the color and materials and even the light scattering in the air (fog, dust, etc.). These effects are partly optical (objective) and partly perceptual (subjective), where the latter form the visual light field [17]. In a recent study, it was found that light diffuseness, light vector, and vertical illumination at a face correlated with the perception of friendliness, how well the faces were judged to be lit, and how the light environment was rated [20]. The light's modelling qualities were found to be crucial, e.g., direction and diffuseness of the actual light with respect to the face. The light modelling refers to the degree to which the light renders the 3D shape of objects. Those are essential to reveal three-dimensional objects' contour distinctness, shape, and details [22,27,28]. Creating optimal illumination for social light fields can help reduce excessive lighting and thus decrease light pollution, while also enhancing visibility, minimizing visual discomfort, and supporting social interaction and dynamics during walking.

2.3. The Light Field

The advantage of the light field framework is that it systematically and qualitatively addresses the spatial and form-giving aspects of lighting [17,29]. The light field is composed of and shaped by various sources, including the light coming directly from light sources and the reflected light from the surroundings [17]. It represents the variations of light within the three-dimensional space, emphasizing key characteristics related to appearance, such as light density (directionally averaged illuminance at a point), direction, diffuseness, and light texture, as well as their spectral, spatial, and temporal variations [17,30]. A first-order description of the light at a point in space can be measured with cubic illuminance measurements in six directions perpendicular to the planes of a cube, from which the light density, light vector, and diffuseness can be calculated [27]. These metrics define the modelling properties and their variation across the three-dimensional space [26,31], and suffice to describe the main part of the appearance of a scene and the objects in it, e.g., contrasts, colors, materials, surface structures and spatial layouts to first order [22,32–34]. The modelling characteristics of light vary according to primary lighting (the sources) and environmental scattering [27]. Normalized diffuseness quantifies the distribution of light around a point in space, ranging from fully collimated or directed light (with a diffuseness value of 0) to completely diffuse light (with a diffuseness value of 1) [27,28]. Traditional lighting approaches for footpaths set the requirements for the minimum maintained horizontal illuminance on the pavement, depending on the function and use of the road or space (e.g., traffic volume and composition). Additionally, for zones requiring face recognition, vertical and semi-cylindrical illuminance should also be ensured: here, vertical illuminance requirements ranges from 0.6–5.0 lx and semi-cylindrical ranges from 0.2–5.0 lx [35] potentially ensuring good enough modelling and appearance of the pedestrians' faces.

The negative effects on nature from extensive artificial light at night (ALAN) entail that lighting designers and engineers have a responsibility to illuminate the surroundings mindfully to reduce the negative effects of light [36]. The urbanist Luc Gwiazdzinski [37] highlights how light designers sculpt the night and give a nocturnal identity to our cities, while also underscoring the importance of preserving the night. Sculpting the social light field by enhancing face visibility, instead of focusing on horizontal illuminance levels, can help to address this problem.

We aim to fill this research gap by exploring the connection between the measurable light above the footpath (social light field) and its impact on how pedestrians perceive their surroundings and others. We compared the effects of two road lighting luminaires, an "alternative" luminaire being considered more eco-friendly due to a correlated color temperature (CCT) of 2200 K, narrow road optics, and lumen output of 4820, compared to the conventional luminaire with CCT of 4000 K, standard road optics and 14,000 lumen (lm). The luminaires are referred to as 'alternative' and 'conventional'; they differ across multiple factors shown in Table 1. The luminaires were studied under two different environmental reflective conditions, with and without a snow cover. We studied how the characteristics of the lighting, on the one hand, and the snow cover, on the other hand, affected the actual distribution of light by performing cubic light measurements. This "distal stimulus" was related to the "proximal stimulus" for the observer via measurements with a luminance camera, for which we analyzed contrast. These metrics were then again analyzed in relation to data of the perceived expression of a face and the environment, using a face-shaped light probe as a stimulus. We hypothesize that the social light field, as a method to assess lighting design effects, provides a reliable framework for urban eco-centric lighting design.

Table 1. Two luminaire types were used, one conventional road luminaire—B (with lumen output of 14,000 lm and CCT of 4000 K)—and one alternative luminaire—A (with lumen output of 4820 lm and CCT of 2200 K).

Luminaire Type	CCT (K)	CRI	Lumen Output	Light Distribution	Power (W)	Distance Between Poles (m)	Height of the Pole (m)	Bracket Arm	Pole Distance from the Road
A. alternative	2200 K	>70	4820	Street comfort	38	30	8	50 cm	50 cm
B. conventional	4000 K	>70	14,000	Medium road	132	30	9	100 cm	50 cm

3. Method

3.1. Experiment Design and Procedure

The study was conducted in a rural area, on the pavement alongside road FV325 in Tønsberg municipality, Norway, during full night conditions. The sun's altitude was more than 18 degrees below the horizon, which corresponds to astronomical night. The experiment was performed along a road's 250 m long and 3.4 m wide footpath, frequently used by pedestrians, joggers, and commuters on bikes. No other light sources apart from the street lighting were visible in the area. The experiment was carried out in two conditions, with and without snow. In January 2024, the experiment was conducted with a snow cover on both the pedestrian path's pavement and the surrounding area, at −16 °C. In October 2024, it was repeated in non-snowy conditions (dry pavement) at +4 °C. The area beside the chosen road is a logging area, meaning that the height of the vegetation is low, except for some tall trees, Figure 1.

The lampposts stand between the road lane and the footpath, spaced 30 m apart (Figure 1) and are intended for illuminating both pavement and footpath. The lighting system was selected because it represents a common lighting practice for footpaths with an absence of other light sources in the area. Two luminaire types were used in the study. Luminaire A (alternative) has reduced lumen output and narrower spectral power distribution; its energy consumption was disregarded in this study (Table 1). Luminaire B (conventional) represents a conventional luminaire type typically deployed for this roadway classification, as can be seen from Table 1. Each of the two luminaire groups included four units.

Figure 1. Image (**a**) shows the footpath with the clear-cut area on its left and the road on its right, with luminaires positioned between the road and the footpath. Image (**b**) shows the head-shaped light probe in one of the luminaire groups and in snowy conditions.

