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Review

Perceived Lighting Uniformity on Pedestrian Roads: From an Architectural Perspective

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Abstract: Lighting uniformity is a key factor in traffic safety, and it could even result in energy savings for light installations. However, highly uniform horizontal road lighting for motorized vehicles may not be optimal for pedestrian roads. Therefore, it is important to evaluate the way in which pedestrians experience road lighting uniformity. Accordingly, we employed a qualitative approach to examine pedestrian road lighting uniformity. Visual analyses were used to exemplify and discuss the perceived uniformity. The case studies were performed on three pedestrian roads with similar light installations. The results show that the experience of road lighting uniformity differs substantially between the three roads. Based on the case studies, there are many aspects that need to be considered beyond the light falling on the horizontal surfaces. This study suggests that the visual experience of road lighting uniformity for pedestrians is difficult to estimate with photometric values because the visual impact of uniformity is highly influenced by the spatial context and landscape.

Keywords: lighting; uniformity; light distribution; pedestrian; road lighting; street lighting; urban space; exterior lighting; architectural lighting; qualitative method

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1. Introduction

For road lighting, uniformity is traditionally considered necessary to provide a background against which objects can be observed and to ensure minimum road visibility [1]. Therefore, standards for road lighting usually include a minimum acceptable level of uniformity. For example, for motorized traffic (M lighting classes), the European standard stipulates that the overall uniformity of road luminance (Uo) must be 0.35–0.40, depending on the class [2]. For pedestrians and pedal cyclists (P lighting classes), overall uniformity is the ratio of the lowest to the average value of horizontal illuminance on a road area [2]. Requirements of high uniformity result in limitations in pole distance, which in turn results in increased resource use and less energy-efficient road lighting installations. Since uniformity may limit the energy savings of an installation, it is important to ensure that the requirements are motivated by the functional needs of the users. Lighting uniformity can affect users' experience of the exterior environment, for example, by providing reassurance [3] and an increased perception of safety [4].

The technical report 136–2000 from the International Commission on Illumination (CIE) gives guidance for lighting in, for example, residential roads, community areas, industrial and business areas, but according to Fotios et al., the report is outdated [3]. Moreover, the criteria behind the recommended target illuminances for pedestrians are unclear [3]. It has been shown that there is a connection between brightness and the experience of reassurance [5]. However, previous research on lighting and reassurance has mostly focused on average horizontal illuminance [3]. This is problematic, since, regardless of which illuminance levels are tested, people generally prefer the brightest levels [5]. It is possible to obtain the same mean values for illuminance from a lighting installation with high and low levels of lighting uniformity [3]. Fotios et al. further suggest that the spatial distribution of light can be more important than the amount of light. They also propose that reassurance is better described by the minimum illuminance or the uniformity of the illuminance (minimum/mean) than by the average illuminance on a horizontal surface [3,5]. Road lighting is often planned from the perspective of motorists, requiring a high amount of wattage to maintain traffic safety, but such roads are commonly shared by pedestrians and bicyclists. For example, a two-lane motorist road normally has adjacent bicycle and pedestrian lanes or sidewalks, and smaller residential roads are often planned for mixed use. Although users commonly share the same road environment, the functions of lighting uniformity are likely to differ significantly between motorists and pedestrians. For motorists, a high priority of uniformity is traffic safety to ensure that drivers see objects in and around the road. Meanwhile, uniformity for pedestrians and bicyclists is important due to perceived safety and reassurance. However, actual traffic safety and perceived safety/reassurance are not the same thing. People may feel safe where the danger is high and insecure where the risk is low. In addition, safety in traffic is not the same as pedestrians' reassurance related to attacks or the risk of falling.

Less research has been performed on lighting for pedestrians than on lighting for motorized traffic [6]. Since this field is diverse and partly unexplored, more studies are needed in various contexts. For example, few previous studies discussed uniformity in relation to spatial context and complexity. One of these studies was conducted by Haans and De Kort [7]. They found that pedestrians prioritize light close to themselves, and thus, the need for total uniformity throughout the road may be of less interest. Fotios et al. suggest that spatial light distribution should be considered as a whole rather than just looking at horizontal illuminances, and thus, the right approach would be to analyze the entire spatial context [5].

This article's main contribution is to "shred light" on visual perception of the complex spatial context as a whole. Even though lighting is a visual phenomenon, perception of an entire spatial context is seldom discussed within the lighting research field. Another important contribution is that this study shows examples of what kind of knowledge lighting researchers can reach with qualitative methods. In this article, we review the connections between pedestrian road lighting uniformity in an urban space and the landscape as a whole. In addition to focusing on this area, we used three roads as case study examples. Since we are introducing a new way to approach road lighting for pedestrians, examples are necessary to illustrate our concept. Thus, we observed three sites with different features to analyze and discuss the visual effects of road lighting.

The three roads have similar lighting equipment but are in different settings. This study takes a holistic perspective of the urban space. Spatial contexts are complex, with many factors interacting [8]. Consequently, the roads were analyzed qualitatively to collect rich examples describing connections relevant for the pedestrian experience.

Based on this introduction, the following research questions were formulated:

- If two roads have the same level of lighting uniformity, will they be visually perceived as equally uniform? If not, why?
- If a site has a uniformly lit road, will it also be experienced as a uniformly lit urban space, despite the spatial context?
- Which physical elements in urban spaces, except for road lighting, can affect the appearance of lighting uniformity?

The requirements for uniformity based on light distribution have implications for sustainability and energy use. For example, the minimum required uniformity limits the maximum pole distance, which in turn results in an increased use of resources (luminaires and poles per km of road) and less energy-efficient road lighting installations. Consequently, if a non-uniform light can fulfill our needs just as well or even better than a more uniform light, it is important to investigate this further.

By lighting uniformity, we refer to lighting measured horizontally at the road surface as well as lighting in the visual field, including vertical surfaces, measurable with a luminance camera. We look not only at the light itself but also at contrasts and shadows and their impact on the perception of the lit areas. We focus on the pedestrian perspective, and even though most pedestrian roads are also often used by bicyclists, we primarily treat them as pedestrian roads. Since articles about visual perceptions of road lighting are scarce, some interior studies with relevance for exterior lighting are also included in the review.

