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LIGHT TOPOGRAPHY AND SPACIOUSNESS IN THE URBAN ENVIRONMENT

ULRIKA WÄNSTRÖM LINDH AND MONICA BILLGER

Abstract

Spaces can be perceived as larger or smaller, according to how lighting affects the spatial boundaries. This is knowledge that can be used for changing the appearance of a desolate square or a cramped space. The following is a full-scale study of changing light scenarios that was conducted with 222 respondents in an urban space over five weeks. The study examines the effect of the spatial distribution of light and the placement of luminaires on our spatial understanding. A mixed methodology strategy, which combines pair-wise comparisons with qualitative interviews and a questionnaire, was used to examine the respondents' perception of differences in spatial size and shape. The findings show that illuminated surfaces and objects, such as facades and trees, create a perception of increased or decreased depth, height and distance, depending on the spatial context and the respondent's pre-understanding. Additionally, the perceived size of space was found to follow the height of the luminaires' placement. This research study raises awareness of the impact of the placement of luminaires at varied heights, by developing the concept of light topography.

Keywords:
Spatial light distribution; lighting design; light topography; scale of light; light patterns; spaciousness; enclosure; spatial boundaries, urban environment, vertical light

1. Introduction

For street lighting, the placement of luminaires is rarely considered other than to create a functional, traffic-safe, uniform and economic lighting installation. The design practice is to a large extent based on experience and praxis, for example, the common praxis that it is important to illuminate vertical walls to gain a more defined space (Heschong Mahone Group, 1999). Spatial boundaries, e.g. vertical walls, affect the experience of spaciousness, which can have an impact on anxiety (Okken, van Rompay, & Ad, 2013). Spatial anxiety is a term used when visual guidance is lacking in urban space (Davoudian, 2019b). Larger rooms are often preferred over smaller rooms (Bokharaei & Nasar, 2016; Stamps, 2009). Therefore, the aim of this explorative study was to evaluate how people experienced changes of room size according to light distribution within the lit urban space, with focus on lit vertical walls and the placement height of streetlights.

The height of the placement of luminaires is a sorely neglected issue, though important for spatial experience. This topic is emphasised in this research by clarifying it as a concept: light topography. Light topography is linked to hierarchies that emphasise a private or a public atmosphere impression. Hierarchies of light can be found indoors (Millet, 1996), as well as outdoors (Davoudian, 2019b). Different road users and speed restrictions correspond to commonly used heights of the placement of luminaires and by the distance between luminaires. Exposing or diminishing buildings or other urban objects with light is another way to emphasise hierarchies, for good and for bad. Conscious light planning can increase spatial understanding and visual guidance through emphasising landmarks, paths, nodes, sightlines and more (Davoudian, 2019b; Lynch, 1960). The knowledge about light for pedestrians is scarce, compared to what we know about motorized traffic (Mattoni, Burattini, Bisegna, & Fotios, 2017). Luminaire poles' standard heights can be regarded as intervals we work with within the scale. Often the scale of street luminaires follows the building scale, but not always, which can splinter the spatial context. Since public spaces usually are larger, their light often comes from higher poles which spread light further. A lower scale indicates a private atmosphere. These differences in height benefit visual guidance. In addition to the scale of height, one should be able to talk about a scale of width and depth in relation to the street space. Thus, light topography is not limited to the placement of luminaires. The attention is not directed to the actual luminaires, but to the light picture as a whole and to the lit fields on surfaces. The light patterns and the luminaire patterns are not the same. A low luminaire may distribute light high up, and a high luminaire can distribute it low down. Yet, the streetlight's the placement of luminaires is often more apparent than the light pattern on surfaces. The concept of light topography can embrace all that which affects the height of light/the scale of light.

Naturally, spatial size is linked to the concept of spaciousness, which is not so easy to grasp. Spatial perception is complex – perceived longer dimensions / larger room surfaces are not necessarily the same as a general increased spaciousness (von Castell, Oberfeld, & Hecht, 2014). Spaciousness (roominess) commonly refers both to the experience of a larger spatial volume or a large ground area. Additionally, spaciousness often represents the opposite of enclosure (Stamps, 2009; 2012). Yet, there is an important distinction between regarding a spacious space as roomy or as open. Furthermore, it has been found that study subjects may confuse open spaces with large spaces, and enclosed spaces with small spaces (Gärling, 1969). In this article, spaciousness is used to talk about volume.

