Intensity and ratios of light affecting perception of space, co-presence and surrounding context, a lab experiment

Hvass, Mette; Van Den Wymelenberg, Kevin; Boring, Sebastian; Hansen, Ellen Kathrine

Published in:
Building and Environment

DOI (link to publication from Publisher):
10.1016/j.buildenv.2021.107680

Publication date:
2021

Document Version
Accepted author manuscript, peer reviewed version

Intensity and ratios of light affecting perception of space, co-presence and surrounding context, a lab experiment.

Mette Hvass[a], Kevin Van Den Wymelenberg[b], Sebastian Boring[a], Ellen Kathrine Hansen[a]

Aalborg University Copenhagen[a], A.C. Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark

University of Oregon[b], 1585 E 13th Ave, Eugene, OR 97403, USA

* Corresponding author. E-mail address: mh@create.aau.dk (Mette Hvass)

Abstract

In this paper, we investigate how intensity of light in a space and ratios between light a space and in its surroundings affect perception of the atmosphere of the space, experience of co-presence and perception of the surrounding context. A preliminary field study in urban public transportation waiting areas showed, through observations and interviews, that the intensity of light influenced how participants experienced the waiting area and its urban surroundings. In this lab experiment, we investigate the perceived qualities of light levels in a controlled environment and thereby inform future field tests of light intensity and ratios in complex urban contexts. The lab setting consisted of two light zones that simulated 1) a public transportation waiting area and 2) the surrounding urban context. We surveyed thirty participants on their perceptions of six lighting scenarios with different light intensities and ratios and asked them to respond to questionnaires based on a semantic differential scale. Non-parametric data from the questionnaires were statistically analyzed. Luminance data were documented in high dynamic range (HDR) photos and luminance maps to document the light perceived by the human eye. Results revealed that participants perceived the atmosphere in the simulated waiting area as relaxed and private when luminance intensity was low. Furthermore, they perceived the lighting as harmonious and less glaring when luminance ratios between the waiting area and the surroundings were low. However, results also showed that higher intensity lighting in the surroundings increased object visibility but did not indicate that contrast influenced visibility.

Keywords:

Urban context, outdoor lighting, architectural lighting, social lighting, luminance intensity, luminance ratios.

1. Introduction

For many years, existing lighting codes and standards have relied mainly on illuminance levels on horizontal surfaces, likely because they are easier to measure. At the same time, research in lighting design has moved towards luminance-based metrics. Current standards include luminance, though illuminance is still the more commonly used measure in practice. [1]. Fotios et al. state that the standards need to evolve and that parameters for the quantifying measures of pedestrian lighting should be based on vertical rather than horizontal illuminance measures, as vertical measures represent what the human eye perceives when observing the space [2]. Dubois et al. point out that illuminance measures the light falling on a surface from all directions while luminance measures light leaving a surface towards a specific location, implying that luminance better describes how the human eye perceive the brightness of a surface [1].

Lighting norms and standards often define minimum illuminance levels in relation to traffic and to people and the lighting requirements necessary for them to navigate and feel safe [2]. But there is an inherent contradiction between providing high-intensity of lighting and increasing perceived safety. High-intensity lighting enables you to perceive nearby details but might make surrounding areas appear dark and unpleasant. Therefore, in this study, we investigate how luminance intensity affects the perception of a space as well as how the ratio between the luminance intensity in the space and in the surrounding area affects perception of that space.

The study builds on a preliminary field study we conducted at two tram stations in Aarhus, Denmark to study the perceived qualities of light intensity in a complex context. The tram station study consisted of observations documented in a series of photos and short semi-structured interviews [3]. The study indicated that a high-intensity lighting can create a tense atmosphere and cause glare, making other travelers appear pale and the surrounding areas appear dark and difficult to perceive due to contrast. Analysis of traveler's perceptions suggested the potential of investigating how light intensity ratios and the hierarchy of light in surrounding areas affects user's perceptions the outdoor space they are situated in, their fellow travelers and the surrounding areas.

Figure 1. Preliminary field study. Waiting area tram station, Aarhus Denmark

Lighting designers, architects and researchers have explored the perceived qualities of intensity and ratios of light. Using a phenomenological approach stresses the potentials of luminance intensity and ratios. In the book *The eyes of the Skin*, Pallasmaa [4] argues that most contemporary public spaces would be more enjoyable with lower light intensity and uneven light distribution. Pallasmaa describes the use of a constantly high level of illumination that leaves no space for mental withdrawal or privacy as an efficient method of mental torture. "Deep shadow and darkness are essential because they dim the sharpness of vision, make depth and distance ambiguous, and invite unconscious peripheral vision and tactile fantasy. Homogenous bright light paralyses the imagination in the same way that homogenization of space weakens the experience of being, and wipes away the sense of place." The architect Zumthor illustrates another approach to the balance between light and darkness when he describes an idea about planning lighting by looking at a space as a "pure mass of shadow, where you put light in as if you were hollowing out the darkness, as if the light were a new mass seeping in" [5]. Pallasmaa explains, "the quality of an architectural reality seems to depend fundamentally on the nature of peripheral vision, which enfolds the subject in the space." He continues, "the preconscious perceptual realm, which is experienced outside the sphere of focused vision, seems to be just as important existentially as the focused image. In fact, there is medical evidence that peripheral vision has a higher priority in our perceptual and mental system" [4]. The Lighting Designer Lam describes the architectural and social potential of light in the urban context: "Moving from the conception of 'the more light the better' to a more granular and refined understanding of light offers opportunities to create lighting solutions that respond to context, people and locality" [6]. As a tool for understanding the complexity of designing with the perceived qualities of different light levels, Cuttle defines three design characteristics in relation to brightness: (a) overall perceived brightness or dimness of illumination, (b) perceived difference of brightness of illumination between the design space and adjacent spaces, and (c) illumination hierarchy. The three design objectives highlight how brightness levels affect the appearance of a space, describing both the quality of light and visibility in the space and the quantity of light in the space [7]. Each of the scholars discussed above stresses the importance of the perception of differences in intensity and the need to understand relationship between relative intensities in terms of a spatial hierarchy with much greater complexity than even luminance level. The concept for this lab experiment is derived from research within the architectural tradition, as described in the introduction [4,5,6], and the following text describes the research within the lighting industry used to define the lab experiment and frame the test parameters.

2. Test parameters

2.1 Framing test parameters

Researchers have identified several strategies for investigating pedestrians' responses to outdoor lighting and their subjective assessments of lighting quality [8,9,10,11]. In their research, Caminada and Van Bommel classify the objectives of requirements for outdoor lighting into four categories: detection of obstacles, visual orientation, identification of persons and pleasantness and comfort [12]. Previous research investigates whether lighting conditions for pedestrians in urban environments are sufficient for the detections of obstacles [13,14] and identification of persons and recognition of emotional body language [15,16,17,18]. In addition to research describing urban spaces from the pedestrian's point of view, research related to cycling [19] and driving [2,20] and the transition between lit and unlit sections of a road [21] offers inspiration for how to design ratios of lighting in the current study. The potential to cause glare [22,23] and elements related to safety [24] should also be considered in the analysis of outdoor space. In a field study, Davourian et al. question the appropriateness of lighting specifications based on illuminance on road and pavement because their analysis revealed the importance of the visual tasks not located directly on the horizontal footpath they are primarily on vertical surfaces in the viewing direction of the human eye [16]. Kato elaborates on urban complexity stating that it is necessary to study the mutual relationship of various "impression of brightness" and move towards an "impression of brightness of an entire space" [25]. To study "the entire space" and the importance of the ratio of lighting between light zones in urban environments, it is important to gather knowledge from research related to detailed components of the whole, the complex or "entire" urban scene.