The structure of this paper is as follows: After Section 1, Introduction, follows Section 2, which details the theoretical background. Section 3 describes the methods and materials used, while Section 4 presents the findings from the case studies. Section 5 includes the discussion. Finally, Section 6 concludes the paper. The Appendix A further illustrates the effect of light distribution in the urban space.

2. Literature Review

2.1. Brightness, Contrasts and Visual Guidance

Luminance distribution can affect the appearance of brightness [9]. Due to the contrast effect, a non-uniformly lit surface's brightest area always looks brighter than the brightest area on a uniformly lit surface. Veitch and Tiller found that non-uniform illumination in an interior room appeared brighter than uniform lighting [9]. Simultaneously, brighter surfaces look even brighter in uniform light [9]. The contrast effect makes darker areas near brighter areas look darker, but this effect is not possible to measure [3]. Brighter light has been experienced as safer than less bright light [10]. Nasar and Bokhaeri found that when brightness is combined with uniform light it can be perceived as safer than non-uniform light [4]. Additionally, the spectral power distribution seems to affect brightness perception [11]. White LED lighting can increase the experience of reassurance [12].

Clear contrast with variation between light levels supports peripheral vision, which we use for spatial orientation. If everything is lit at the same level, there will be no contrast. Contrasts created by differences in shadow and lightness, support three-dimensional perception of shapes and depth [13]. Luminance contrasts can, for example, both reinforce and reduce the saliency of a building [14]. If contrasts are planned carefully, a less uniform light might be beneficial for orientation.

It is well known that our gaze is attracted by light and the brightest contrasts in a room [15,16]. Moreover, we automatically search for meaningful patterns [17,18]. In daytime, we obtain a broad and immediate overview of the urban scene. At night, the gaze needs to find a meaningful pattern by jumping from light spot to light spot. Unclear guidance can be caused by too few light spots, which cannot give a meaningful picture of the scene, or by light spots placed in an irrational pattern.

Illuminating only the horizontal surface will not contribute much to visual guidance. Few people recognize where they are by looking at the asphalt. If we only plan road lighting for horizontal uniformity, we miss the opportunity to benefit from reflective vertical surfaces. We need to detect spatial boundaries, sightlines, entrances, exits and where people can hide. To grasp the urban space at a quick glance, we need contrasts. With light on vertical surfaces, the contrast between the illuminated ground and the dark view at eye height can be softened. Illuminated vertical elements aid in our perspective vision, distance judgement and visual guidance. The concept "wayfinding" was first developed in 1960 by the architect Kevin Lynch [19], who formulated a number of categories for analyzing cities (paths, edges, districts, nodes and landmarks) [20]. Spatial understanding increases when key elements are highlighted. Consequently, everything cannot be illuminated with the same intensity or uniformity. If a space lacks contrast, nothing will call for attention, and the space will lack interest.

2.2. Horizontal and Vertical Light Distribution

When several light zones are close enough, they can be perceived as a coherent light pattern [21]. According to Nasar and Davoudian, overlapping circular patterns of light can be regarded as uniform, while separate light zones constitute non-uniform light [4]. If such a pattern is horizontally or vertically positioned, it may affect the perceived size and shape of the urban space [21]. Research on interior lighting also has relevance for outdoor lighting [21,22]. Architectural praxis indicates a relationship between a painted vertical-striped pattern and a raised spatial impression of height [23,24]. Matusiak's studies of window shapes support this relationship [25,26]. A horizontal pattern seems to increase the impression of width, and a pattern following the road's length can emphasize the depth of the urban space [21].

Road lighting is often planned with a focus on the road surface, i.e., horizontally. Further, also, interior light planning has since long focused on uniform lighting on horizontal surfaces, which are mainly used for work tasks [27]. However, vertical light on walls is important for creating interest [13,28,29]. Streetlighting often spills light onto surfaces along the road, such as trees or ditches, due to the required edge illuminance ratio or the lighting design. The light beside the road can also be consciously planned so it illuminates an adjacent bicycle path. If only the street surface is lit, the contrasts with the unlit background appear darker, affecting the visually perceived uniformity of the road. Hence, in such circumstances, there is an increased need to consider the surrounding contrasts. Since our spatial orientation, which is based on the peripheral vision (surrounding vision), depends on field contrasts, the vertical surfaces at the site can be used as reflectors. Vertical surfaces can consist of different objects such as a slope or a fence. Still, there is no need to illuminate all vertical surfaces, just a selection of them. In addition, it does not have to be done with spotlights or floodlights. The placement of vegetation or trees in relation to streetlighting or the placement of streetlighting in relation to building corners or trees can be enough.

Vegetation (e.g., bushes and trees) can act like vertical surfaces that reflect light. Indeed, the beautiful bushes and trees we appreciate during the day do not have to become scary at night. If they reflect some light they may work as a visible vertical surface. Nikunen et al. [30–32] propose that the attention restoration theory (ART) can be applicable to exterior lighting [33], meaning that illuminated vegetation is beautiful and attracts attention, forcing one to look farther and maintain one's gaze. Thus, vegetation can contribute to restoration and to the feeling of being safe.

When there is a gap between a coherent row of light, it can be experienced as a dark spot, adding to the perceived insecurity on the road. An example is when a row of facades reflects the road lighting. Between the facades, bushes that are not reached by the road lighting appear to be dark spots. Furthermore, dark spots are often the result of too much light in other places [4].

Very bright and uniform illumination on a walking path with dark surroundings may disturb dark vision. This reduces the possibility of seeing threats from the dark spots along the road, and pedestrians may be exposed and easier to attack. This feeling of exposure can increase feelings of insecurity. Haans and De Kort discuss the perception of light coming from a close distance compared to a far distance with regard to perceived safety [7]. In their study, a number of luminaires were controlled so either the light of the participant's closest luminaire was weaker, with an increased level farther away, or the closest luminaire had the highest light level, with the level decreasing to the farthest luminaire. The results revealed a preference for more lighting close to the observer. However, it is likely that contrast had a large effect (e.g., if it was very dark or even slightly dark at the end of the street). They do not report whether or not the light reached vertical surfaces and if that might have influenced the results. A street with lit facades or a lit landmark in the observer's sight line has clear spatial boundaries, which have an important impact on the feeling of being safe. With an overview (prospect), it is easier to see how large a space is, where the space ends and where the exits are located (escape). With an up-lit background it is also easier to detect places where other people may hide (refuge/concealment). Cutting and Vishton describe the "action space" as the possible area for acting in response to an attacker [7,34,35]. The action space is a circle of 30 m around a person. Therefore, an action space 100 m away makes no sense. "Vista space" is defined as the area outside of the action space. Lighting in the vista space is more useful for planning actions, orientation and wayfinding [7]. The speed of pedestrians, bicyclists and drivers also matters. When travelling at a lower speed, one sees more of the surroundings. Accordingly, cyclists may need a wider light compared to pedestrians.