To study the effects of lighting on size perception in an urban environment, a full-scale study was conducted in a park next to a church, in a small-scale historical wooden town called Alingsås, Sweden, from September 24 to October 31, 2010. A temporary installation with 90 luminaires was made in collaboration with Lights in Alingsås 2010, an event of the Professional Lighting Designers Association (PLDA). In this year the festival had more than 65,000 visitors. This research project investigated how light distribution affects perception of public spaces. The study concentrated on light direction, distance between illuminated areas, light topography and its effects on perceived depth and size of spaces.

2. Existing Knowledge about Perceived Spaciousness and Enclosure

In the late 19th century, Ashley (1898) found that the surface brightness of objects influenced distance judgements. Additionally, Coules (1955) found that a brighter object farther away is perceived as being the same distance away as a dimmer object that is nearer. However, the effect for spaces, viewed from the inside, may not be the same as for a perceived object, viewed from outside. Many factors interfere in complex spatial contexts (Bokharaei & Nasar, 2016). It has been shown that people perceive a room as larger when they are inside it, not being able to grasp the whole space at the same time (Holmberg, Almgren, Söderpalm, & Küller, 1967). People prefer exterior lighting close to themselves, rather than light at a distance (Haans & De Kort, 2012). The comfortable size of a personal space can be affected by the light level (Adams & Zuckerman, 1991). The position of a respondent during an observation is obviously important.

Brightness and lightness contrasts appear to change depth and distance perception when room surfaces are being viewed. The distribution of luminance can affect the perceived brightness of the whole space. A bright surface in non-uniform light looks brighter than had the lighting been uniform (Veitch & Tiller, 1995). It is possible to use lower illuminance

in a room with uniform lighting, and still keep an acceptable level of reassurance (Boyce, 2019). With an increasing number of bright objects in the background, the more difficult it is to perceive the saliency of an illuminated building (Davoudian, 2013). According to the relation between brightness and spaciousness, it seems possible that the figure-ground relationship can impact perceived distance. The relationship between perceived size and brightness contrast is highly context dependent, and perception psychology shows many examples where the figure-ground relation shifts (Davoudian, 2013; Gibson, 1950; Wagemans et al., 2012). The play of contrasts makes darker zones near brighter zones look darker, more than what might be expected from measurements (Fotios, Johansson, Miller, & Uttley, 2019). Matusiak found that a strong brightness contrast at the border between daylit room surfaces helped the visual observer assess the actual room size (Matusiak, 2004). However, when distinct contrasts were missing it was easy to manipulate the perception of size. Another study by Matusiak (2006a) describes relationships between a horizontally oriented, rectangular window and a wide spatial impression, as well as between a vertically oriented, rectangular window and a higher spatial impression. She also showed that stronger light on a room surface makes the surface appear farther away (Matusiak, 2006a).

The "enclosedness" of a space can decrease with both a higher and a lower light level (Hesselgren, 1975). The experience of cosiness, which relates to "enclosedness", has been studied with different combinations of brightness and uniformity (Stokkermans, Vogels, de Kort, & Heinderickx, 2018). It was found that the experience of cosiness could be decreased, either with changes in light level or in uniformity. A space with uniform light may feel more detached and less tense, than with non-uniform lighting (Stokkermans, Vogels, & de Kort, 2017). In his work on perception of room size, Flynn found that a more uniform and higher level of light in a room caused subjects to perceive the room as larger. A wall-oriented "peripheral" lighting, or a combination of peripheral lighting and a low level of overhead lighting, appeared to be most beneficial to a spacious impression. In particular, direct light at low levels seemed to make spaces confining. Flynn and others tried similar lighting arrangements in both rectangular and irregular shaped rooms, but found no significant difference in perception (Flynn, Spencer, Martyniuk, & Hendrick, 1973, pp. 88–90; Murdoch & Caughey, 2004, p. 71). Later experiments based on Flynn's studies, conducted by other researchers, arrived at similar findings (Brent Prozman & Houser, 2005; Durak, Camgöz Olguntürk, Yener, Güvenç, & Gürçinar, 2007; Stokkermans et al., 2018). But these researchers have been of different opinions with regard to whether peripheral light should be at high or low levels.