2.2 Space, co-presence and surroundings

In this lab experiment, we investigated perceptions of three parameters of urban space: the atmosphere of the space, referred to as *space*; the experience of others within the space, or *co-presence*; and the perception of areas adjacent to the space, or *surroundings*.

The first test parameter, space, concerns perceptions of the light zone in which the test participant is placed, the embodied experience of the local space, which we call the waiting area. Here, the intensity of light affects vision and the dark adaptation period [26,27]. When the eye is exposed to higher or lower light levels, it needs time to adapt, potentially reducing perceived quality of the light. The dark adaptation period's length depends on the intensity of light received by the eye, and lighting should be designed to avoid large differences in lighting levels between adjacent urban lighting zones to reduce the time required for adaptation. Light intensity also affects physiological perception of a space. Research has found that non-uniform, dim and peripheral lighting increases perceived feelings of privacy [28,29]. This experiment focuses on the effect luminous intensity has on the experience of the local space.

The second test parameter, co-presence, concerns the perception of other people within the light zone and is used to investigate how the light intensity consciously or unconsciously affects meetings with other people. Lofland's definition of the public realm and urbaneness refers not to the physical complexity of the urban form but to the co-presence of people, persons who are personally unknown to one another, the social-psychological environment [32]. Meetings occur every day, during the day and at night; lighting helps define this frame during the dark hours and sets the scene for the co-presence of people. During everyday activities, each person presents themselves and their activities to others [33], and this study seeks to understand how to examine this random co-existence in the public realm. When it comes to perceived safety, defined as maintaining a clear view of obstacles and security and deterring offenders [8], studies have shown that uniformity (evenly distributed) high intensity lighting are the most important factors [8,15, 24,27]. Some studies indicate that people feel safer when the intensity of light allows inter-personal judgements such as facial recognition [30], while other studies highlight that lower light intensity leads to more relaxed feelings and has a positive influence on a social attitude [31].

The third test parameter, surroundings, concerns the light zone that the test participant is looking at; in this lab experiment, the surroundings are a wall opposite the participant with a bench in front, lit by two fixtures. In real urban contexts, a complex set of parameters, such as background luminance, contrast, target size and location in the visual field, and spectral characteristics of the target and background are likely to influence how well people can see [8] in the lit urban space at night. The relationship between different lit areas changes depending on the context [26]. Davourian examines how the contrast between a lit object, a statue, and the background urban lighting influences how the object is perceived. These test shows that when the contrast between the lit object and the background lighting is increased, the target stands out from the surroundings and grabs more attention. Davourian stresses the importance of lighting levels and proximity in the surrounding context [34]; when the surroundings are dark, lighting on the object should be planned accordingly. Other studies show that dark adaptation time depends on the local intensity of light in the viewing direction. Stokkermans et al. found that a background with bright areas close to the viewing direction yields longer adaptation times than a background with bright areas at a larger visual angle from the viewing direction. They conclude that local light levels strongly affect dark adaptation [35] and stress the importance of considering the local area in combination with the surrounding area when investigating the role of perceived light in an urban context.

Investigating the complex settings of spatial luminance in field tests requires an understanding of how light intensity and ratios of light affect perception of the space, co-presence in the space and its surroundings

3. The experiment

3.1. Conditions of the experiment

3.1.1 Test setting

The light lab measures 5.8m x 5.8m, with a ceiling height of 4.2m. One wall is painted matt white, and three walls are covered with black Molton curtains. The floor is covered with gray linoleum, and the ceiling is white with a rig for mounting fixtures.

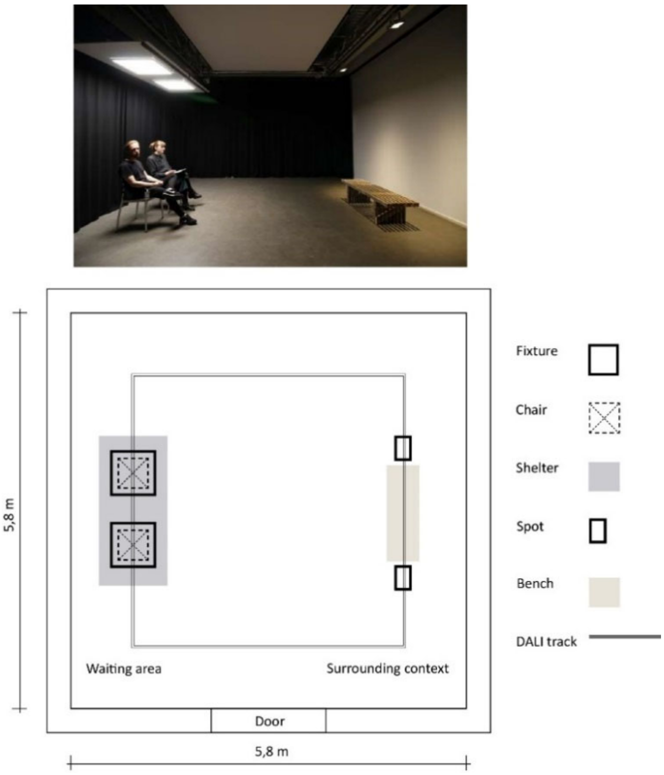

Figure 2. Photo and plan of the two light zones, the waiting area and surrounding context, in the lab facilities at Aalborg University Copenhagen.

We divided the lab into two light zones to simulate a waiting area and the surrounding context. We placed two chairs in the waiting area, one for the test participant and one for the interviewer. To simulate a shelter and provide lighting for the waiting area, we mounted a 1 m x 2.44 m white plate with lighting fixtures 2.5 m above the chairs. Opposite the two chairs, we placed a wood bench of neutral shape and color to represent an object in the surrounding context. Test participants used the object to evaluate details in each of the six lighting scenarios. A rig mounted 3.3 m above the bench held lighting fixtures to create ambient lighting in the surrounding area.

3.1.2 Lighting fixtures and lighting control

Fixtures in the waiting area were from Fagerhult: type, 23511-402 Multilume Slim Opal; measure, 60 x 60 cm; optics, front, opal; color rendering, Ra (CRI) 80; color temperature, CCT, K 4000; and light source, LED. Fixtures in the surrounding context were form ERCO: type, Logotec Floodlight, 72560.000; measure, 16.8 cm (h) x 18.1 cm (w); optics, front, Spherolit lens flood; color rendering, Ra (CRI) 90; color temperature, CCT, K 3000; and light source, LED. The fixtures were connected to or mounted in a DALI track, and the scenarios were programmed in Helvar Design software. The scenarios were controlled via a computer, with eight programmed scenarios in total: six lighting scenarios for the experiment, one baseline condition and one scene with all lights turned off.

3.1.3 Lighting scenarios

We defined and tested six lighting scenarios in the experiment (LS1-LS6). To define intensity, we used lux measurements taken directly under the fixtures to program the lighting scenarios. For the waiting area, we defined high, medium and low intensity illuminance levels as 200, 100 and 30 lux. For the surroundings, we tested high and low intensities of 20 lux and 5 lux. Luminance maps based on HDR images represent the luminance intensities in each scenario [41].

	Waiting area	Surroundings
Lighting scenario 1	200 lux	20 lux
Lighting scenario 2	100 lux	20 lux
Lighting scenario 3	30 lux	20 lux
Lighting scenario 4	200 lux	5 lux
Lighting scenario 5	100 lux	5 lux
Lighting scenario 6	30 lux	5 lux

Figure 3. Lighting scenarios, lux values for programming the intensities

The guiding lux levels in the waiting area were set based on light conditions at the tram stations tested during the preliminary field study and on legal requirements. In the waiting area, we measured light levels with a lux meter Hagner Model EC1 at the ground surface under lighting fixtures. The high intensity value was set to 200 lux based on lux measurements taken at the station during the preliminary field studies, which indicated values close to 200 lux. The low intensity value was set to 30 lux based on two norms that describe the legal requirements for tram stations: According to tram standard Banenorm BN2-81-1 [42], the light level at a small station must be at least 30 Es,mid (the mean lux value of the lighting intensity), and Danish road regulations, Vejregler [43], offer only recommendations for how to light stations. The light intensities in the surrounding context were based on contextual lighting levels, e.g. 20 lux for a brightly lit street and 5 lux for a street with lower intensity lighting.