People's experience of spatial contexts can be rather unpredictable. In an experimental study, it was found that less uniform lighting from lower-placed luminaires (4.5 m) along a street, increased feelings of reassurance, compared to more uniform lighting from higher-mounted luminaires (6 m) [36]. The interviewees explained that the lower lighting height made them feel as if pedestrians were being personally addressed. The lower height also provided more vertical light on the facade and created a smaller light space. To them, this was more important than the light distribution. The concept of light topography focuses the awareness of the impact of luminaire placement height.

2.3. Spaciousness and Enclosure and Their Impact on the Perception of Uniformity

Uniform light can make a space feel more detached and less tense than a space with non-uniform lighting [37]. Spaciousness can be enhanced with uniform lighting, while the experience of privacy can be reinforced with non-uniform and peripheral lighting [4]. Legible spatial boundaries enhance the enclosed space around an individual and reveal the size of the space. When creating legible spatiality, contrasts are more important than uniformity. Spaciousness is connected to anxiety [38], and the term spatial anxiety refers to uncertainty caused by unclear visual guidance [20].

For both humans and animals, the feeling of being safe is related to the theory of fight or flight. Both need the ability to move and to get an overview of the scene [39,40]. This is the foundation of prospect-refuge theory [41], which holds that individuals wish to see but not to be seen [42]. If the road is dark, it is only possible to see what is on the road, leaving one exposed to someone hiding in the darkness. Lighting research shows that people feel more comfortable when sitting against a wall when looking out into an open area [43–45]. A related theory is Stamps' permeability theory [46–49]. This theory holds that enclosedness reduces safety, as one may feel trapped, and a possible threat may lurk behind visual obstacles. It is unsurprising that Stamps proposes a focus on openness rather than enclosedness. Indeed, an experimental study on a campus demonstrated that prospect is the most important factor for perceived safety [7]. However, this article proposes Wänström Lindh's theory of visual spatial boundaries [21]. Wänström Lindh's theory is based on the notion that visible (illuminated) spatial boundaries are essential for spatial understanding, which is beneficial for reassurance. Spatial enclosure relates to the experience of being inside a legible space.

Light on vertical walls emphasizes spatial enclosedness, since they define the space around us. With lit walls, enclosure becomes more noticeable. Vertical light can increase or decrease the sense of spaciousness, and according to the context, spatial size affects reassurance. Visible walls make it possible to estimate the size of the space and where it ends and to locate entrances and exits. It also facilitates perspective viewing. Therefore, vertical light assists with visual guidance. This is crucial for reassurance. If the space is totally open, there are too few clues to help an individual orientate. Thus, both openness and enclosure are essential.

It was found that coziness increases with both changes in raised light level and uniformity [50]. Coziness is connected to emotion and atmosphere, which are related to an enclosed space. Street lighting may not often be associated with coziness, but if the term coziness is replaced with comfort and pleasantness, it is possible to see connections.

3. Materials and Methods

Lighting research has a long tradition in physics and engineering, primarily using quantitative methods based on measurements and calculations [51,52]. Indeed, the gap between engineering-based research and lighting design research is evident due to the designer's use of qualitative methods [53,54]. There are few studies based on qualitative methods, such as field observations of complex urban spaces and interviews about peoples' experiences [51,55–57]. Most previous studies were laboratory based [37]. In recent years, more studies have been conducted in complex environments [4,7,12,14,20,58–63], and the number of studies based on qualitative methods is increasing [64–68].

3.1. Case Studies

For the case studies, three pedestrian (non-motorized) roads were selected. These were chosen from the network of pedestrian and bicycle roads in Jönköping City, in Sweden. All of them were designed by the same energy municipality lighting planner and installed in 2017. The selection criteria involved roads with similar lighting equipment and identical luminaires (CREE Road TS with LED 4000 K) but with some variation in uniformity caused by distance between poles or luminary height. It is difficult to locate streets with exactly the same prerequisites where only one variable is changed (in our case, the uniformity). Hence, the aim of the case studies was not to find totally comparable street lighting. Rather, the purpose was to find examples of different variations that might occur and to observe and discuss the visual effects of the lighting. In this city, 4000 K is used for this category of roads and is in line with recommendations at the national level (3000 K is mainly recommended for urban areas, and 4000 K is recommended for motorized roads when a white light source is used) [69].

The case study observations were performed by researchers to generate rich descriptions, which may have been difficult without experienced visual observers. Visual observations of spaces and phenomena by one observer have a tradition within the field of color and light perception [57,64,65,67,70–74]. The observation process was inspired by experimental phenomenology [75]. The intention was to see the lighting situation as it is but also to see it in relation to the whole space (e.g., pavement, trees). The observation sessions started with watching to obtain an overall impression (see Table 1). Aiming to avoid snap conclusions, the second step involved describing the environment. In the third step, these observations were associated with functions and spatial elements. The fourth step aimed to find patterns characterizing the urban space. The fifth step involved reflecting on the interpretations, and the sixth step focused on the lighting and the site characteristics. It is important to minimize personal assessments of the site to reduce the risk of bias. When observers describe what they see, it is usually something other people can recognize as well as an intersubjective experience [76]. In the seventh step, the different sites were compared with themselves and with other environments in the researchers' personal frame of references. This analyze can be performed by a single person as well as by a group of researchers. If a single researcher is used, the discussion will be performed by discussing own results in relation to previous literature. With several researchers this strategy will also comprise discussions between the researchers.