There are studies about how vertical light (when light falls on walls) compared to horizontal light (light falling on horizontal surfaces) affect

spatial experience and behaviour (Flynn et al., 1973; Loe, Mansfield, & Rowlands, 2000). Yet, since relationships like these are complex and context-relative, there is a need for more research about the effect of bright, vertical surfaces. Stamps and Krishnan tested light conditions in two experiments and found that the difference in light level is essential for the experience of spaciousness. The difference in a spacious impression was small when comparing two rooms, one with 136 lux and the other with 500 lux, with the darker room seeming more spacious; but in comparing a room of 300 lux to a room of 600 lux, the brighter room was judged as more spacious. Additionally, the researchers found that the floor area was a strong predictor of a spacious impression, followed by boundary height (walls) (Stamps, 2009; 2010; Stamps & Krishnan, 2006). On the contrary, Thiel, Harrison and Alden investigated the experience of spatial enclosure through respondents judging images. They found that the floor was assessed as contributing the least to the perception of enclosure. The overhead surface (ceiling) appeared to be the most important spatial surface for the perception of enclosure, followed by the side walls and the centre (rear wall) (Thiel, Harrison, & Alden, 1986). Since enclosure and spaciousness can be seen as opposite concepts (Stamps, 2009; 2012), it is interesting that the floor in this experiment was of the highest importance for an impression of spaciousness, but when studying enclosure, it was of the least importance.

The perception of depth is related to width and height, and vice versa (Holmberg, Küller, & Tidblom, 1966). One factor of height, width or depth can have a larger impact on the impression of spaciousness than the other factors. In particular, the length and depth of a room are important (Bokharaei & Nasar, 2016). Using virtual reality, Oberfeld, Hecht and Gamer found that the painted lightness in contrast of walls works, together with ceiling lightness, to increase impressions of spaciousness, while floor lightness is not a significant factor for increasing perceived height. The total brightness of the space had no impact on perceived room height (Oberfeld, Hecht, & Gamer, 2010). According to Oberfeld and Hecht (2011), there remains a need for more studies about width and depth. Acking and Küller found that a room with a black floor was perceived as 10% smaller than a room with a white floor. They also compared two rectangular rooms in which either the opposite short walls or the long walls were painted dark grey, while the other walls were painted white. A clear majority of the persons who were tested judged the room with dark long walls as more oblong than the other room. The researchers concluded that dark walls visually contract a space, while bright walls seem to be further away from each other (Acking & Küller, 1966; Küller, 1971; 1995).

It is a widespread practice among architects and the general public that a vertical striped pattern gives a higher room impression, and a horizontal striped pattern widens the room (Neufert & Neufert, 2000). Hård (1995)

reports on a study of identically furnished rooms, one with dark blue and white vertical striped wallpaper, and the other room painted with a single colour of light blue and grey. The single-coloured room was judged as being brighter than the striped room, and as long, wide and low, whereas the vertically striped room was perceived as high, narrow and short. A similar room, but with horizontally striped wallpaper and without furniture, was also tested; it was assessed as being wide, short and high. However, the contrasts in these experimental rooms shifted a great deal, which may have affected the results.