3.1.4 Luminance maps

In each of the six lighting scenarios, luminance data were recorded using HDR photography techniques and calibrated through Photosphere software [44] to produce luminance maps [41]. Luminance levels, cd/m^2, were measured with a Konica Minolta LS-150 Luminance Meter from the position and eye height of a seated test participant. Each HDR image was calibrated in Photosphere using the physical luminance measurements and according to the same scale, allowing comparison of the results from the six scenarios.

A Canon EOS 70D camera with a Sigma circular fisheye lens 4,5mm 1:2,8 DC HSM was used for the experiment. The camera settings were ISO 100 and aperture 4, with ten shutter speeds: 1/50, 1/25, 1/13, 1/6, 0'3, 0'6, 1''3, 2''5, 5 and 10 seconds. Note that the camera had a crop factor of 1.6 (as it has an APS-C sensor), thus the focal length for the photographs was 7.2 mm. Images were recorded at eye level from the position of a person sitting in the waiting area. The camera was directed towards the corner of the room with a “person” sitting next to the test participant visible, representing co-presence in the local space.

The luminance maps show the actual light distribution and light levels on the horizontal and vertical surfaces in the test environment. They provide measurable figures for the light levels in the space and a visual representation of the light levels and the distribution of light. They also provide a visual representation of the effects of changes in light levels on appearance of the space and the effects of light spilling from the waiting area on the appearance of the surrounding area.

The false color image, figure 4, illustrates the high contrast between the luminance level on the mannequin doll in LS1 and the luminance in the surroundings. It also shows how the contrast is less dominant in the lowered lighting of the LS3 scenario as well as the effects of this light setting on the luminance levels of other surfaces in the test area. Figure 5 illustrates how the lighting is distributed in the room when the lighting levels in the surroundings are lowered and how this affects the contrasts in the room.

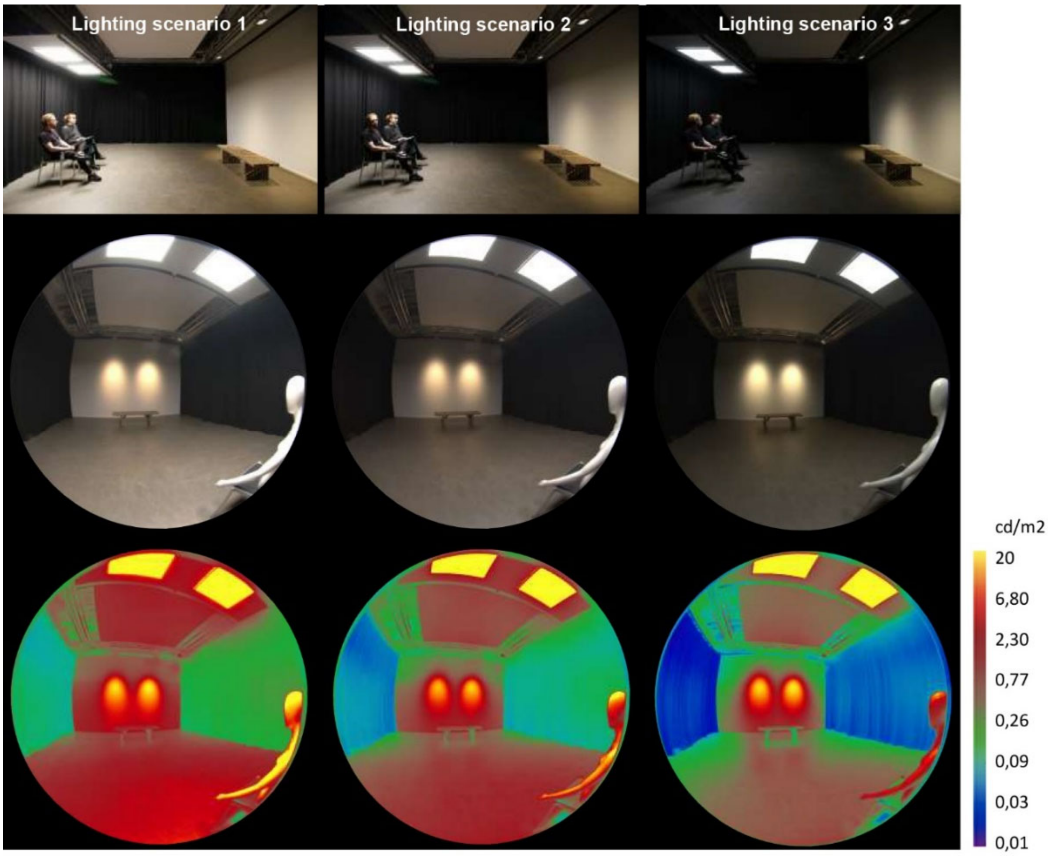

Figure 4. Photos and luminance maps, LS1- LS3, scenarios with high luminance intensity in surrounding context

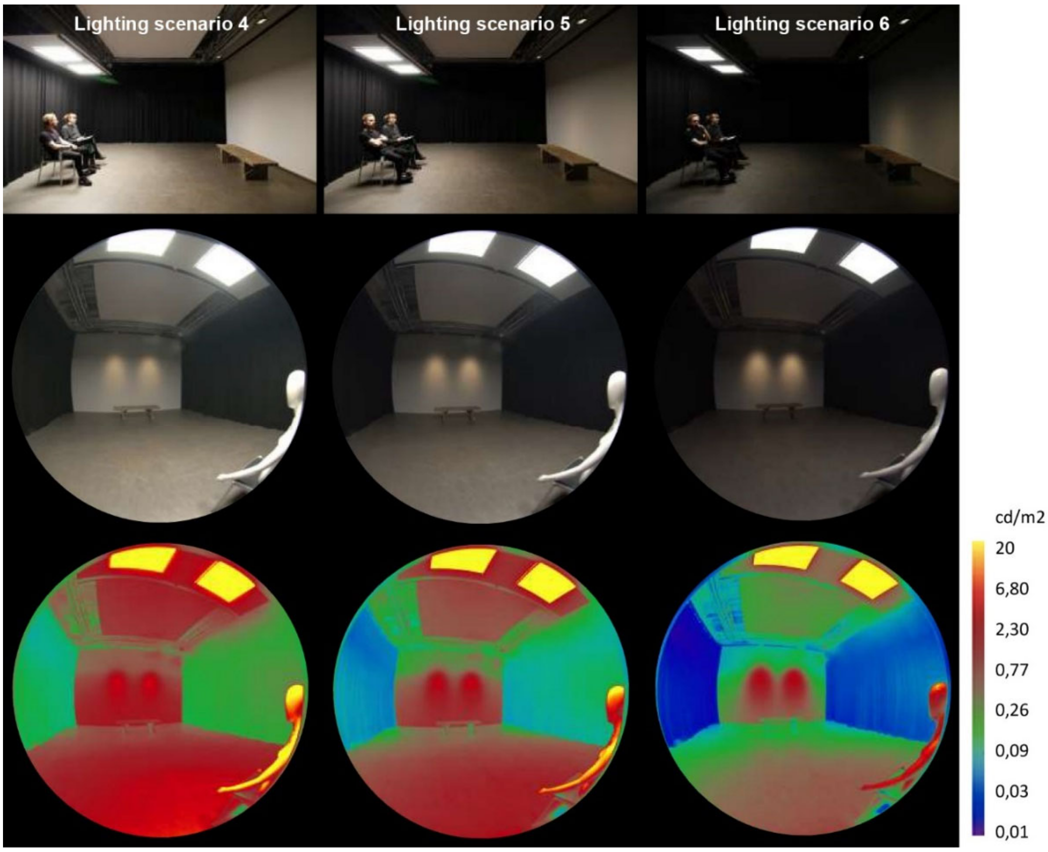

Figure 5. Photos and luminance maps, LS4- LS6, scenarios with low luminance intensity in surrounding context

3.1.5 Objective

The objective was to understand how luminance intensity and the ratio between the luminance of a space and that of the surroundings influenced test participants' experience of space, co-presence and the surrounding context.