The observations took about an hour at each site. When walking the roads, spots where the character of the spaces change were documented with sketches and photos. Sketching is a beneficial tool for observing in detail as well as with an overview, without becoming stuck in immediate theoretical interpretations. Mäkelä argues that drawing is not just to illustrate; it can drive the research inquiry further [77]. Thoughts are processed during sketching. Polanyi's concept, tacit knowledge, emphasizes that there are values we do not usually formulate into words [78]. Such values can emerge through sketching. When sketching is allowed to take time, more details appear. After a while, it becomes possible to see beyond the first impression. When considering in detail where shadows fall and how far the light reaches, prejudices start to fade away. While sketching, one needs to be very attentive. Visually documenting different spatial shifts is an approach inspired by Cullen's serial vision method [79]. Cullen's analysis method implies that series of pictures (drawings/photos) are taken while walking along a distance. When something apparently changes in the urban scene, a picture is captured. By this, serial sequences, emphasizing rhythm and spatial character in the urban space, are visually observed and noted. The experience of spatial boundaries is the focus of Branzell's sketching method [80]. Both researchers analyzed the first two roads in Råslätt and Lockebo, while the third road was analyzed by only one researcher. The analysis procedure was the same at all sites. Rather than during the analysis, the discussion for the third site occurred afterwards.

Table 1. Phases in the visual observation and the analysis process.

Steps	Moments	Analysis Focus	Variables, from Steps 1–2
1.	Watching	Overall impression	Attention point
2.	Describing the environment verbally/visually How?/Where?	Spatial light distribution Atmosphere	Brightness/shadows Contrasts/gradients Light patterns Uniformity Reflecting surfaces/objects Spaciousness/enclosure Light topography Verticality/horizontality Light on/beside roads Road type/location Spatial context Visual guidance Public/private character Variation/monotony Reassurance Prospect/refuge
For steps 3–7, all the variables from steps 1–2, are included.			
3.	Discussing associations	What Why	
4.	Searching for patterns	Which Why	
5.	Discussing interpretations	How Why	
6.	Discussing preferences/bias	What Why	
7.	Comparing with the other sites	Which What How Why	

The procedure needs to be adjusted for each study context. In this case, the procedure above did not take color characteristics into account. Another study could build on a similar structure yet focus more on color than light distribution.

DIALux evo 9.2 was used to calculate average horizontal illuminance, minimum illuminance and the overall uniformity of road surface illuminance of the road area for each of the field sites. The same dimensions (luminaire height and pole distance) as in the field were used with road widths of 3 and 4 m, respectively. The road lighting for all three roads was permanent, installed by the municipality energy company in 2017. Nothing was changed for the study. The luminaire light distribution specification was provided by the luminaire manufacturer (CREE Ledway road TS 20 LED 4K, 49 W). A correction was made to adjust the average illuminance and minimum illuminance for a 75% effect (37 W) for Råslätt and Lockebo and for a 49% effect (24 W) for Ljungarum.

3.2. Sites

The road sites have different characters. The first road (Råslätt) is a walking road in an enclosed forest, without motorized traffic nearby. The second road (Lockebo) is a walk-way adjacent to a frequently trafficked car road in a spacious, open landscape. The third road (Ljungarum) runs next to the motorized lane but is of a different character, with trees between and separated lighting principles (see Figure 1).

Råslätt and Ljungarum had similar average horizontal illuminance, minimum illuminance and overall uniformity, whereas Lockebo had lower average horizontal illuminance but higher minimum illuminance and overall uniformity (Table 2). Lockebo had 30% higher uniformity compared with Råslätt and Ljungarum. All three roads fulfill the criteria for lighting class P5 for average illuminance (3.00 lux) and minimum illuminance (0.6 lux) [2].

Table 2. Lighting specifications.

Site	Råslätt GPS 57.746888, 14.153410	Lockebo GPS 57.732863, 14.145858	Ljungarum GPS 57.751750, 14.171973
Height of luminaires	6 m	7 m	5 m
Pole distance	40 m	42 m	32 m
Correlated color temperature (CCT)	4000 K	4000 K	4000 K
Effect	37 W	37 W	24 W
Average horizontal illuminance (lux) *	4.20	3.40	4.19
Minimum illuminance (lux) *	0.68	0.77	0.73
Overall uniformity *	0.16	0.23	0.17

* Calculated in DIALux evo 9.2.

4. Results and Analysis

4.1. Spatial Character

Råslätt's pedestrian road has the character of a walking path in the forest. It runs separately, not adjacent to any road. The pedestrian road is characterized by curves, slight hills and vertical surfaces, with light falling on the pine trees surrounding the road. It is an enclosed space, with vertical surfaces constituted by the tree trunks. The vegetation makes the surroundings colorful, including the red ground cover of conifers and the green pines. The luminaires are one-sided, which results in some spilling of light onto the sides of the nearest part of the forest.

On the walking path in Lockebo, the street lighting is one-sided and positioned on one side of the road, with an adjacent road for motorized traffic on the other side (see Figures 1 and 2). The light mainly falls on the pavement, but not on the car side. The row of light poles is adjacent to the car lane, without separation other than a curb strip. The landscape is flat and wide with open areas on both sides of the straight road. There is virtually no vertical light, with the exception of the low grassy slope, which receives a weak spill of light. The space is more open on the lamppost side, which is also lighter. There is a forest on the other side of the car lane, but it is relatively far away from the pedestrian road and the lighting, so it does not contribute as a vertical surface.

Further, in Ljungarum the pedestrian and bicycle road are adjacent to the motorized traffic road, separated by vegetation. The road's closest surroundings are leafy, with partly overhanging foliage. Beyond the foliage is a dense, but small forest. Deciduous trees are growing next to the pedestrian path, and there are sparsely planted trees between the path and the car road. The pedestrian road is on one side, with a tree-planted green ditch between the car road and the pedestrian road. Despite the car traffic being so close, the experience is that the pedestrian road is positioned separately. The spatial character is semi-open, and there is visual contact with the car lane. The luminaires are placed shorter distances apart (32 m) in comparison to the other roads. The luminaires are positioned both on the pedestrian/bicycle path and on the motorized road next to it. The pedestrian road's cold LED light contrasts with the warm high-pressure sodium light on the adjacent motorist's road. The motorized road has higher-positioned luminaires, and the luminaire poles are placed close to trees.