3. Initial Assumptions and Research Questions

This project began with several qualified assumptions that were developed from the researcher's experience as a lighting designer and earlier studies, as well as knowledge from the field of colour research (Billger, 1999; 2006; Fridell Anter, 2000; Fridell Anter & Billger, 2010). Common architectural praxis tells us that a horizontally striped pattern on wallpaper makes a space appear wider, while a vertical pattern can make the space appear higher (Hård, 1995; Neufert & Neufert, 2000). This assumption is supported by Matusiak's studies of window shapes and placements in rooms (Matusiak, 2004; 2006b; Matusiak & Sudbø, 2008). Accordingly, it was assumed that the pattern created by light beams on a facade also transform perceived spatial size. The aim was to gain knowledge about if and how a placement of light beams, shifting from a centred position to an edge or corner, changed perception of width and depth. Furthermore, the assumption that the limits of an exterior space do not have to be continuous, solid walls, and in fact can be a row of pillars, raised the question of how illuminated tree trunks can define a space and affect perceived size. Since we are accustomed to seeing higher luminaires in larger urban places and roads, and lower luminaires in smaller squares and streets, it was assumed that luminaire height can also impact the perceived size of a space. Indirect light can make a raised impression of an interior ceiling; however, this is not evidently the case in outdoor spaces, as there "the ceiling" is not as distinct but can still be indicated by leaves and overhead streetlights. The concept of ceiling is here treated as a general upper spatial limitation, something that does not necessarily need a direct physical counterpart. At night, a kind of ceiling can be represented by streetlights.

Research questions:

1. Does the height of street luminaires' placement influence perceptions of spatial height? If so, how?
2. Does upward-directed light on thin vertical facade elements emphasise perception of height?
3. Does placement of luminaires, with respect to a background facade, influence perception of distance to the facade/the depth of the urban space? If so, how?
4. Does placement of luminaires, in relation to a background facade, influence the perception of width? If so, how?
5. Do illuminated tree trunks affect perceived sizes of space? If so, how?

The study included more questions concerning atmosphere, enclosure and feelings of security (Wänström Lindh, 2013a). These are presented in another article and are not included here.

4. Methods

4.1 Mixed Methodologies and Combined Strategies

Research methods in the lighting field match differences in the profession between lighting engineers and lighting designers, and science and art (Boyce, 2017; Cuttle, 2011; Dugar, 2018). In recent years, the number of studies in complex urban spaces, experimental full-scale studies and field studies has increased (Bordonaro, Entwistle, & Slater, 2019; Calvillo Cortés & Falcón Morales, 2016; Davoudian, 2013; 2019a; 2019b; Haans & De Kort, 2012; Kelly, 2019; Markvica, Richter, & Lenz, 2019; Nasar & Bokharaei, 2017; Peña-Garcia, Hurtado, & Aguilar-Luzon, 2015; Rahm, 2019). Studies with qualitative methods have entered the arena (Acuña-Rivera, Uzzell, & Brown, 2011; Bülow, 2013; Häggström, 2010; Madsen, 2006; Mandrup Stidsen, 2013). Still, within the field there is a need for more studies using qualitative methods (Fridell Anter & Billger, 2010; Fridell Anter & Klarén, 2017; Kelly, 2017). Everything is not possible to measure quantitatively, for example the contrast enhancement effect, when brighter zones make the surrounding areas look darker (Fotios et al., 2019). Design and architecture are multidisciplinary fields that are mirrored by methodological approaches with combined strategies and mixed-methodology designs (Groat & Wang, 2002). Qualitative methods are better suited for answering "how and why questions" to develop an understanding of people's reactions, interpretations and behaviours, as opposed to quantitative methods, which are more beneficial for studying one variable at a time (Kelly, 2017). At this experimental site, many variables interact with each other: illuminance, light distribution, light directions, luminance contrasts, colour contrasts, colour temperature, surface colours, spatial character and context, spatial size observer position, gaze direction and the observer's perceptions and interpretations. To study this illuminated spatial complexity, several research questions were focused

on a single object. Each object was visually observed with pair-wise comparison (the street, the Town Hall and the trees), or with three alternative scenarios (the church).

4.2 Questionnaire and Interviews

A spatial analysis through sketching, inspired by the combined methods of Kevin Lynch (Lynch, 1960) and Arne Branzell (Branzell, 1976; 1995) Proceedings of the 2nd European Architectural Endoscopy Association Conference, was initially performed by the researcher. A questionnaire was developed through the author's own observation and spatial analysis. In the main study, the questionnaire was combined with interviews. The questionnaire was designed simply on two pages, with 11 check-box questions to facilitate collecting answers by a large number of people passing by, during a light walk at the event. The questionnaire included more questions than listed here; these are included in an earlier article (Wänström Lindh, 2013a).