The following three hypotheses were defined:

H1) Space – lowered lighting intensity in the waiting area will have a positive impact on the perception of the atmosphere of the space.

H2) Co-presence – lowered lighting intensity will improve test participants' impression of other people in the space.

H3) Surroundings - lower ratios between luminance in the waiting area and in the surrounding context will have a positive impact on perception of the surroundings, including for the visibility of objects.

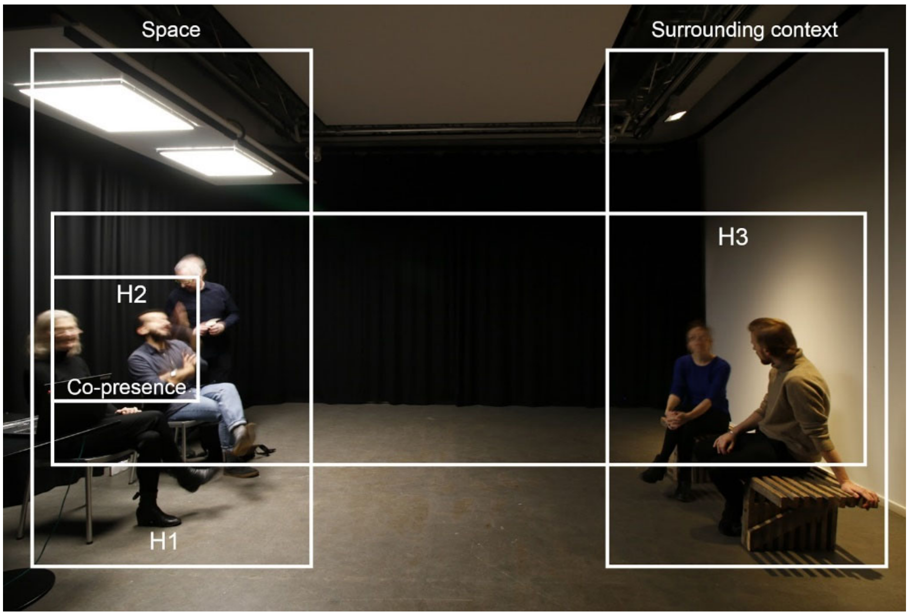

Figure 6. Space, co-presence and surrounding context

3.2 Assessment of perceptions

Subjective assessment of how spatial luminance is experienced in urban space has been examined through different methods. Test subjects' experience of lighting scenarios can be assessed in a lab setting [10,23,36,37] through the use of models or visual fields in models [8,13,18,19,21,25] or simulations [29,31], in a field study / real-site tests [8,9,16,22,24] or by arranging tours with test participants to visit existing lit spaces, to evaluate the lighting [38]. For this study, we choose to set up a lab experiment to explore the findings from the preliminary field study [3] and to be able to manipulate intensity levels and ratios between light levels in two defined light zones in a controlled environment. In the lab, we were able to isolate the experience of the lighting scenarios and direct the test participants to focus on how their perception of the light in the two light zones affected them.

Researchers often use a rating-scale methodology or a paired-comparison methodology to assess subjective impressions of a lit space [39]. We chose to work with a semantic differential scale inspired by an experiment from 1973 in which Flynn [40] used the dimensions of light; uniform/ non-uniform, bright/dim and visually warm/visually cool and asked test participants to judge scenes using a semantic differential scale by responding to the following prompts: evaluative: Like – dislike, friendly – hostile, interesting – monotonous, sociable – unsociable, pleasant – unpleasant and relaxed – tense; visual clarity: clear – hazy, bright – dim and faces clear – faces unclear; spaciousness: spacious – cramped and large – small. Inspired by this work, we developed a questionnaire to evaluate the importance of luminance intensity in visually related light zones to the perception of the waiting area, the co-presence of other people and the surroundings.

3.3 Conducting the experiment

3.3.1 Participants

The experiment included thirty participants (n=30), fifteen male and fifteen female test participants in the following age group: 20-29 years – 16 participants, 30-39 years – 5 participants, 40-49 years - 1 participant and 50-59 years – 8 participants. Test participants included Aalborg University administrative staff, teachers, research staff, students and people outside of the university recruited from Copenhagen.

3.3.2 Procedures

We conducted the experiment in five steps.

Step 1. Test participants began the experiment in an arrival room without daylight, lit only by a table lamp that provided a low level of indirect light. They took 5-10 minutes to fill out a consent statement and provide general information about age, gender and usage of visual aids as well as about their habits related to public transport, how many times a week they use public transport, and what they do during while waiting.

Step 2. Test participant and interviewer entered the light lab and took their places on the two chairs set up in the waiting area. The surroundings were illuminated with 20 lux, the baseline scene.

Step 3. The interviewer gave a brief explanation of the interior of the room, the lighting and the test. The introduction ended with a one-minute sound file from a waiting area at a tram station in

Aarhus, with sounds of people walking, talking, doors closing, the train start signal and a train starting and leaving a station.

Step 4. The first lighting scenario was set, and the test subject was given a questionnaire for each of the six lighting scenarios. The questionnaire was divided into three parts. In the first part, the test participant was instructed to concentrate on the waiting area; in the second part, they were to focus on the lighting relative to the person sitting next to them; and in the third part, they were asked to look at the bench standing in front of the opposite wall.

For questions related to co-presence, participants were instructed to answer the questions as if they had arrived at a station and another person was present. They were to evaluate whether the luminance level had a positive or negative impact the experience of presenting themselves and meeting other people in the waiting area and what effect the lighting might have on their behavior. They were instructed to judge their motivation for socialization based on a social or an antisocial attitude towards the other people waiting rather than on factors such as verbal interaction.

While each lighting scenario was on, test participant marked their answers on paper with printed questions and sematic differential scales for each question. Between each lighting scenario, the baseline scene was restored for approximately one minute. To limit the time needed for the interview to approximately half an hour, we kept the time at the baseline scenario, and therefore the time for the eyes to adapt, to a minimum.

Step 5. The experiment was concluded with minimal discussion, and comments related to the questions or the test in general. The information was collected in field notes.

The participants saw three scenarios, LS1 - LS3, with high-intensity lighting in the surroundings, with the three scenarios for the waiting area shown in random order. Then participants saw three scenarios, LS4-LS6, with low intensity in the surroundings, and the three scenarios for the waiting area again shown in random order. See figure 7. We separated the lighting scenarios based on the surrounding luminance levels to simulate different times of day, e.g. twilight and half an hour later. The two surrounding lighting levels could also be seen as simulating two different urban densities with different lighting levels, such as a waiting area in a dense urban context where the surrounding area is brightly lit, compared to a waiting area in a rural setting where there is little or no light in the surroundings.