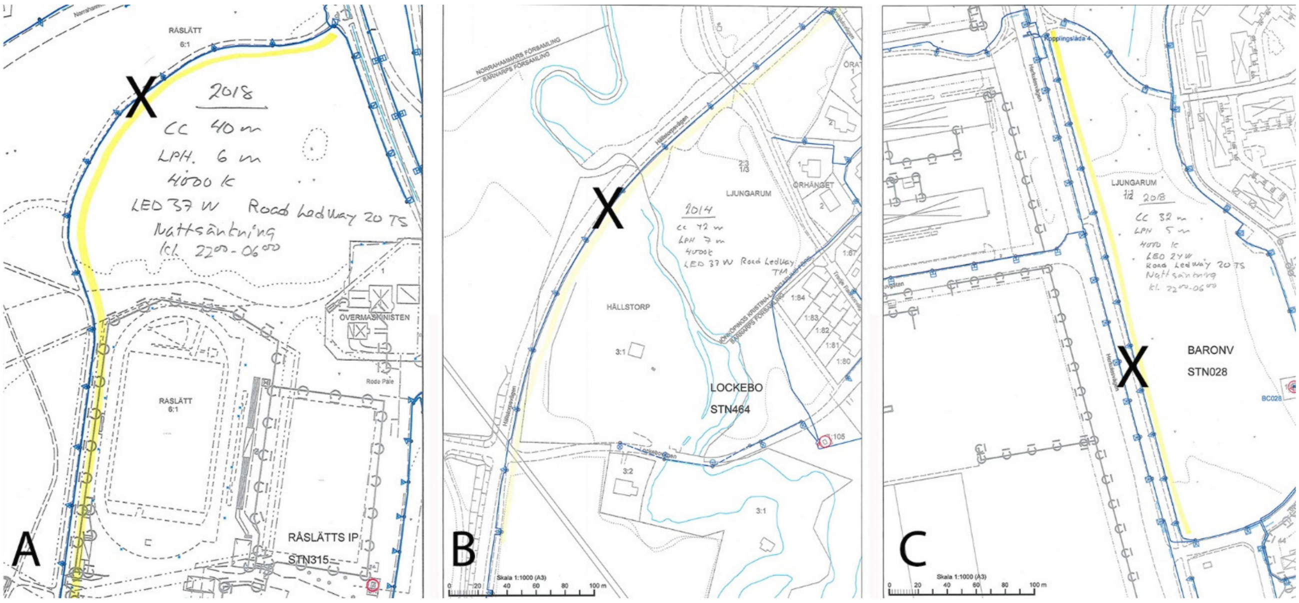

Figure 1. On the images with maps, we see the roads from left to right: (**A**) Råslätt; (**B**) Lockebo; (**C**) Ljungarum. The cross marks the position of photos and drawings.

Figure 2. On the photos, we see the roads from left to right: (**A**) Råslätt; (**B**) Lockebo; (**C**) Ljungarum.

4.2. Uniformity Analysis

The lighting is less uniform in Råslätt because there is a hilly and varied landscape. The distance between the luminaire poles is slightly larger in Råslätt, compared to Ljungarum. This is unusual considering that this road is smaller, than the other roads (the poles are placed in old fundaments). Yet, in this context, it was not experienced as uneven. This could be related to the spatial context—uniform light distribution is not expected on a small, curvy and hilly forest road. Therefore, the lighting distribution is sufficiently uniform for the spatial context.

In Lockebo, one might expect totally uniform lighting since the road is broad, flat and straight and is situated in a monotonous landscape. The repetitive light poles constitute the only variation. However, the light creates a striped pattern between light and shadow when the road is seen at a distance. This pattern was probably more obvious because of the lack of contrast in the visual field. It is possible that a similar pattern could have been discovered in Råslätt but that it was "conjured away" by the trees and the curves and hills of the road.

The visual observations in Ljungarum gave the impression that the light at eye height was uniform and abundant. The poles are closer together and shorter than at the other sites. However, the branches in the forest edge cast heavy shadows, which create a striped pattern on the ground. The light on the tree foliage increases the feeling of reassurance, while the ground shadows decrease it. The road is uniformly lit, but the impression of nonuniformity is strong. While Lockebo was experienced as deserted and repetitive, Ljungarum created a lively and varied impression. In wintertime, when the leaves have fallen from the trees, the lighting in Ljungarum gives a more uniform impression.

4.3. Light Topography

Comparing the other case study roads with the pedestrian road in Råslätt, there are several differences. The lamp poles in Lockebo are 7 m high, while in Råslätt they are 6 m high. On such a wide road as in Lockebo, higher poles seem reasonable. At the same time, the wide, open, urban space means that the free-standing poles are perceived as much higher in Lockebo than in Råslätt, where they blend in with the pine trunks. The space assumes a clear angular shape when seen at eye height, with a wide base and a high side next to the car lane. In Ljungarum, pedestrians and cars are clearly separated by the different luminaire heights. This can be compared with Lockebo, where the pedestrian light seems to be planned with motorized traffic in mind rather than pedestrians.

4.4. Light on Vertical Surfaces

Vertical light, consisting of spill light from the road lighting, falling on trees, is more apparent in Ljungarum than in Råslätt. In Råslätt, the most light reaches the pines trunks a few meters away. In Lockebo, there is no vertical light at all. Light on vertical surfaces may give a brighter impression, since the environment is primarily seen at eye height. It also reduces the contrast between the bright light source and unlit areas. Moreover, the lit trees constitute a vertical wall that gives stability to the architectonical space.

The spill light, which falls on the trees in Ljungarum, adds considerably to the street space. The trees both give and take reassurance. Their lit appearance softens the hard road surface impression and gives a feeling of personal liveliness. On the downside, the light only reaches the closest branches, not deeper than 1–2 m into the forest growth. The contrast between the lit and the unlit areas increases the impression of dark spots. It is not possible to see if anyone is hiding there. The problem is not the existing light on the trees but rather the lack of an adaptation area connected to the trees and bushes at the forest's edge.

4.5. Visual Description of Spatiality and Enclosedness

The sketches show the architectural experience as a co-play between common lighting principles in the landscape (Figure 3). The artist's observation and interpretation are visible in the drawings. The variation between the urban spaces is emphasized by the simple sketches. The spaces' shifting character, with openness (Lockebo) and enclosedness (Råslätt and Ljungarum), is emphasized. The differences can be seen between the lit ground and/or illuminated vertical surfaces, such as trees. We can reflect upon the difference between visual guidance with continuous light following the road (Lockebo) and guidance with unevenly distributed light zones as milestones (Råslätt).

In Appendix A, there are more illustrated examples of the possible effects and consequences of different light distributions and uniformity.