The questionnaire consisted of the following questions:

The height of the streetlights and its impact on how spatial size is perceived:

1. Do you detect any difference considering the public space's shape? Does the six-metre-high luminaire level make it: higher, lower or is there no difference?

The pilasters (columns) on the pink Town Hall:

2. Do you experience any difference regarding the height of the building when the columns are illuminated with up-directed light? The building as a whole becomes: lower, higher or is there no difference?

The illuminated sections at the church facade:

3. How do you experience the difference between five, three and two illuminated sections (the corners) at the church facade? Make a cross when you think the space becomes deepest and respectively widest!

Deepest:	2 sections	3 sections	5 sections	no difference
Widest:	2 sections	3 sections	5 sections	no difference

The tree trunks:

4. Do you experience any difference in spatial size when the tree trunks are illuminated? Does it become: smaller, larger or is there no difference?

Interviews, using S. Kvale's interview method, complemented the questionnaires (Kvale, 1996). The interviews were spontaneous, and rather loose in structure; subjects were often asked about their immediate thoughts, what they thought of the lighting of different objects, how they experienced the time-scheduled changes and how they would describe the atmosphere in the park. The purpose of the interviews was to find out how people had answered the questionnaire, and how and why they had answered in the way they did. Focus group discussions were also held, but they added more to the general understanding of peoples' experience of the lit park. The data from the focus groups have a very limited use here – what they said was already covered by the questionnaires and the individual interviews.

4.3 Experimental Set-up

The original illumination of surrounding streets consisted of 12 mercury lamps at heights varying from 4.0 to 5.5 m. The park's original illumination consisted of two high-pressure sodium floodlights directed towards the church and eight old park luminaires with incandescent lamps that merely light up themselves; the light was scattered throughout the park. The park was quite dark. Only the eight old park luminaires were lit during the study, the street lighting and the church lighting was switched off (see figure 1 and 2). Shop windows and entrance lighting at the residential buildings were still lit.

Figure 1
The existing lighting.
PHOTO: ULRIKA WÄNSTRÖM LINDH

The temporary experimental illumination was designed to have more than 90 luminaires, but they were not all illuminated at the same time. The illumination was designed by the researcher with the aim of creating a clearly defined tangible space and a pleasant, inviting atmosphere. This lighting was designed with the purpose of creating an appealing atmosphere with a voluminous, emphasised, spatial expression, inviting the festival visitors to the site. At the same time, it was designed according to the research questions. These were adjusted according to the park space and available lighting equipment. In addition to the experimental lighting, other objects were lit as well – the tree crowns, a narrow walking path in the centre, benches, a gravestone and a gateway, but their illumination was fixed during the entire time of the experiment, and thus did not affect any scenario more than another.

Figure 2
Overview of the church park with the experimental lighting on the church, the trees, the benches and the path.
PHOTO: PATRIK GUNNAR HELIN

Figure 3
The temporal street luminaires had varying heights (4.5 m on the left and 6 m on the right).
PHOTO: PATRIK GUNNAR HELIN

4.3.1 Light topography – Luminaire placement height

The research question regarding whether the placement of luminaires affects the perception of spatial height was tested by changing the street lighting. A six-metre-high luminaire alternated with a lower, four-and-a-half-metre-high luminaire. The original lamp posts were used; on each post, two new luminaires were mounted at different heights (see figure 3).

Figure 4
The Town Hall.
PHOTO: PATRIK GUNNAR HELIN

4.3.2 Light patterns – Emphasized height

The research question concerning emphasized height was tested by adding light to the facade, which already had existing facade lighting directed down from the eaves. At regular intervals, the white pilasters on the Town Hall were illuminated from below, to study how upward-directed light on thin, vertical elements reinforced the height of the building (see figure 4).

The illumination changed every 3 to 15 minutes, so the respondents could assess all the different scenarios (see figure 7, luminaire plan in relation to luminaire specification, see table 1).