Measurements were performed at six positions (P1–P6), that is, three between each two central sets of lampposts in both luminaire groups, at distances of 5, 15, and 25 m from the first of the two lampposts, positioned at a height of 1.5 m above the pavement surface (see Figure 2). At each position, a face-shaped light probe was placed sequentially for the perception testing and a cubic measurement was conducted. Observers assessed appearance at a position two meters in front of each position P1–6. Luminance images were taken from exactly the same points (see Figure 3).

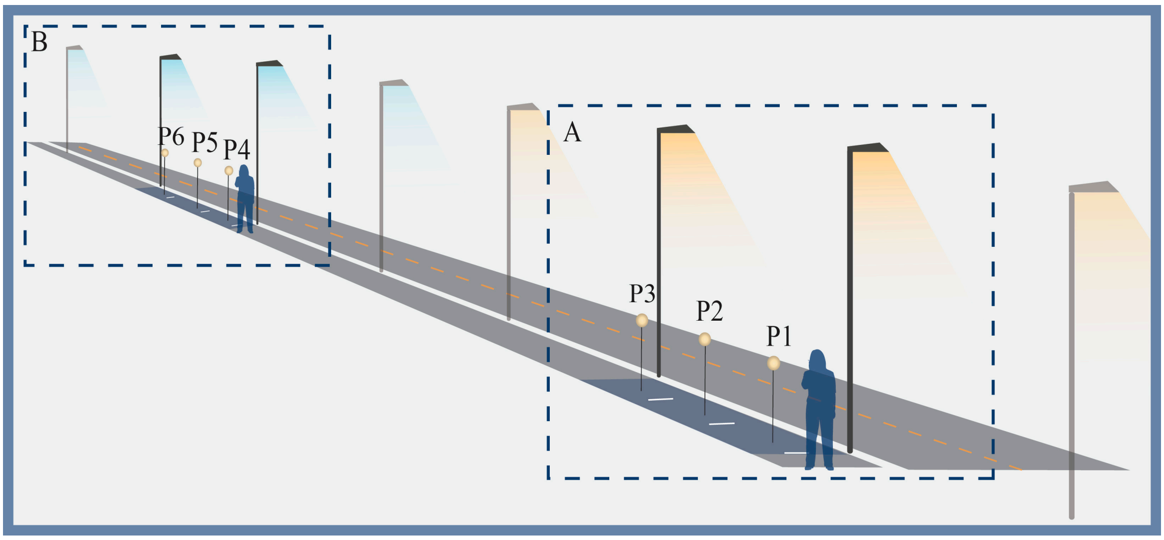

Figure 2. Experimental site and two groups of luminaires (A and B). Three measurement positions (P1–P3 for luminaire A, and P4–P6 for luminaire B) were defined between the two central lighting poles for each luminaire type. At each position, cubic illuminance measurements and luminance images were captured, accompanied by perceptual ratings from observers. During perceptual evaluations, a light probe was sequentially placed at positions P1 through P6. Participants moved alongside the probes, standing two meters away and facing directly towards the probe.

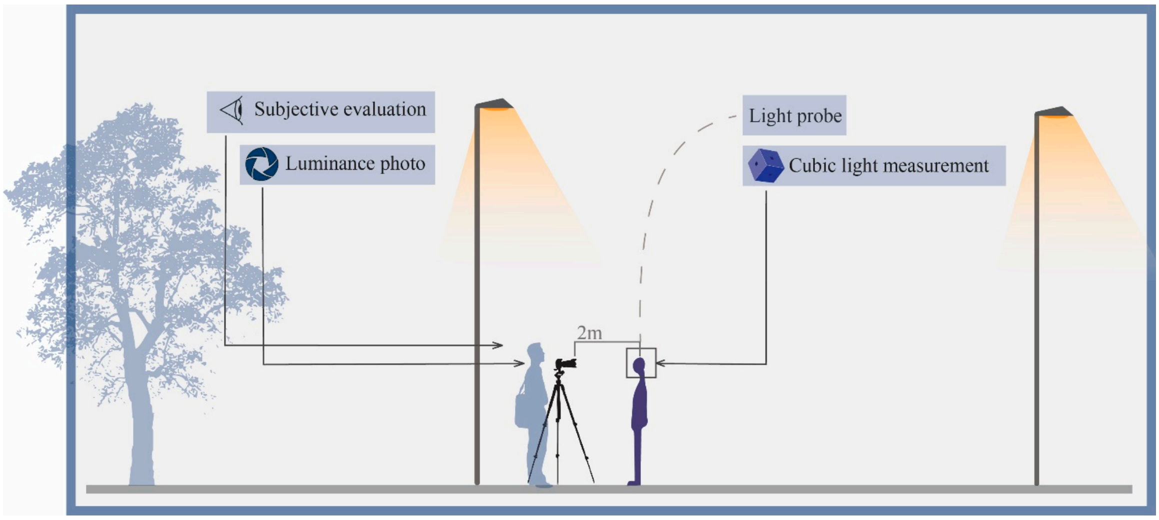

Figure 3. The social light field was evaluated using cubic light measurements, luminance measurements and subjective ratings of the probe.

3.2. Participants

The participants were recruited through social media and mailing lists of the nearest university campus. 29 participants (16 females, 13 males; age range: 18–65 years, median of 38) attended the study in snowy conditions (11 January 2024), and 37 participants (21 females, 16 males; age range: 16–69 years, median of 41) in non-snowy conditions (23 and 24 October 2024). All participants self-reported normal or corrected-to-normal visual acuity. However, one participant in the non-snowy group reported a color vision deficiency while maintaining normal visual acuity. The participant's response was included in the study, since the study did not focus on color perception and the data of this participant did not show clear differences from the rest of the data.

The study was carried out according to the rules and regulations laid down by the Norwegian National Committee for Research Ethics in Science and Technology. Information about the aim of the study was given, and written informed consent was obtained from all the participants. For the 5 participants under the age of 18, informed consent was obtained from their parents, who were present at the experiment site. All the participants were informed of their right to withdraw at any time, within one month, without explanation. No personal data was gathered. Participants received a voucher worth 150 NOK as compensation for their participation.