	High intensity, surrounding context	Low intensity, surrounding context
Series A, 5 participants	(LS1)200 - B - (LS2)100 - B - (LS3)30 - B	(LS4)200 - B - (LS5)100 - B - (LS6)30 - B
Series B, 5 participants	(LS1)200 - B - (LS3)30 - B - (LS2)100 – B	(LS4)200 - B - (LS6)30 - B - (LS5)100 - B
Series C, 5 participants	(LS2)100 - B - (LS1)200 - B - (LS3)30 - B	(LS5)100 - B - (LS4)200 - B - (LS6)30 - B
Series D, 5 participants	(LS2)100 - B - (LS3)30 - B - (LS1)200 - B	(LS5)100 - B - (LS6)30 - B - (LS4)200 - B
Series E, 5 participants	(LS3)30 - B - (LS2)100 - B - (LS1)200 - B	(LS6)30 - B - (LS5)100 - B - (LS4)200 - B
Series F, 5 participants	(LS3)30 - B - (LS1)200 - B - (LS2)100 - B	(LS6)30 - B - (LS4)200 - B - (LS5)100 - B

B = baseline, LS = Lighting scenario

Figure 7. Order of lighting scenarios

3.3.3 Questionnaires

The questionnaire consisted of 12 questions, divided into three topics associated with the three hypotheses:

1. Space - the perception of the waiting area.
2. Co-presence - the experience of fellow passengers in the waiting area (the interviewer sitting next to the test participant).
3. Surroundings - the perception of the waiting area in relation to the surrounding context.

The questions were inspired by the research discussed in section 2.1. Answers to the questions marked in bold had significant differences, and we discuss our analysis of these responses in the result section (QU 1, QU5, QU8, QU10 and QU 12). We found no significant differences in the answers to the remaining questions; therefore, we do not discuss those questions in this paper.

Questionnaire instrument	
Item ID	Semantic Differential Scale, 1 - 7
	(H1) Space - How is the atmosphere in the waiting area experienced?
QU 1	**Relaxed / tense**
QU 2	Safe / unsafe
QU 3	Comfortable / uncomfortable
QU 4	Exciting / boring
QU 5	**Public / Private**
	(H2) Co-presence - How are fellow passengers experienced in the waiting area?
QU 6	How are faces lit? - Comfortable / uncomfortable
QU 7	How does the lighting affect socialization? – Motivating / not motivating
	(H3) Surrounding context - How is the lighting in the waiting area experienced in relation to the lighting in the surrounding space?
QU 8	**Harmonious / non-harmonious**
QU 9	Comfortable / uncomfortable
QU 10	**Non-glaring / glaring**
QU 11	Light / dark
QU 12	**Object (bench) is visible / Object is not visible**

Figure 8. Questionnaire

4 Results

We analyzed responses to the 12 questions separately, across all lighting scenarios. First, we looked for potential outliers in the responses but did not identify any (i.e., no participant was further away from the mean than three times the standard deviation). We separated the lighting scenarios based on the luminance levels in the surrounding area (i.e., LS1-LS3, which had 20 lux; LS4-LS6, which had 5 lux) as they resembled different times of day and/or different urban contexts. We then conducted separate repeated measures analyses of variance (we used Friedman ANOVAs as we were analyzing non-parametric data) per question with the responses for each lighting scenario as dependent variables. For post-hoc tests (if significant differences were found between lighting scenarios), we used Dunn-Bonferroni post-hoc tests to ensure that all *p* values were corrected for the multiple. All non-reported *p*-values were above the significance level of 0.05.

4.1 Space

H1) Lowered lighting intensity in the waiting area will have a positive impact on the perception of the atmosphere of the space.

Relaxed versus Tense

We asked participants whether they experienced the atmosphere as relaxed or tense given the different lighting scenarios. Both Friedman tests revealed a significant difference (20 lux: $\chi^2(2) = 8.766$, $p < .012$; 5 lux: $\chi^2(2) = 12.875$, $p < .002$). Post-hoc tests further revealed that LS1 was perceived as more tense than LS3 ($p < .043$). Similarly, LS4 was rated as more tense compared to both LS5 and LS6 (all $p < .009$). Overall, LS1 and LS4 (both scenarios in which the contrast was highest) were rated as more tense (LS1: MED = 5, M = 4.93, SD = 1.574; LS4: MED = 6, M = 5.6, SD = 1.476) than LS3 and LS6 (the two scenarios with the least difference in lighting levels). This suggests that high intensity and high contrasts between the waiting area and the surrounding area increases the perception of feeling tense.

Public versus Private

We asked participants whether they felt the space in the waiting area was private or public in the different lighting scenarios. Again, both separate Friedman tests revealed a significant difference (20 lux: $\chi^2(2) = 13.380$, $p < .001$; 5 lux: $\chi^2(2) = 6.596$, $p < .037$). Post-hoc tests, however, only showed a significant difference between LS1 and LS3, where LS1 was rated as more public than LS3 ($p < .003$). Overall, LS1 was perceived as the least private (MED = 2, M = 2.03, SD = 1.217), and LS3 was rated the most private (MED = 3, M = 3.5, SD = 1.526). Although we did not find significant differences for 5 lux in the surrounding area (LS4-LS6), we observed the same trend, as shown in Figure 9. Finally, we compared LS1 (brightest waiting area and higher surrounding light level) to LS6 (darkest waiting area and lowest surrounding light level) and found a significant difference ($p < .006$). These results partially suggest that the lower lighting levels in the waiting area increase the perception of privacy.

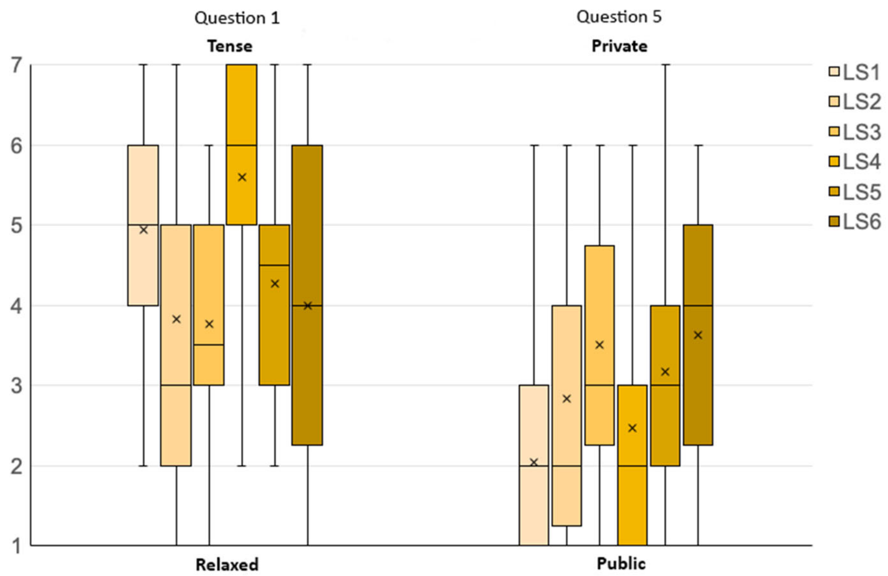

Figure 9. Waiting area, results questions 1 and 5

4.2 Co-presence

H2) Lower lighting intensity will be motivating for socialization.

We found no significant differences in how fellow passengers were experienced in the six different lighting scenarios.