4.3.3 Light patterns – Dimensions

The research question regarding whether the placement of the luminaires, with respect to a background facade, influences the perception of distance to the facade / depth of the urban space was studied through facade lighting. The same installation was used to study light patterns' relation to perceived width. The church facade was primarily illuminated as a rear wall in the public space, with raking light from below, from luminaires standing on the ground. By alternating between two, three and five illuminated facade sections, their relation and mutual distance could be studied by their impact on the respondents' perception of depth and size (see figure 5).

Figure 5
The church facade.
PHOTO: PATRIK GUNNAR HELIN

4.3.4 Illuminated Spatial Boundaries – Spaciousness

The research question regarding whether illuminated tree trunks affected the perceived size of the space was studied by illuminating the trees that surrounded the park (see figure 6).

Figure 6
The tree trunks.
PHOTO: PATRIK GUNNAR HELIN

4.3.5 Luminaire specification

Figure 7
Experimental lighting – luminaire plan.
SOURCE: ULRIKA WÄNSTRÖM LINDH

The luminaires marked with blue on the map symbolise the street lighting – L1, the warm-white colour stands for the Church light – L2, the green colour is for the trees – L3, and the pink colour symbolises the Town Hall facade lighting – L4 (see table 1).

Most luminaires turned on and off in a scheduled time loop, visible in the table below:

Table 1
Luminaire specification

Illuminated object	Placement	Light source	Time shift	No. of luminaires	Luminaire type
L1 – Streets (blue)	4.5 m and 6 m high, on the same post.	LED, 4000K, 10W.	Every 5 min	18	Prisma Light: Elliot
L2 – Church facade (warm-white)	2, 3 or 5 sections, lit from below, standing on the ground.	LED, 4000K, 30W	Every 3 min	5	Philips: EW Burst Powercore, with optic 24°.
L3 – Tree trunks (green)	Lit up from below, wired at the lower part of the trunks, at one-meter height.	CDMT, 35W	On and off every 15 min	16	TYCO-Schréder: Medium angle spotlights
L4 – Town Hall (pink)	Pilasters lit up from below, standing on the ground	CDMT, 35W	On and off every 15 min	4	Annell: R1 MiniS, Spotlights, Narrow angle

4.4 Empirical Data Collection and Procedure

Since 65,000 people attended the "Lights in Alingsås 2010" event, there was potential to receive a vast number of responses, and 222 questionnaires were answered at the experimental site. Since it was an international event, the questionnaires were available in both Swedish and in English. Twelve people (5%) answered in English. These were most likely international lighting designers, workshop leaders and students from all over the world, connected to the event. The number of architects and designers who filled out the questionnaire was relatively high (33%). The gender distribution was rather equal (54% women), and the age span ranged from 16–80 years, with 45 being the average age of respondents; 23 respondents (10%) were above the age of 65.

Table 2
Respondents' distribution in age

Age	0–25	26–30	31–40	41–50	51–55	56–65	66–100
Number	31	29	28	30	27	37	23

Those who lingered in the space were asked whether they were interested in contributing to the research by answering a few questions about the design. Questionnaires were also available at the information building for the event and on the web, and some were distributed to mailboxes in the neighbourhood. Respondents spent between 15 and 45 minutes answering the questionnaire at the site. Several answered that they lived in the town and were familiar with the park, while most were visitors at the event for only one evening. Most respondents did not walk around the park much when answering, despite being encouraged to do so. Over the course of 22 evenings, 27 video-recorded interviews were conducted by the researcher, with 39 respondents. The interviews lasted between 5 and 30 minutes. Some of these interviewees also answered the questionnaire. On three occasions, focus groups, with around 10 respondents each, were also assembled to discuss the same experimental lighting as described above; two of these groups comprised master's students in architecture, and one of the groups consisted of experienced colour and light experts from the research project SYN-TES (a project organised by the University College of Arts, Crafts and Design in Stockholm (Konstfack).