Figure 3. Analyzed sketches, from left to right: (**A**) Råslätt; (**B**) Lockebo; (**C**) Ljungarum.

5. Discussion

This study visually analyzes three cases. In each of those cases, the analyses reveal context-related insights. The perspective shifted between the sites, from a site-specific context (Råslätt), to a spatial context (Lockebo) and, further, to a functional context (Ljungarum):

- The roads in Råslätt and Ljungarum had similar uniformity (0.16 and 0.17, respectively). In Råslätt, the hills and curves caused the lighting to appear even less uniform. However, in Råslätt, the light did not feel non-uniform because of the spatial context—one seldom expects to find a uniformly lit road in a forest. In Ljungarum, the shadow pattern on the ground was distinct. The spatial context, with asphalt pavement next to a residential area, made the shadows more apparent. Additionally, the shadows cast by trees strengthened the impression of non-uniformity. On the other hand, the tree shadows also masked the lighting uniformity. Shadow patterns were seen at both sites, but the non-uniformity was more obvious in Ljungarum, demonstrating that two roads with the same level of lighting uniformity are not necessarily visually perceived as equally uniform.
- The Lockebo road, which had the highest uniformity (0.23, 30% higher than the other roads), was regarded as both uniform and non-uniform at the same time. The monotonous landscape contributed to the impression of uniformity. Despite this, the soft and uniform impression emphasized the non-uniform striped shadow pattern on the road surface. This shows that visual perception is not easy to predict. The impression of uniformity was reduced in relation to the uniformity of the landscape. Because of the uniformity, the non-uniformity became more obvious.
- The cultural context (a forest) and spatial context (enclosedness and openness), curves and hills as well as vertical surfaces and vegetation impacted the visual experience of lighting uniformity. Hence, there are many physical objects and surfaces that affect visually perceived uniformity, separately or in combination.

According to Veitch and Tiller, the contrast effect can make non-uniform surfaces appear brighter [9]. The largest contrast difference was found in Råslätt. Because the pine trees were so tall, the light at the ground level had a smooth gradient up to the sky level. This means that there were no hard contrasts. At the monotonous scene in Lockebo, only the pedestrian walkway was lit, and the open landscape was dark. Fotios et al. noted that dark surroundings may look even darker in contrast to a lit road [3]. This means that a pedestrian will be exposed by light and be more visible for the other traffic. Boyce refers to research showing that brighter light is generally considered to be safer [10]. This is not always the case, however, if it is exposing a person (e.g., to an attack). Hence, Boyce may not have considered the contrast effect when describing uniform light as safer [10].

The non-uniformity in Råslätt gave a pleasant impression. It would have been strange for a forest path to be lit as uniformly as a road intended primarily for motorized traffic. Nevertheless, there was enough light, and it was well placed. Cutting and Vishton found that people mostly fixate their gaze on a spot close to themselves [34]. Similarly, Haans and De Kort concluded that people prefer a light close to themselves [7]. This relates to the experience of light topography [22]. Matusiak and Sudbø showed that vertical window patterns emphasize the perception of a high room [26]. The pine trees give a vertical emphasis even without added light. Since the light does not reach higher than the luminaires, a lower light zone is created. Considering the study of Wänström Lindh, where people felt safer in a lower personal space, it seems possible that people also feel safer in a light zone that is not too high [36]. In Råslätt, separated light zones enhance wayfinding, as they can be read together as a coherent pattern [19–21].

In Lockebo, the lighting was uniform, and the impression of uniformity was strengthened further by the poor variety of the landscape. Only horizontal surfaces were lit. All one could see was a huge open space. It is likely that the lack of vertical surfaces affected the impression of uniformity in Lockebo. The experience would have been the same if the site had vertical surfaces, but they were invisible in the darkness. Nasar and Bokharei found that uniform lighting contributes to a spacious impression, so in Lockebo, the lighting strengthened the impression of desertedness [4]. Moreover, their finding that the impression of privacy increases when a space has more non-uniform and peripheral light is applicable in Råslätt and Ljungarum. Visible vertical surfaces are important for stimulating visual interest [13,28,29]. In both Råslätt and Ljungarum, trees acted as reflective surfaces, catching light and casting shadows, which created more enclosed spaces. This created more varying contrasts on these roads compared to the uniformity of the Lockebo road. In Råslätt and Ljungarum, the visible vertical surfaces—vegetation—directed less attention to the road lighting falling on the ground. This space included both vertical and horizontal light, and none of the directions were more prominent than the others.

Regarding the physical spatial boundaries, the enclosure of the three spaces were contrasting: Lockebo was totally open, with a lot of prospect but no refuge; Råslätt was totally closed with minor prospect but refuge; Ljungarum was semi-open, with both prospect and some extended refuge [41]. In Ljungarum, the bushes along the walkway were dense, and so it is more likely that a pedestrian would wish to have prospect than to seek refuge there [4,41]. If the wall of foliage was even more dense, there would have been less risk that anyone could hide inside the bushes. From the perspective of visual interest, the variation and rhythm created by the foliage in Ljungarum contributed to variation and rhythm, emphasized the vertical walls and fostered a warm, lively atmosphere with a personal expression. According to Nikunen and Korpela, it is possible for illuminated foliage to contribute to well-being and a feeling of safety [32]. A more detailed and context-adjusted light plan could have directed more spill light onto the bushes. The combination of a pattern of light zones, with basic light on the lower level between them, was effective on the forest road in Råslätt.

From an architectural point of view, the Lockebo road would have more visual interest with less uniform lighting. The danger of stumbling and falling is lower, since the road surface is so smooth and the road so straight, and there are no places to hide due to the open surroundings. It may be possible to save energy if uniformity could be reduced in the planning stage of similar environmental road conditions. A less uniform pattern of light zones could have added a varied rhythm to the urban scene. By directing more spill light to the grass slopes and the luminaire poles, at least some vertical light would been added to the urban scene.

An analysis from the pedestrian view differs from the drivers in the time they spend at a site. The pedestrian sees more details, has a wider view, and can turn around. There are also differences in what a pedestrian or, respectively, a driver need to detect. With an increasing speed, the beautiful surroundings become less interesting. Traffic safety is important for everyone, and the need for safety increases with the driving speed. Uniformity at the ground surface is considered important for traffic safety. Yet, we do not need to light up the pedestrian zone with the same light levels and uniformity as for the motorized traffic. In pedestrian zones, the focus is directed towards the vertical spatial boundaries, while the motorized areas have more focus on horizontal surfaces, and mixed traffic roads need a combination of both horizontal and vertical light. Light at vertical surfaces can sometimes also be sufficient for motorized traffic; illuminated landmarks can help to locate the position.