4.3 Surroundings

H3) Lower ratios between luminance in the waiting area and in the surrounding context will have a positive impact on perception of the surroundings, including for the visibility of objects

Harmonious versus Non-harmonious

We asked participants whether they perceived the lighting in the waiting area as being harmonious with lighting in the surroundings. Both Friedman tests again showed a significant difference (20 lux: $\chi^2(2) = 9.525$, $p < .009$; 5 lux: $\chi^2(2) = 16.388$, $p < .001$). Post-hoc tests also showed significant differences between LS1 and LS3 as well as between LS4 and LS6 (all $p < .024$). The two lighting scenarios with largest contrast between the waiting area and the surrounding area (LS1: MED = 6,

M = 5.47, SD = 1.592; LS4: MED = 6, M = 5.57, SD = 1.675) were rated as less harmonious than the two scenarios with least differences in lighting levels (LS3: MED = 3, M = 4.00, SD = 1.722; LS6: MED = 4, M = 3.97, SD = 1.629), suggesting that low contrast in the brightness levels in the two areas lead to more harmonious perception.

Glary versus non-glary

We asked participants whether they perceived the light in the waiting area as glary or non-glary for each lighting scenario. Friedman tests revealed significant differences in both cases (20 lux: $\chi^2(2) = 18.242$, $p < .001$; 5 lux: $\chi^2(2) = 17.333$, $p < .001$). Post-hoc tests further revealed that LS1 and LS3 differed significantly ($p < .001$), unsurprisingly suggesting that for 20 lux in the surrounding area, a high lighting level in the waiting area is perceived as causing more glare (LS1: MED=6, M=5.17, SD=1.84; LS3: MED=3, M=2.93, SD=1.741). For the scenarios with 5 lux in the surrounding area, LS4 (with the highest difference in lighting levels between the two areas) differed significantly from both LS5 and LS6 (all $p < .029$), indicating that larger differences lead to even higher perception of glare in the waiting area (LS4: MED = 6, M = 5.27, SD = 1.799; LS5: MED = 5, M = 4.03, SD = 2.042; LS6: MED = 3.5, M = 3.50, SD = 1.656).

Object visible versus Object not visible

We asked participants whether they perceived an object (the bench) in the surrounding area as visible or not visible. Friedman tests did not reveal a significant difference, suggesting that a change in lighting levels in the waiting area did not significantly affect the perception of objects in the surrounding area. We therefore conducted a Friedman test across all lighting scenarios and found a significant difference ($\chi^2(5) = 51.581$, $p < .001$). Post-hoc tests revealed that LS1, LS2, and LS3 resulted in clearer perceptions of the object than LS4, LS5, and LS6 (all $p < .02$), suggesting that it is the surrounding light level and not the waiting area light level that influences the perception of this object as visible or not visible, as shown in Figure 10. LS1, LS2, and LS3 all had similar responses (LS1: MED = 2, M = 2.80, SD = 1.472; LS2: MED = 2.5, M = 2.63, SD = 1.273;

LS3: MED = 2.5, M = 2.73, SD = 1.172), and the same can be observed for LS4, LS5, and LS6 (LS4: MED = 5, M = 4.43, SD = 2.012; LS5: MED = 5, M = 4.27, SD = 1.552; LS6: MED = 5, M = 4.60, SD = 1.589).

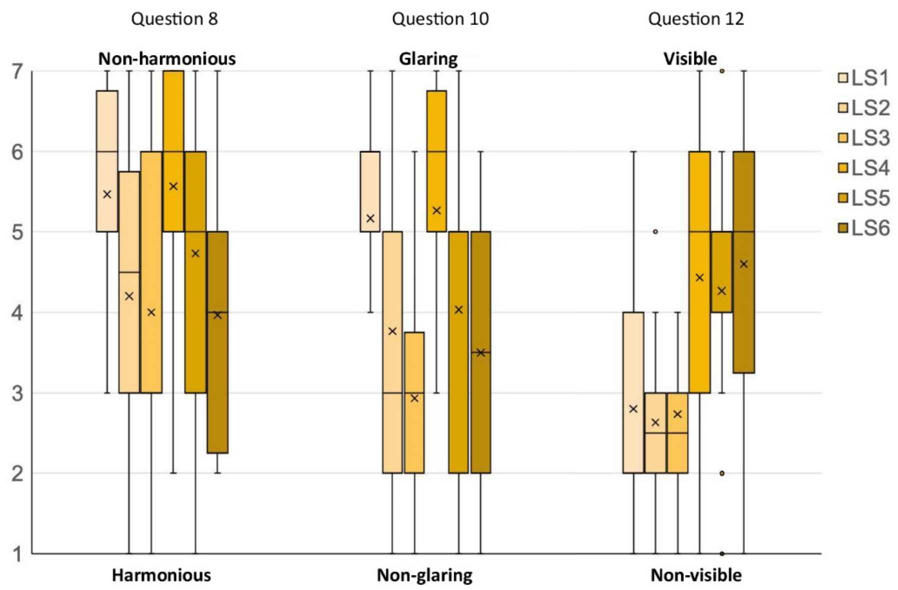

Figure 10. Surrounding context, results questions 8, 10 and 12

5. Discussion

According to international and Danish lighting regulations [45], demands for illuminance intensity are defined in relation to the traffic flow and the pedestrian's ability to navigate and feel safe. Research has found that high illuminance uniformly distributed meets these criteria [8,15,27,29] and outdoor public space lighting designers and engineers tend to recommend high lighting intensities to support visibility and increase perceptions of safety. But in this lab experiment, we found test participants perceive the atmosphere as more tense and public with a high intensity of light. Furthermore, when the contrast between the intensity of light in a space and in the surrounding context is high, it is perceived as non-harmonious and glary. These findings reveal the complexity of creating lighting environments in the public realm, where we would like to exploit the architectural and social potential of light by adjusting spatial luminance. When we lowered light intensity in the test, the space was perceived as more relaxed, private, harmonious and less glary, perceived values that can support a livable and safe outdoor public environment.

When test participants were asked to evaluate the local space of the waiting area, the light zone they were sitting in, they perceived it as relaxed and private in lower lighting intensities. These findings challenge the knowledge we have from studies that suggest uniform, evenly distributed and high luminance intensity are the most important factors when creating lighting for a safe space.

The lighting intensity scenarios were presented in a random order in the waiting area, three scenarios with high intensity in the surroundings and three scenarios with low intensity in the surroundings. We are aware that if both intensity in the waiting area and intensity in the surrounding context had been sequenced in a random order, we would have received different answers from the test participants, thereby obtaining another picture of how the balance between the luminance intensity in the waiting area and the luminance intensity in the surrounding context influence the perception of space and people. Furthermore, we found no significant differences concerning co-presence. Questions about the impression of light on the interviewer and the motivation for socialization may have been too abstract for the test participants to answer in the context of this lab experiment. Likewise, instructions about social aspects of the waiting situation might have biased the results. A different approach to this topic may yield different results when tested in the field. However, the findings show that lower intensities of light can lead to perception of a relaxed and private atmosphere, which could also lead to a more relaxed impression of co-presence in the waiting situation. When we regard the urban context as a social-psychological frame where people gather [32], lighting should be seen as a tool to enhance the qualities of a space. Research on indoor lighting, such as the study by Baron et al., suggests lower intensities of lighting can lead to an improved social behavior towards other test participants [31].

The perception of the difference of luminance intensities in the two light zones, the waiting area and the surrounding context, was significant, illustrating that the test participants were able to distinguish between the different light settings. The two scenarios with the highest intensity in the waiting area, and therefore the highest contrast to the surroundings, were rated as the most tense, non-harmonious and glaring. This demonstrates the importance of balancing the intensity of light in visually related urban spaces, to create lighting that enhances the qualities of the space and the surroundings, the architectural potential of light. When the lighting in the waiting area was lowered and therefore the contrast to the surroundings was lowered, perception of the lighting as relaxed, harmonious and non-glary increased.

The results support previous research findings about how the perceived quality of an object in a space is affected by the light level on the object seen in relation to the light pattern in the background [34]. Similarly, the results support the idea that dark adaptation is influenced by the relationship between the light level in a local space and the light level in the background [35], thus, supporting the idea that balancing light levels leads to lighting solutions that respond to the context, people, and locality [6].