3.3. Experimental Procedure

Upon arrival, the participants were instructed on the procedure of the study and the questions they would be asked. They were instructed to walk along the two sequences of four lampposts to evaluate the two sets of face-shaped light probes. To balance potential order effects, half of the participants started at luminaire type A, and the second half began at luminaire type B. For each probe, the participants were instructed to stop at markings two meters in front of the probe and were asked to fill in the form. Four questions were asked, the same as previously used by the authors for a survey in an on-screen test in laboratory conditions [20]. These were:

Q1. *The face is well-lit.*
Q2. *The face looks friendly.*
Q3. *The environment is well-lit.*
Q4. *I feel comfortable in this lit environment.*

Answers were given on the 7-step Likert scale. The term "well-lit" was chosen to describe the visual appearance of the light probe and the surrounding environment. The term "friendly" was taken from [13], who propose "friendly" and "non-friendly" as categorization criteria for identifying emotions. The term "comfortable" from Q4 was chosen based on a study by Johansson et al. [14], emphasizing how public lighting should facilitate comfort. After finishing, the participants were instructed to return to the starting point, where they were debriefed and thanked.

Figure 4 presents a collection of non-calibrated snapshots of the face-shaped light probes, illustrating the position variations and differences in visual appearance under the two luminaire types in non-snowy conditions.

Figure 4. Appearance of the heads under the conventional (**top**) and alternative (**bottom**) luminaire. The photos were taken using the same shutter speed to illustrate the perceived difference in brightness. They are not calibrated though, so they do not represent luminance.

3.4. Objective Measurements

Cubic light measurements were conducted, using the light spectrometer Spectis 1.0 Touch + Flicker, from GL Optics, Puszczykowo, Poland, equipped with a Salli diffusor, from the same company, to allow for measurements at illuminance levels below 10 lx. The light meter was sequentially oriented to the six directions of a gauge cube at a height of 1.5 m above the footpath, at P1–6. The height of the probe and corresponding measurements were determined based on the standard for calculating semi-cylindrical illumination on footpaths [38]. The light field metrics were later derived from these measurements using the methods specified in Xia et al. [27].

Luminance images were captured to provide complementary data to the cubic measurements, regarding facial contrast (Figure 5).

We will analyse how the cubic illuminance measurements relate to the luminance data for the face, with in mind that the light in which the face is placed (captured to first order with the cubic illuminance and derived metrics) will determine its appearance (captured objectively by the luminance camera, and subjectively by the participants' responses). However, since faces are very complex 3D shapes, those relationships are much more complex than those for simple flat targets, as have been used a lot in road lighting research. This is the main reason to include luminance data with a 3D facial light probe here, and we think that it actually builds forward on the problem signaled by van Bommel [39,40], namely that flat targets are not representative for the illuminance-luminance relationships in the real 3D world. An LMK 6 luminance camera calibrated with a V(λ) filter and equipped with an 8 mm lens from TechnoTeam, Ilmenau, Germany, was used, capturing images of 55° by 45°. The camera was placed in the same position as the observers' eyes.

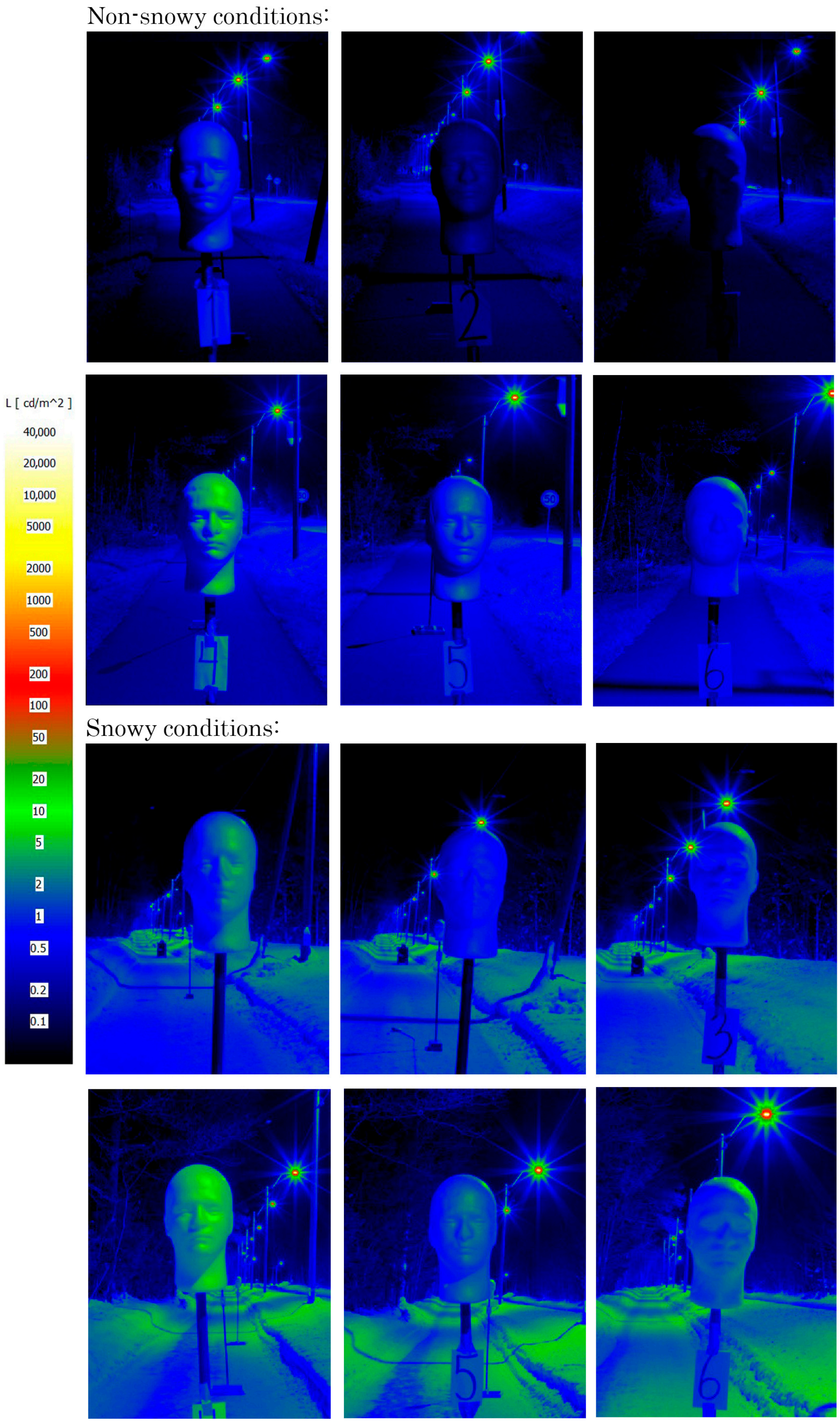

Figure 5. Luminance images of the face at each position under non-snowy conditions (**top rows**) and snowy conditions (**bottom rows**).