It is possible that light at eye height is more important for pedestrian's orientation and reassurance than light on the ground. Today, it is likely that energy is wasted by focusing on illuminating horizontal surfaces with a high level of uniformity. Reflecting vertical surfaces could increase the impression of brightness in the whole space. Light in spread-out spots could provide visual guidance, and thus, light at eye height does not need to be completely uniform. However, uniform/non-uniform as well as horizontal/vertical light need to be balanced. There must be some light on the ground, and the lighting should not be too non-uniform.

To achieve lighting that is better suited for each site, there is a need to allow for individual adjustments. The design of street luminaires could be improved, enabling light to be directed with precision onto vertical surfaces, vegetation and architectonic elements behind the lighting poles. Naturally, this must be done in a holistic and sustainable way to meet the demands for visual performance, security and safety without increasing light pollution or ecological impacts. A better understanding of the perceptions of lighting uniformity could lead to improvements in lighting design, resulting in energy savings without adversely impacting the pedestrian perception. The proposed optimal criteria for reassurance and obstacle detection could be used in combination with an improved feeling of spaciousness to improve users' perceptions of a pedestrian road. Light on pedestrian roads could probably be reduced and combined with some spill light on vertical surfaces next to the road. An increased feeling of spaciousness could be created by a lighting design where light is spread slightly into the vertical side areas on each side of the pedestrian road to enlighten trees or vegetation in the nearby surroundings (see Figure A3b). The proposed optimal criteria for reassurance are a horizontal illuminance mean of 4.0 lux and a minimum illuminance of 0.8 lux, while for obstacle detection, a minimum horizontal illuminance of 1 lux should be adequate [3]. An increased feeling of spaciousness combined with optimal criteria for reassurance and obstacle detection could enable a decrease in uniformity without negatively impacting user experiences. This could save energy, and the trees will serve as a physical light barrier that will, together with the lower illuminance levels, reduce light pollution and ecological impacts. Light barriers, decreased illuminance and energy consumption and an improved light distribution that is better adapted to the functional needs of the users are all suggested as improvements to ensure that outdoor lighting is designed in a more sustainable way [81,82]. Other measures for reducing ecological impact are, for example, to use low correlated color temperature. Our study focused on uniformity, and for the case study, we investigated road lighting that had the same correlated color temperature and spectral power distributions. For future studies, it might be interesting to study perceptions when combining different road lighting uniformities with some variation in color temperature, for example, 2500 K or 3000 K.

Method Discussion

Qualitative studies do not aim to answer a specific question with measurable accuracy. In a holistic study, the number of variables is endless and not possible to control. This study focused at one variable—uniformity. Hence, the spatial characteristics, such as colors and luminaire position, impact as well. Qualitative studies are exploratory, with a strive for rich explanations based on a holistic contextual analysis. Since the result is based on the context, it is more relevant to use the term adequacy than reliability [55]. The case studies should be viewed as diverse examples that serve as a basis for discussing and developing hypotheses. As Nasar and Bokharei point out, spatial impressions are highly context related [4]. The aim of this study was not to allow generalizations, which is often the case with studies of a more quantitative character. Instead, this study was performed to broaden the view on road lighting uniformity. Hopefully, this study can encourage and stimulate a more vivid discussion within the lighting research field as well as among practitioners.

All three roads were situated at the outskirts of a city. Pedestrian roads within a city seldom have this rich variation in openness/closedness, hills and curves. Yet, in cities, there are other kinds of vertical surfaces, facades that can be used as reflectors. Weather conditions, time and season are naturally important to the outcome. The road in Ljungarum was observed when the trees still had leaves on the branches. The other road observations were performed in the winter season, without leaves. Naturally, this affects the comparison of the results. However, the intention of this study was to study different sites and not similar conditions.

A qualitative study performed by only the researchers as observers is naturally subjective or intersubjective [1]. Sketches can be biased since the sketcher decides what to focus on and what to display. However, in comparison to photos, simple sketches make it easier to follow the observer's interpretations. From a small study like this, it is hard to say whether these roads would be described in the same way by people in general. Our intention is for the reader to recognize and compare the descriptions in the texts and sketches with familiar settings. To be able to walk around and see the site in real life from several directions increases the understanding of the context, compared to assessing images. The photos and sketches from the three sites (Figures 2 and 3) are derived from Cullen's serial vision analysis [79] because they depict interesting scenes. Followingly, the distances to the nearest luminaire can change from one road photography to another. These images are chosen as examples, representing the character of each road. The analysis was primarily done on-site, while walking around, observing from several perspectives, not by picture analysis. The analysis did not include quantitative measuring; hence, the different distances to the nearest luminaire on the photos had no impact on the findings.

The methods described in this article, for example, the serial vision analysis by Cullen [79], are originally developed by architect researchers and practitioners. Practice in visual observation and spatial experience, such as architect student training, is required for a fully sufficient result. Yet, guidelines can also make the method available to other professions. For example, the sketching phase can be simplified [83]. An interesting future purpose would be to develop such guidelines. Naturally, these methods can also be used for motorized roads and roads with mixed traffic. However, it is hard to sketch while driving. If so, the analysis needs to be done through images or video films. While sitting in a car, it is hard to turn around much. It would still be a visual analysis with a holistic perspective and the same analyzing steps can be followed. Yet, the major point with the sketching moment, to take time to detailly observe the entire real scene, is harder to perform with photos, videos and digital visualizations [77]. The methods can to some extent also be used in interior settings. This approach is neither limited to a specific type of light installations; it is applicable for installations with artificial intelligence (AI) as well. The lighting equipment is not in focus; the approach is applicable anywhere where the perception of light interacts with the surrounding spatial context.