Our findings support Pallasmaa's emphasis on the importance of understanding the surroundings and the need for a multi-sensory architecture that facilitates a sense of belonging and integration [4]. The relaxed and private atmosphere in a public space created by lowering luminance intensity could meet these potentials. The findings introduce another way to regard the role of light and suggest lowering and balancing the intensity of light between a space and its surroundings can help create comfortable urban areas for people waiting for public transportation and in other similar urban places. Pallasmaa contends that a high level of diffuse light obliterates details and leads to loss of tactility. Materials lose their signs of age and time because details disappear at high light levels [4]. Tanizaki also stresses the importance of seeing detail in surroundings and of using materials that reflect light [45], touching again on the importance of intensity of light in the immediate area and its surroundings. Pallasmaa states that contemporary urban settings tend to make us feel like outsiders because they provide little of interest in the range of peripheral vision. "Unconscious peripheral perception transforms retinal gestalt into spatial and bodily experiences. Peripheral vision integrates us with space, while focused vision pushes us out of the space, making us mere spectators" [4]. Our results support this statement, showing that test participants experienced a harmonious connection between the local space and its surrounding context when the contrast between the lighting levels of each was low. Thus, our findings from a technical lab experiment support a phenomenological approach that stressed the potentials of bodily experience of space and the surrounding context.

However, our study also supports lighting designers' tendency to provide higher intensity of light to improve visibility; specifically, our results show that high-intensity lighting in the surroundings resulted in better visibility of objects in the surrounding context. This contradicts our hypothesis that balanced intensity would increase visibility.

The object in our test was a bench of neutral shape and color—far from what you would see in a complex urban space. Light spilling from the waiting area and the low intensity of the lighting in the surroundings may also have affected the results. Therefore, we see this as an example of the complexity of studying the balancing of light intensities and evidence that while some issues can be evaluated in lab experiments, other issues must be evaluated in field tests.

The lab experiment was based on the waiting situation at an urban tram station. We are aware that a controlled lab environment cannot exactly replicate the real-world condition of a public waiting area. In an actual urban setting, light from surrounding facades, advertisements, cars and other urban sources influence perception of the space. But these situations are impossible to replicate in a lab setting. Lighting for advertisements often plays a dominant role in station lighting. Backlit screens create vertical surfaces with high light levels at eye level, causing glare in the waiting area and influencing dark adaptation. Such vertical illumination is just one example of the complexity in urban environments, reinforcing the need to analyze the space, the people and the surrounding context to create appropriate lighting solutions for public urban spaces.

6. Conclusion

There is an inherent contradiction between providing high-intensity lighting and increasing perceived safety. Bright lighting allows improved perception of nearby details but may make the surrounding context appear dark and unpleasant, leading to perception of decreased safety. High intensity in local lighting can also impair perception of the surrounding city and cast unpleasant light on people in the space.

To better understand how luminance intensity influences this situation, we designed this lab experiment to investigate how differences in luminance intensity influence perception of the atmosphere of a space, the experience of co-presence and perception of the surrounding context. Testing different luminance intensities in the local space and different ratios between the luminance of the space and that of the surrounding context in this specific lab setting revealed the following findings:

- Low luminance intensity in the local space increases perception of the space's atmosphere as relaxed and private.
- Low contrast in lighting levels between the local space and the surrounding context increases perception of the area as relaxed and harmonious and decreases perceptions of glare. However, high luminance intensity in the surroundings increases visibility of objects in the surrounding context.

Results from this lab study, which included few variables and was set in an environment that differed significantly for the experience of being in a real-world public transportation waiting area, help define different luminance intensities to be investigated further in field tests. Taken together, insights on how luminance intensity and ratios affect perceptions of privacy, safety and harmony and the contradictory results related to visibility raise important questions about how to determine the appropriate lighting intensity for a public space and the ideal ratio of lighting intensity in the immediate area to that in the surrounding context. This study makes the important distinction that higher intensity lighting in public settings does not always support improved visibility and increased perception of safety. It suggests that outdoor lighting designers may be able to differentiate zones, such as where visibility is most important and where privacy and safety are most important, and develop design approaches that optimize lighting for the most important aspects in each zone.

The results highlight the importance of conducting further research examining vertical luminance-based metrics and the importance of adjusting lighting intensity based on lighting in the surrounding context. Based on our results, it is not sufficient to focus on only the local light zone and the light level at the horizontal ground surface.

The lab experiment has limitations related to investigating perceived qualities. Most significantly, we found it was not possible to replicate the social conditions of an actual waiting area. Therefore, we could not successfully assess the social dimensions of the test. Nevertheless, the results show a direction for future field tests aimed at increasing understanding of the architectural and social potential of lighting in the public realm.

The findings from this controlled lab situation can inform the design of a real-world field test, where all the complex elements of an urban scene are present. We have planned a field test at the Nørreport tram station in Aarhus, Denmark. We will conduct interviews under two lighting condition and include go-along interviews, use of pictures in the process and conduct shorter vox pop interviews. Furthermore, we will take lux and luminance measurements to support the results from the interviews in order to understand how test participants perceive the complexity of an urban space in two different lighting settings. This knowledge will help bridge the gap in the current standards, allowing the design of urban lighting and dynamic lighting scenarios that balance human needs for perceived atmospheres and visual safety. Providing a more pleasant atmosphere at stations may encourage more people to choose public transportation, providing sustainable transportation solutions in urban communities and energy savings from decreased brightness levels.

7. Funding

This research is part of a Ph.D. project in urban architectural lighting funded by the industrial partners Schréder (BE), Holscher Design (DK) and Aalborg University, Copenhagen (DK).

8. Acknowledgement

We would like to acknowledge support from the Lighting Design Research Group at Aalborg University Copenhagen concerning the lab settings and programming of the lighting control for the scenarios and to thank the 30 test participants for their time.

References:

[1] M.C. Dubois, , N. Gentile, T. Laike, I. Bournas & M. Alenius,2019, Daylighting and lighting under a Nordic sky. vol. 1, First edn, Studentlitteratur AB, Lund.

[2] S. Fotios and R. Gibbons, Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations, Lighting Research and Technology, vol. 50, no. 1, pp. 154–186, 2018. https://doi.org/10.1177/1477153517739055

[3] M. Hvass, E.K. Hansen. Architectural and social potential of urban lighting, a field study of how brightness can affect the experience of waiting for public transportation. PLEA Conference proceeding, 2020.

[4] J. Pallasmaa. The Eyes of the Skin: Architecture and the Senses. Chichester, UK: Wiley-Academy. 2005

[5] P. Zumthor. Atmospheres. Architectural Environments. Surrounding Objects. Basel: Birkhäuser. 2006

[6] F. Lam, S. Schemel, F. Zu Dohna, and L. Schwendinger, Cities Alive: Rethinking the Shades of Night (Arup), Arup, no. January, p. 68, 2015.

[7] C. Cuttle, Lighting design: A perception-based approach. Routledge. Taylor & Francis Ltd. New York 2015.