3.5. Analysis

For the cubic illuminance measurements, Mathematica 13.3 was used to calculate the light density (mean illuminance at a point (E_{scalar})), light diffuseness (D), mean illuminance, light vector (E_x, E_y, E_z) and its magnitude ∣E∣, vertical illumination (E_{x+}), and horizontal illumination (E_{z+}) [27,28,30,41], using the following equations:

$$E_{(x)} = E_{x+} - E_{x-} \quad (1)$$

$$|E| = \sqrt{E_{(x)}^2 + E_{(y)}^2 + E_{(z)}^2} \quad (2)$$

$$\sim E_X = \frac{E_{x+} + E_{x-} - \left|E_{(x)}\right|}{2} \quad (3)$$

$$\sim E = \frac{\sim E_X + \sim E_Y + \sim E_Z}{3} \quad (4)$$

$$E_{scalar} = \frac{|E|}{4} + \sim E \quad (5)$$

$$D = 1 - \frac{|E|}{4E_{scalar}} \quad (6)$$

The luminance images were analyzed using the company software for the luminance camera, obtaining the standard deviation of the selected image region of the face.

4. Results

The results from the cubic illuminance measurements (Figures 6–8) showed a strong variation between the two luminaire types and between snowy and non-snowy conditions. Figure 6 demonstrates the variations in horizontal and vertical illuminance at positions 1–6, where positions 1–3 correspond to the luminaire type A and positions 4–6 to the type B. As expected, based on the poles' positions, the horizontal illuminance was lower for positions P2 and P5 than in P1, P3 and P4, P6, respectively.

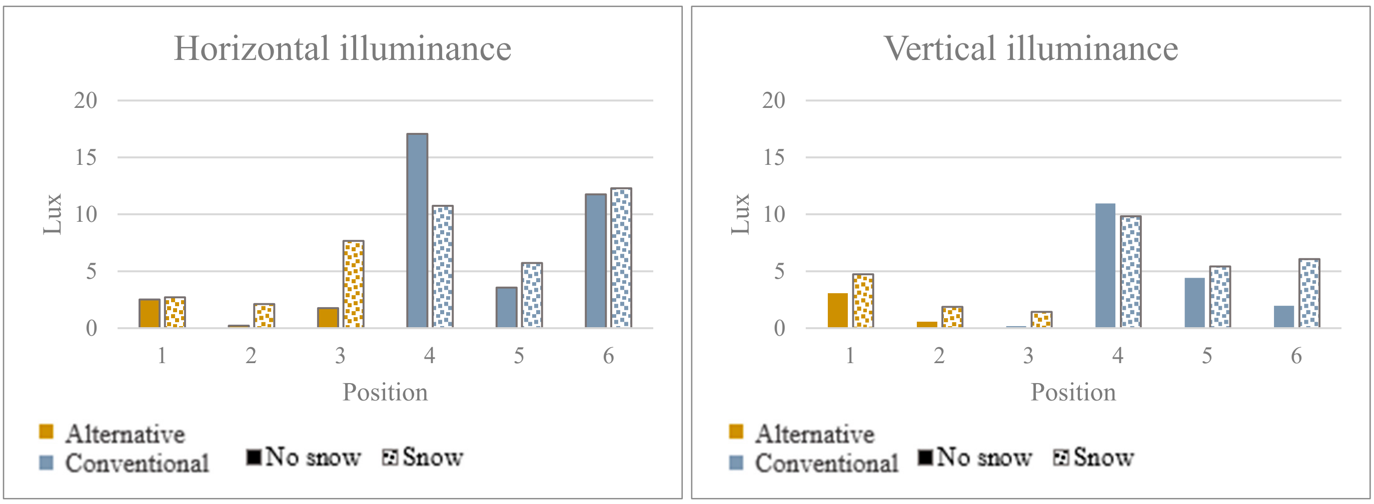

Figure 6. shows plots for horizontal and vertical illumination for snowy (textured fill) and non-snowy conditions (solid colored fill) for the six different positions, where 1–3 (orange) corresponds to luminaire type A and 4–6 (grey) corresponds to luminaire type B.

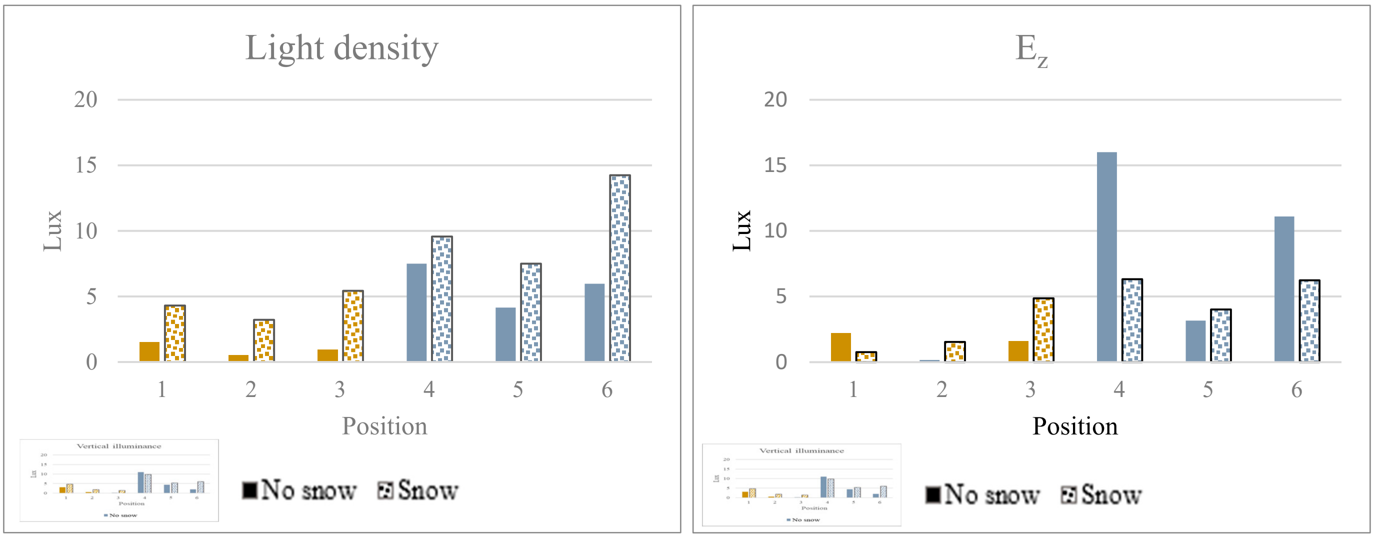

Figure 7. Plots for light density and E_z displayed using the same format as the previous figure.