Previous studies show that the design of lighting systems often involves competing criteria in addition to uniformity. This could be handled by integrating techniques for decision support to help designers. Carli et al. have developed a tool, a strategic lighting design guide, for decision making, beneficial for energy efficiency [84]. This tool has been tested in the real street study by Beccali et al., in which energy and economic measures are combined with user preferences [85]. However, aesthetic values and insight into the pedestrian's spatial experience are not usually included in tool like this. It is important that visual qualities are not forgotten in the planning process just because they do not fit into a mathematical model. Followingly, there is a gap to fill. This article can provide a foundation for detecting strategic elements in the urban scene, which can be added to a planning guide for practitioners. The PERCIFAL method (Visual analysis of space, light and colour), developed for interior lighting and color analysis, can be used as a model [72,73]. The PERCIFAL method is a guide for assessing visually perceived characteristics, such as shadows and light distribution, in the room. This method needs some adjustments to also be valid for exterior environments. To this could be added, for example, an analysis about spaciousness/enclosure, vertical/horizontal patterns, light topography, light spaces, sightlines and dark spots. It also needs to include aspects of experienced reassurance.

The actual light installations with LED were retrofits for an earlier installation with high-pressure sodium light sources. The same pole distances were used. An analysis such as this can describe how the lighting environment will be changed, when new luminaires are placed at existing positions. Luminaires with a different light distribution, color characteristics, intensity, glare protection and more, also impact how tree trunks and faces are displayed. In future studies, it would be interesting to study color characteristics in relation to light distribution and uniformity. In the future, it would also be beneficial to combine quantitative and qualitative perspectives, both in research and in the practice of light planning. More and larger field studies as well as studies that include participants must be performed to validate the possible connections between light on vertical surfaces, visual guidance and reassurance. We also need to determine how to balance illuminance levels on horizontal surfaces with those on illuminated vertical surfaces. Do we need less light on the ground if we have light on the tree trunks?

6. Conclusions

The case study started with an intention to observe and exemplify how lighting uniformity varies on pedestrian roads in different settings but with similar lighting. Perceived uniformity was found to vary more than the measured horizontal uniformity. The landscape, street type and functional context play important roles in the lighting experience. The finding from these cases is that the conditions of the space and which surfaces the light falls on can have more impact on the perceived space than the lighting installation itself. The art of lighting is not only about distributing light from luminaires but also how the lit surfaces appear within the whole urban space. While the light distribution is important, the shape and position of slopes, rocks, tree trunks, fences and facades are just as important to the total impression of the scene.

Even if lighting is well calculated and measured, we need to be aware that it is not possible to foresee all circumstances. We need to visit the sights we plan so that we can visually analyze what we see there. It may not be possible to find a solution that fits every site. Through careful and flexible planning, we can avoid putting light where it is not needed and focus our resources on where it is needed, thereby saving energy and avoiding unwanted side effects, such as light pollution.

The method used here are unusual within the lighting research tradition, firstly, because it is based on qualitative methods and, secondly, because it treats the spatial context holistically. Hopefully, it can function as an eye-opener so more studies in the field take on this perspective. Qualitative methods are not the solution for everything, they need to be combined with quantitative studies, in the same way as quantitative methods cannot cover all perspectives. Therefore, a future research direction would be to extend the project to investigate the importance of road lighting uniformity by using field experiments and investigate users' perceptions and satisfaction.

To conclude, the spatial context influences the experience of lighting, and lighting impacts the whole spatial context. These aspects of a more holistic character need to be better incorporated in the decision-making process for road lighting.

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Appendix A. Implications and Recommendations

The following images show different possible scenarios. They can be regarded as a visual discussion, proposing the effect of the light distribution. If the light is positioned slightly differently, the effect of the perceived spatial context can change a lot.

Figure A1. Reflective sketches from Råslätt, showing possible implications from lighting variations (from left to right, top to bottom): (**a**) A somewhat non-uniform lighting, which creates light zones and visual guidance. (**b**) More uniform lighting that emphasizes the pedestrian walkway. Such lighting can be exposing, and the surrounding receives less attention. (**c**) The light zones reach behind the poles. It makes it harder to hide in the foliage. (**d**) A major part of the ground and the trees are illuminated, by the street lighting. There are both horizontal and vertical light—this is how the lighting looks today.

Figure A2. Reflective sketches from Lockebo, showing possible implications from lighting variations (from left to right, top to bottom): (**a**) Just the walkway is lit, not the car road. It is a primarily uniform light; the road seems prolonged. It is far to walk. The road looks repetitive. A pedestrian would be exposed. This is the light situation of today. (**b**) Less uniform light creates rhythm that reduces the repetitive expression. The light zones give visual guidance as milestones. (**c**) Both the walkway and the slope next to it are reached by light. In a way, this contributes to creating a vertical wall in the landscape. Therefore, the walkway receives less attention, and the sense of exposure can be reduced. (**d**) Both the car lane and the walkways are lit. The horizontal surfaces appear, while everything else disappears in darkness. The urban space can be experienced as wide, large and empty.

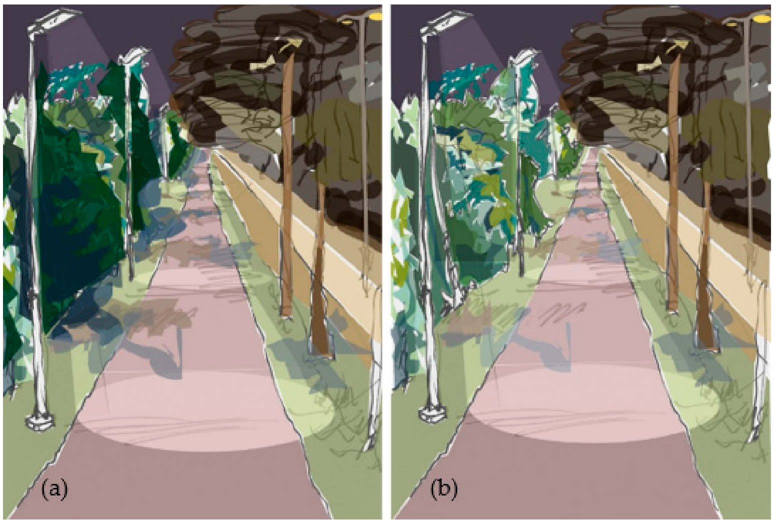

Figure A3. Reflective sketches from Ljungarum, showing possible implications from lighting variations (from left to right, top to bottom): (**a**) The spill light falling on the nearest trees makes the walkway lively and personal. The problem is the darkness behind them. This is the lighting of today. (**b**) By adding light shining a few meters into the dark forest, the contrasts will be reduced and reveal any possible attacker hiding there.

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