[8] M. Johansson, E. Pedersen, P. Maleetipwan-Mattsson, L. Kuhn, and T. Laike, Perceived outdoor lighting quality (POLQ): A lighting assessment tool, Journal of Environmental Psychology, vol. 39, pp. 14–21, 2014. https://doi.org/10.1016/j.jenvp.2013.12.002

[9] G. R. Patching, J. Rahm, M. Jansson and M. Johansson, A New Method of Random Environmental Walking for Assessing Behavioral Preferences for Different Lighting Applications. Frontiers in Psychology, 08 March 2017. https://doi.org/10.3389/fpsyg.2017.00345

[10] J. Rahm and M. Johansson, Assessing the pedestrian response to urban outdoor lighting: A full-scale laboratory study, Published: October 4, 2018 https://doi.org/10.1371/journal.pone.0204638, PLOS ONE

[11] A. C. Allan, V. Garcia-Hansen, G. Isoardi & S. S. Smith, Subjective Assessments of Lighting Quality: A Measurement Review, LEUKOS, 2019, 15:2-3, 115-126, DOI: 10.1080/15502724.2018.1531017

[12] J.F. Caminada, W.J.M. van Bommel. New lighting considerations for residential areas. International Lighting Review 1980; 3: 69–75. https://doi.org/10.1080/00994480.1984.10748787

[13] S. Fotios, C. Cheal, Obstacle detection: A pilot study investigating the effects of lamp type, illuminance and age. Lighting Research and Technology 2009; 41: 321–342. https://doi.org/10.1177/1477153509102343

[14] S. Fotios, C. Cheal Using obstacle detection to identify appropriate illuminances for lighting in residential roads. Lighting Research and Technology 2013; 45: 362–376. https://doi.org/10.1177/1477153512444112

[15] M. Johansson, M. Rosén, and R. Küller, Individual factors influencing the assessment of the outdoor lighting of an urban footpath, Lighting Research and Technology, vol. 43, no. 1, pp. 31–43, 2011. https://doi.org/10.1177/1477153510370757

[16] N. Davoudian and P. Raynham, What do pedestrians look at night? Lighting Res. Technol. 2012; 44: 438–448. https://doi.org/10.1177/1477153512437157

[17] S. Fotios, H.F. Castleton. Lighting for cycling – A review. Lighting Research and Technology First published online 6 October 2015. DOI: 10.1177/1477153515609391.

[18] M. Dong, S. Fotios, Y.Lin, The influence of luminance, observation duration and procedure on the recognition of pedestrians' faces. Lighting Res Technol. 2015; 47(6):693–704. https://doi.org/10.1177/1477153514539781

[19] S. Fotios, H. Qasem, C. Cheal and J. Uttley, A pilot study of road lighting, cycle lighting and obstacle detection, Lighting Res. Technol. 2017; Vol. 49: 586–602. https://doi.org/10.1177/1477153515625103

[20] S. Fotios, C.J Robbins, S.R. Fox, C. Cheal and R Rowe, The effect of distraction, response mode and age on peripheral target detection to inform studies of lighting for driving, Lighting Res. Technol. 2020; 0: 1–20. https://doi.org/10.1177/1477153520979011

[21] S. Fotios, C. Cheal, S. Fox and J Uttley, The transition between lit and unlit sections of road and detection of driving hazards after dark, Lighting Res. Technol. 2019; 51: 243–261, https://doi.org/10.1177/1477153517725775

[22] C. Villa, R. Bremond and E. Saint-Jacques, Assessment of pedestrian discomfort glare from urban LED lighting, Lighting Res. Technol. 2017; Vol. 49: 147–172. https://doi.org/10.1177/1477153516673402

[23] M. G. Kent, S. Fotios & S. Altomonte, An Experimental Study on the Effect of Visual Tasks on Discomfort Due to Peripheral Glare, LEUKOS, 2019, 15:1, 17-28, DOI: 10.1080/15502724.2018.1489282

[24] P. R. Boyce, N. H. Eklund, B. J. Hamilton and L. D. Bruno. Perceptions of safety at night in different lighting conditions, Lighting res. And technol., 2000, 32(2) 79-91. https://doi.org/10.1177/096032710003200205

[25] M. Kato, K. Sekiguchi, "Impressions of Brightness of Space" Judged by Information from the Entire Space. J. Light & Vis. Env. Vol. 29, No3, 2005. https://doi.org/10.2150/jlve.29.123

[26] M. S. Rea, L. C. Radetsky, and J. D. Bullough. Toward a model of outdoor lighting scene brightness, Lighting Research and Technology, vol. 43, no. 1, pp. 7–30, 2011. https://doi.org/10.1177/1477153510370821

[27] P. R. Boyce, Human factors in lighting, third edition. CRC Press. 2014.

[28] E.J. Flynn, Lighting-design decisions as interventions in human visual space. In J. L. Nasar (Ed.), Environmental aesthetics: Theory, research and applications. New York: Cambridge. 1988

[29] J. L. Nasar and S. Bokharaei, Impressions of Lighting in Public Squares After Dark, Environmental Behavior, vol. 49, no. 3, pp. 227–254, 2017. https://doi.org/10.1177/0013916515626546

[30] S. Fotios and M. Johansson, Appraising the intention of other people: Ecological validity and procedures for investigating effects of lighting for pedestrians, Lighting Research and Technology, vol. 51, no. 1, pp. 111–130, 2019. https://doi.org/10.1177/1477153517737345

[31] R.A. Baron, M.S. Rea & S.G. Daniels, Effects of Indoor Lighting (Illuminance and Spectral Distribution) on the Performance of Cognitive Tasks and Interpersonal Behaviors: The Potential Mediating Role of Positive Affect. Motivation and Emotion, Vol. 16, 1-33, 1992. https://doi.org/10.1007/BF00996485

[32] L.H. Lofland, The Public Realm. Exploring the City's Quintessential Social Territory. New York:Routledge. 2017

[33] E. Goffman, The presentation of self in everyday life. New York: Anchor Books. 1957

[34] N. Davoudian, Visual saliency of urban objects at night: Impact of the density of background light patterns. LEUKOS, 8:2, 137-152, https://doi.org/10.1582/LEUKOS.2011.08.02.004

[35] M. G. M. Stokkermans, I. M. L. C. Vogels, and I. E. J. Heynderickx, The effect of spatial luminance distribution on dark adaptation, Journal of Vision, vol. 16, no. 8, pp. 1–15, 2016. https://doi.org/10.1167/16.8.11

[36] J. E. Flynn, Study of Subjective Responses To Low Energy and Nonuniform Lighting Systems, Light. Des. Appl. LD A, vol. 7, no. 2, pp. 6–15, 1977.

[37] J. E. Flynn, C. Hendrick, T. Spencer, and O. Martyniuk, A Guide to Methodology Procedures for Measuring Subjective Impressions in Lighting, The Journal of the Illuminating Engineering Society, vol. 8, no. 2, p. 96, 1979. https://doi.org/10.1080/00994480.1979.10748577

[38] I. Vogels, Atmosphere Metrics, InProbing experience, January 2008, pp. 25-41. Springer, Dordrecht.

[39] M. Stokkermans, I. Vogels, Y. de Kort, and I. Heynderickx, A Comparison of Methodologies to Investigate the Influence of Light on the Atmosphere of a Space, LEUKOS - J. Illum. Eng. Soc. North Am., vol. 14, no. 3, 2018.https://doi.org/10.1080/15502724.2017.1385399

[40] J. E. Flynn, T. J. Spencer, O. Martyniuk, and C. Hendrick, Interim study of procedures for investigating the effect of light on impression and behavior, The Journal of the Illuminating Engineering Society, vol. 3, no. 1, pp. 87–94, 1973. https://doi.org/10.1080/00994480.1973.10732231

[41] M. Inanici, Evaluation of high dynamic range photography as a luminance data acquisition system, Lighting Research and Technology, vol. 38, no. 2, p. 135, 2006. https://doi.org/10.1191/1365782806li164oa

[42] Banenorm BN2-81-1. https://www.bane.dk/da/Leverandoer/Krav/Tekniske-normer-ogregler/Banenormer

[43] Vejregler, standsningssteder for letbaner http://vejregler.lovportaler.dk

[44] G. Ward Photosphere. http://www.anyhere.com

[45] J. Tanizaki, In Praise of Shadows. Stony Creek, CT: Leete's Island Books. 1977