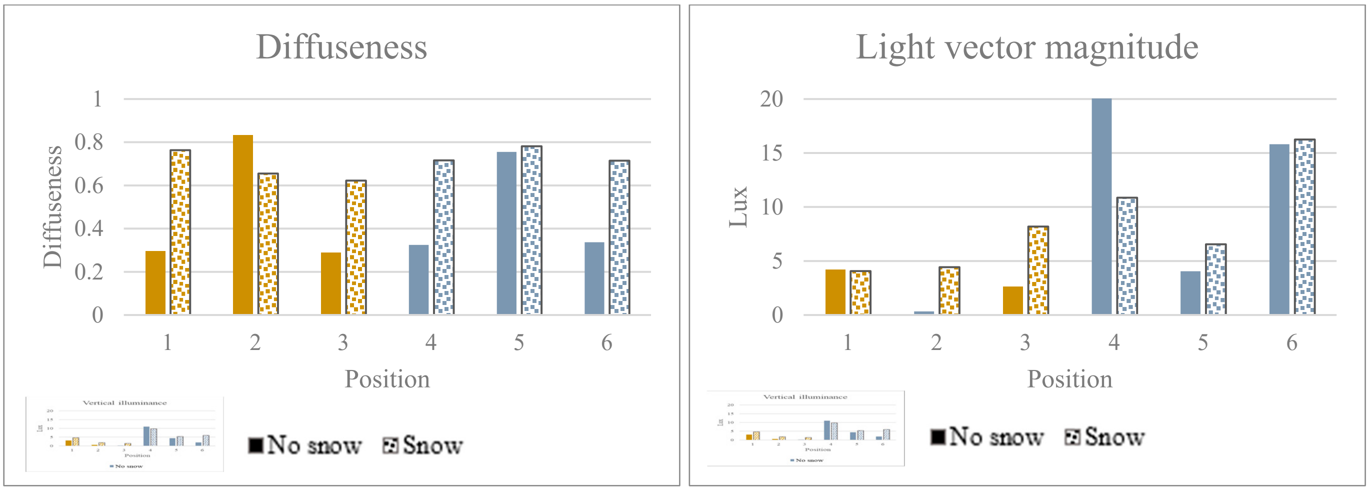

Figure 8. shows plots for diffuseness and light vector magnitude, displayed using the same format as the previous figure.

The vertical illuminance showed a non-symmetric pattern for both A and B, that is, a continuous decrease, because this was measured facing towards the pole in front of P1 and P3. The effects of snow seem not to be systematic in these plots.

Figure 7 shows the variation in light density and E_z. Light density was significantly higher under snowy than non-snowy conditions, as confirmed by an independent samples *t*-test in IBM SPSS 28 ($t(10) = 1.943$, $p = 0.040$), likely due to increased reflections from the surroundings. The plot for E_z, calculated by subtracting the upward-facing illuminance from the downward-facing illuminance, reveals how snow cover reduces the average directionality of the light due to the light reflected from the ground. This effect is particularly seen for the conventional luminaire (B).

Snow cover was also found to impact the diffuseness level (Figure 8). Under non-snowy conditions, the two middle positions (P2 and P5), in between two luminaires, exhibited a diffuseness of about 0.8, while for the other four positions (P1, P3, P5 and P6), closer to the luminaires, we measured a diffuseness of 0.3. In snowy conditions, the diffuseness showed reduced variation (0.6–0.8) while in non-snow conditions, it showed greater difference (0.2–0.8). An independent samples *t*-test confirmed a significant difference in the light's diffuseness between snowy and non-snowy conditions ($t(10) = 2.246$, $p = 0.024$), while not being significantly affected by the luminaire types ($t(10) = 0.220$, $p = 0.415$). A one-way ANOVA confirmed that the distance between light probe and luminaire had a significant effect on diffuseness under non-snowy condition, $F(2,3) = 103.234$, $p = 0.002$, effect size ($\eta^2 = 0.986$), while for the snowy conditions, no significance was found, $F(2,3) = 0.607$, $p = 0.601$ ($\eta^2 = 0.288$). These results reveal how strongly diffuseness is affected by variations in the distance to the light pole.

The Michelson contrast of the face luminance (contrast face) was derived from the luminance maps shown in Figure 5. The face area was selected from the luminance map, and the Michelson contrast was calculated by excluding the top 5% and bottom 5% of the values to minimize the influence of outliers.

A Pearson correlation analysis showed a statistically significant positive relationship between the standard deviation of the luminance values at the face (here called contrast face) with light density ($r(10) = 0.79$, $p \leq 0.001$), E_z ($r(10) = 0.77$, $p \leq 0.001$) and vertical illuminance ($r(10) = 0.84$, $p \leq 0.001$). This suggests that the factors light density, E_z, and vertical illuminance affect facial luminance variance, possibly due to more variability in shadows and highlights.

For the subjective data (Figure A1 in Appendix A), under non-snowy conditions, the differences both between different positions and luminaire types were more pronounced than in snowy conditions. In snowy conditions, the highest average ratings for Q1 (the face is well-lit) were observed at positions P1 (5.6) and P4 (6.0), while the lowest ratings were found at positions P2 (4.3), P3 (4.4) and P6 (4.3).

For Q2 (the face looks friendly), the lowest average rating was found at position P6 (3.8), while the other positions had a consistent average rating of 4.3. For Q3 (the environment is well-lit) and Q4 (I would feel comfortable in this environment), some differences were observed between the two luminaire types, particularly under non-snowy conditions, luminaire A gave overall lower ratings than luminaire B. Snowy conditions partly mitigated these differences, leading to more uniform results.

To analyze the subjective data further, the Shapiro–Wilk Test was performed. Results showed that the data is not normally distributed, and a non-parametric test was required for data analysis. The Mixed-Effects Ordinal Logistic Regression was therefore applied. Several models were compared to identify the factors (like lighting parameters and luminance measurements) that best explained the responses to Q1–Q4, and demonstrated the highest number of statistically significant predictors, while exhibiting the lowest AIC values. The best model we found examined how luminance-based contrast on the face (Michelson contrast), vertical illuminance (Ev), diffuseness, luminaire type, and snow conditions affected participants' responses. This model also allowed us to account for repeated measures from the participants by including participants in the model as a random effect.

Vertical illuminance as measured at the face level (Ev) and luminaire type were significant predictors of the face being rated as well-lit (see Table 2). Both increased vertical illuminance and the alternative luminaire were associated with a higher likelihood of faces being evaluated as well-lit. Despite its lower lumen output, compared to the conventional luminaire, the regression model shows a subjective preference for the alternative luminaire. No significant effect was found for Q2 evaluating friendliness of the faces observed and predictors included.

Analysis of the responses to Q3 (the environment is well-lit) showed that four predictors were statistically significant, i.e., luminaire type was the strongest predictor ($\beta = -1.485$, $p = 0.00020$), indicating that amber light color led to lower ratings of the environment's well-lit evaluation (Table 3). This suggests that the alternative luminaire was less favorable for perceiving the overall environment. Vertical illuminance at the face showed statistically significant and positive correlation with the responses ($\beta = 0.15029$, $p = 0.0028$), showing that an increase in vertical illuminance was associated with higher rates in answers to this question. The variables snow conditions and diffuseness were also statistically significant (β = −1.03632, p = 0.01100, and β = −1.26629, p = 0.00280, respectively), indicating that non-snowy conditions and higher diffuseness were associated with lower ratings for Q3. This apparent contradiction arises because the regression models account for multiple predictors simultaneously, as well as individual differences between participants. Thus, effects such as the benefit of snow cover or the disadvantage of diffuse light only become apparent when isolating their contribution from other variables. In other words, these effects only become clear when we use statistical analysis to separate their influence from other factors, for example, vertical illuminance levels or where the measurements were taken. Diffuseness was measured at the location of the face, while the question pertained to the overall environment. This mismatch may account for the negative association observed with this predictor.

Table 2. Regression analysis results for Q1 (the face is well-lit).

Predictor	Estimate	Std. Error	z-Value	Pr (>|z|)
Contrast face (0 = low, 1 = high)	−1.09643	1.00788	−1.08800	0.27670
Ev (0 = low, 1 = high)	0.39245	0.05617	6.98700	0.00000 ***,[1]
Diffuseness (0 = low, 1 = high)	0.24914	0.57172	0.43600	0.66300
Luminaire (0 = conventional, 1 = alternative)	0.77724	0.38568	2.01500	0.04390 *,[1]
Snow conditions (0 = snowy, 1 = non-snowy)	0.77724	0.38568	2.01500	0.04390 *,[1]

[1] Signif. codes: 0 '***'; 0.01 '*'.

Table 3. Regression analysis results for Q3 (the environment is well-lit).

Predictor	Estimate	Std. Error	z-Value	Pr (>|z|)
Contrast face (0 = low, 1 = high)	0.35575	1.03446	0.34400	0.73090
Ev (0 = low, 1 = high)	0.15029	0.05021	2.99300	0.00280 **,[1]
Diffuseness (0 = low, 1 = high)	−1.26629	0.59283	−2.13600	0.03270 *,[1]
Luminaire (0 = conventional, 1 = alternative)	−1.48513	0.40163	−3.69800	0.00020 ***,[1]
Snow conditions (0 = snowy, 1 = non-snowy)	−1.03632	0.40755	−2.54300	0.01100 *,[1]

[1] Signif. codes: 0 '***'; 0.001 '**'; 0.01 '*'.

The results for Q4 showed that vertical illuminance was the strongest predictor for the space being perceived as comfortable (β = 0.19513, p = 0.0003), followed by the "snow" variable (β = −1.24688, p = 0.0463), which indicated that non-snowy conditions were associated with less perceived comfort than in snowy conditions (Table 4).

Table 4. Regression analysis results for Q4 (I feel comfortable in this environment).

Predictor	Estimate	Std. Error	z-Value	Pr (>|z|)
Contrast face (0 = low, 1 = high)	−1.31866	1.09951	−1.19900	0.23040
Ev (0 = low, 1 = high)	0.19513	0.05337	3.65600	0.00030 ***,[1]
Diffuseness (0 = low, 1 = high)	−1.11815	0.61173	−1.82800	0.06760
Luminaire (0 = conventional, 1 = alternative)	−0.59953	0.41859	−1.43200	0.15210
Snow conditions (0 = snowy, 1 = non-snowy)	−1.24688	0.62586	−1.99200	0.04630 *,[1]

[1] Signif. codes: 0 '***'; 0.01 '*'.

No statistically significant effects were observed for snow and the face-related questions (Q1 and 2). However, for the environment-related questions (Q3 and 4), statistical significance was found for a decrease in how well-lit (Q3: β = −1.04, p = 0.011) and comfortable (Q4: β = −1.25, p = 0.046) the environment was perceived under non-snowy conditions, suggesting that a snow cover has a positive effect on how the environment was perceived.

5. Discussion

This study aimed to examine objective lighting metrics (illuminance- and luminance-based) and their variation over a footpath in different environmental conditions (snow) and lighting types (conventional vs. alternative). We investigated how a more eco-centric lighting (A, alternative) affects the light field at a footpath, and how it relates to social aspects, like pedestrians' perception of observed faces and the surroundings, using the light field framework. Since artificial lighting influences the experience of both the surroundings and fellow pedestrians when walking on footpaths after dark [42,43], facial visibility is particularly relevant even if the time observing another pedestrian is limited [44]. The light distribution over the face varies according to the distance to the light source [13], while conventional horizontal illuminance at a pavement does not account for this variation. In winter, snow cover can strongly influence the light field [20,45]. The overall pattern of the objective results showed that the distance to the pole and snow conditions systematically influenced the light distribution. Luminaire type affected the light density and horizontal and vertical illuminance, and snow impacted the diffuseness and light vector. The subjective results showed less variation between the two luminaire types and did not consistently align with the measured light intensity. For instance, in snowy conditions, the position with the highest light density (position 6) received the lowest subjective rating for Q1 and Q2. Similarly, position 3 (with the same distance to the light pole) also tended to receive lower ratings. At these two positions (6 and 3), the light vector originated from behind the subject, resulting in negative contrast. These findings imply that a frontal light vector is important for the subjective perception of faces. Regression analysis confirmed that vertical (frontal) illuminance significantly influenced responses to Q1, highlighting its role in perceived facial visibility.

Under non-snowy conditions, light diffuseness varied by position with a notable "factor" of more than 3 (which is large, certainly considering that diffuseness is defined at a scale of 0–1). Snow cover increased and equalized diffuseness across all positions, likely due to its high albedo, enhancing hemispherical reflectance and upward illumination.

The greater variation seen in the objective data compared to the subjective evaluations indicates that objective data alone is not a sufficient basis for lighting design of the footpath, and that the light environment and the social light field are affected by factors beyond mere illuminance levels. This observation aligns with the human visual system's adaptability to varying illuminances [46].

Although visual inspection of the descriptive bar plots (Appendix A.1) shows a relatively general overview of the participants' responses, the regression analysis revealed several significant effects. This was due to the ability of the regression models to provide a more precise understanding of how factors like snow cover, lighting type, and vertical illuminance influence perception by isolating the effect of each factor and showing which ones have a meaningful impact on participants' ratings.

Despite the measured horizontal illuminance at points 1–3 (luminaire A) being lower than the corresponding points for the conventional luminaire, the regression analysis showed that participants actually rated Q1 higher, under luminaire A. We found the same effect for the vertical illuminances and subjective ratings. Although this finding may seem counterintuitive at first, it suggests that luminaire A may have positively influenced face perception through a 'warmer' appearance of the face color. Previous studies have also found a preference for lower CCT [47–49], while white light (5511 K) was, in one study, found to increase visual performance on roads, at low luminance levels, but should be used only at low light levels to avoid scattering [50]. For environment evaluation (Q3), the relation was opposite, showing that the surroundings were evaluated as well-lit when the vertical illuminance was higher, as well as under the white light (B). In the tested regression models, vertical illuminance exerted a stronger effect than horizontal illuminance on the visual assessment of faces and surroundings. Additionally, the preference for the alternative luminaire, with lower lumen output and CCT, indicates that horizontal illuminance alone is not sufficient for ensuring optimal visibility. It should be noted that if comparing luminaires with significantly different CCTs, their contributions to luminance and color contrast may vary. However, this problem was out of scope of our study.

These findings point to limitations in conventional lighting design practices when primarily assessing horizontal illuminance at ground level. In current practice, the requirements for vertical and semi-cylindrical illumination are considered only when facial recognition is defined as a specific objective [35], and its application is generally determined by the lighting designer. Our findings indicate that considering vertical illumination is a must in situations where interactions between people occur. Lindh [51] found that a more frontal lighting facilitated facial recognition, aligning with our findings of a preference for vertical lighting. Notably, pedestrian path lighting is complex, as illumination optimal for facial visibility can simultaneously cause glare for the observed individual [52]. The light field framework provides complementary data to the lighting designer (in addition to the conventional measurements), enabling a more comprehensive understanding of the spatial and directional light distribution and its interaction with the environment.

One limitation of this study includes the use of a static white face-shaped probe, which did not account for different skin tones and details in the face (e.g., contrast between eyes, lips, and hair). Posture, movement and gait, known to influence interpersonal judgment [12], were not included to limit the study's scope, but are clearly of interest. Observation time of faces in a real-world setting would normally be shorter than in this study [44]. However, the light field above the footpath plays a critical role in interpersonal judgment during walking, as it influences the assessment of approaching persons. The face-shaped probe provides valuable data on the quality of this light field. Social interaction relies on visual cues like orientation, proximity, and motion [23]. McMahon and Isik [23] argue that recognizing core components of social interactions is, first and foremost visual, and includes distance and facingness (the extent to which the subject is facing), as well as motion and interaction. We propose that the ability to derive these visual cues depends on light, and more specifically, the quality and characteristics of the lighting.

6. Conclusions

This study introduced an alternative way of assessing the lit environment above a footpath using the light field framework. The findings demonstrated that lighting type, distance to the luminaire, and environmental conditions such as snow cover drastically influence the light field, thereby influencing the perception of faces along a footpath. Subjective evaluations revealed that vertical (frontal) illuminance was found to have more influence on the subjective responses than horizontal illuminance. Despite its lower light output and CCT, the alternative luminaire (amber) was rated more favorably for facial perception, despite lower measured horizontal illuminance, suggesting that CCT and light directionality are important factors in pedestrian experience. At the same time, the conventional luminaire with higher CCT (cooler white light) was preferred by the participants when evaluating the surrounding environment. This means that the eco-centric lighting can be a viable alternative, especially considering the additional positive effects on the environment.

Contrast was derived from the luminance maps, but contrary to our expectations, the luminance contrast over face did not correlate with the subjective responses.

Our method, assessing the light field, offers an evidence-based approach to sustainable and user-oriented footpath lighting and urban lighting design. Our findings demonstrate that cubic illuminance plays a critical role in shaping the visual perception of pedestrian faces. Cubic light measurements offer an easy and effective method for measuring the lit environment, complementing existing methods. The social light field framework provides additional data for evaluating the spatial distribution, directionality, and quality of light, which are crucial for optimizing both visual comfort and social perception in outdoor pedestrian environments. It emphasizes light quality over light intensity, enabling design strategies that can enhance social interaction, promote perceived social security, and sustainability.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. The processing of personal data has been assessed by the Norwegian Agency for Shared Services in Education and Research. The assessment is as follows: According to the notification form dated 27 April 2022, including attachments and correspondence, the project will not process any data that can identify individuals either directly or indirectly. Therefore, the project does not require an assessment from the Data Protection Services.

Informed Consent Statement: Informed consent for participation was obtained from all subjects involved in the study.

Data Availability Statement: The original data presented in the study are openly available in https://doi.org/10.23642/usn.29196077.v1 (accessed on 21 August 2025).

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Appendix A

Appendix A.1

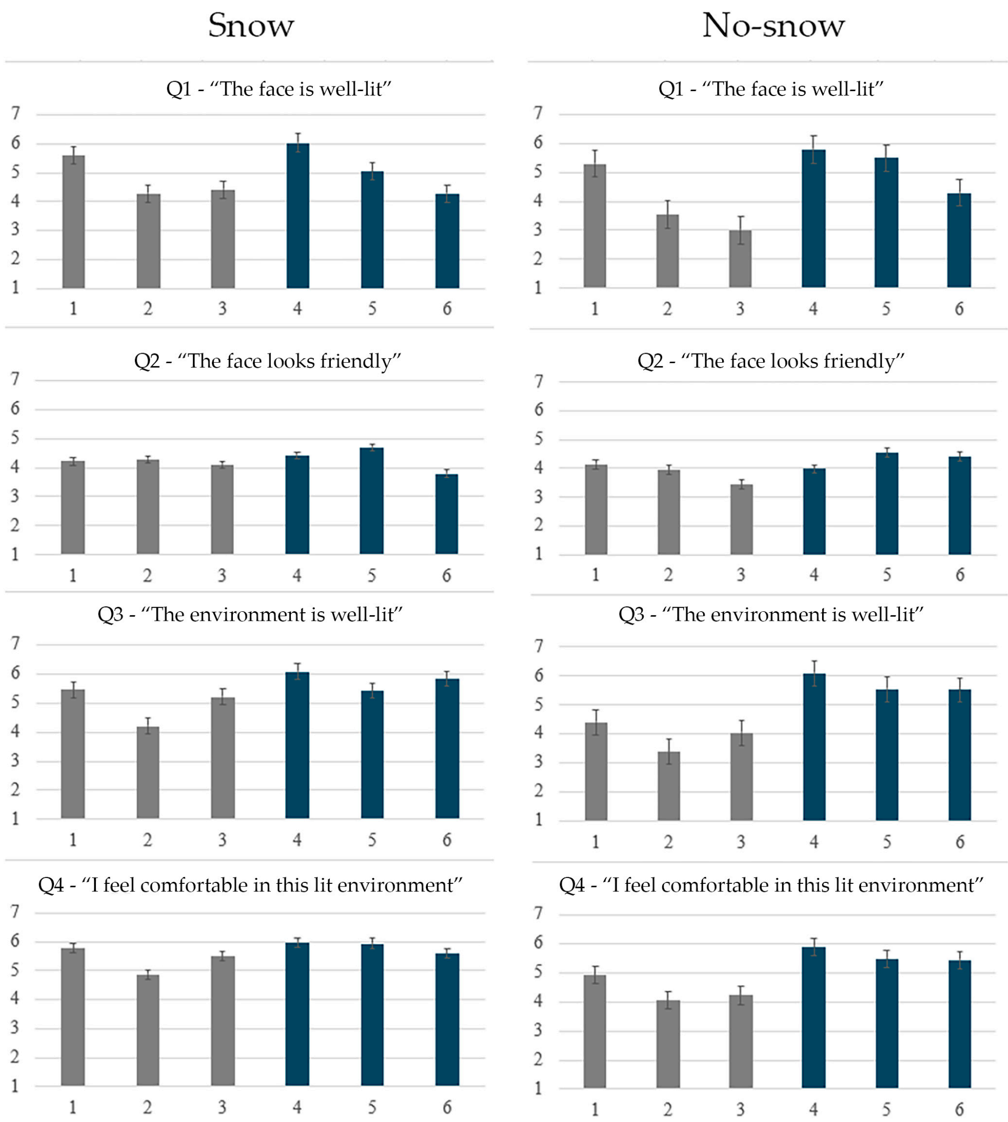

Figure A1. Means plots of the responses to the four questions for snowy conditions on the left and non-snowy conditions on the right. Error bars depict standard deviations.

Appendix A.2

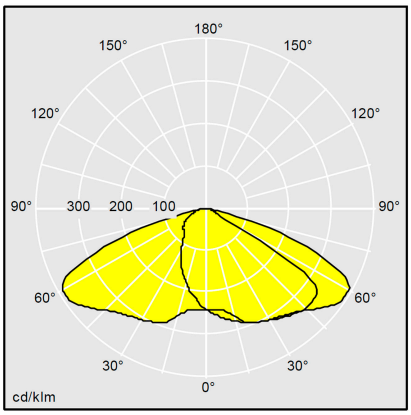

Figure A2. LID for Luminaire A. Alternative.

Appendix A.3

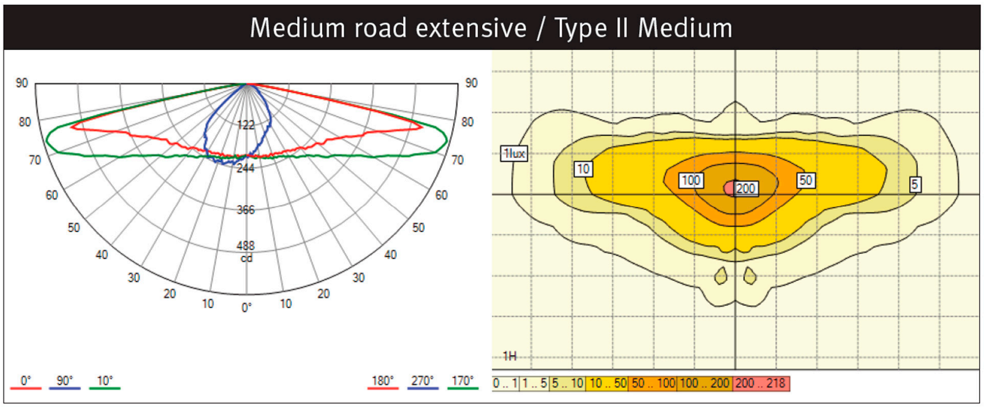

Figure A3. LID for luminaire B. Conventional.

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