4.5 Analysis of Data

Some respondents neglected to answer one or more of the questions or gave several responses to a single question. These individuals were excluded from the analysis for that part of the experiment, but their answers on other parts were used. Therefore, the number of responses that were collected differ for the various questions. The interviews were analysed by first sorting quotations into different themes for each question. These were then grouped with respect to contrasting answers. Similar quotations were paired, and the ones that were both highly representative for other answers, together with the most expressive and explanatory, were chosen for the article. When it was possible, the use of quotations was preferred for emphasising statements representing different opinions, in those cases in which a question generated contradictory answers. This data shed light on how the respondents came to their conclusions when filling in their questionnaire, and it was often the case that opinions from both sides were then made understandable. A deeper, qualitative analysis of the interviews followed the reflexive interpretation approach by Alvesson and Sköldberg (Alvesson, 2011; Alvesson & Sköldberg, 2009). The methodological strategies mentioned previously were combined with analyses of the empirical material in a process of triangulation to fully capture people's experiences (Stake,

2006; Yin, 2003). The interviews, together with the focus discussions, were used as random samples to interpret the questionnaire answers to see how people interpreted the questions, and to determine what motivated them to answer the way they did. The author's own observations and spatial analysis on site have been useful in arriving at an understanding of the findings, and to describe the spatial context of the data collection.

5. Results and Discussion

5.1 Light Topography – Luminaire Placement Height

According to the respondents, the whole street-space appeared higher when luminaires were positioned higher, and lower when the placement was lower. The initial assumption that the luminaires' height affects the perceived size of the public space was confirmed by the respondents. About 75% of the respondents (154 out of 205) answered that luminaires at a height of 6 metres made the space higher, while 10% answered that the space felt lower (see table 3).

Table 3
The height of the streetlights and its impact on how spatial size is perceived

Do you detect any difference considering the public space's shape? Does the six-metre-high luminaire level make it: Higher, lower or is there no difference?	People n=205	Percentage
The space feels higher	154	75%
The space feels lower	20	10%
No difference	31	15%

According to most of the respondents, the street-space as a whole appeared higher when the luminaires were positioned higher, and lower when the luminaires were placed lower. Those who said the opposite may have related the luminaires' height more to the scale of the buildings. The houses may then have looked smaller in contrast to the higher placed lighting, and vice versa. When the space seemed higher with higher luminaires, the perceived spatial size followed the lighting scale. This indicates that it is possible that the "light space" was regarded separately from the built surroundings.

It has been found in previous research, in a study by Flynn and Hawkes, which Boyce refers to, that whether respondents were asked to assess a rooms' lighting or the lighting within the room, the result was consistent (Boyce, 1981).

A middle-aged male engineer explains how the lower light position affects the spatial experience:

> *The ceiling becomes lower. It becomes cosier. This changes the spatial experience because if it was pitch-black here, there would have been no space here. When luminaires are lit, it defines the dimensions of the space, one could say. This is similar to walking into a hall with a high ceiling. That is not comfortable. You then feel vulnerable. The lower the ceiling level, the more significance you have in this big volume. One becomes a larger percentage part of the whole space. The case is similar when you lower the ceiling, when you decrease the luminary height.*

Several respondents explained that they preferred the lower light because it comes closer to the pedestrians, therefore it increased their reassurance. 138 respondents (62%) assessed the lower light as safer; only 57 respondents assessed the higher light as safer (20 respondents answered no difference, and 5 did not answer this question) (Wänström Lindh, 2013a). People prefer a higher light level close to themselves, rather than brighter light from luminaires standing farther away (Haans & De Kort, 2012). It is possible that this also regards light from different heights. Several research studies report that a more uniform light usually is experienced as safer (Boyce, 2019; Fotios et al., 2019). These contradict the findings from this study in which the lower luminaires gave a less uniform light, compared to the higher ones. On the other hand, the lower position increased the amount of light on the facade. Bright light has been found to be experienced as safer (Boyce, 2019). Other studies found that brightness was connected to reassurance, if combined with a uniform light distribution, but not with a non-uniform distribution (Nasar & Bokharaei, 2017). Since research has defined the experienced limits of personal space between people (Adams & Zuckerman, 1991; Welsch, von Castell, & Hecht, 2019), it might also be possible to define the boundaries of an experienced personal space within the physical environment. Unexpectedly, several interviewees spontaneously expressed that the lower positioned light felt warmer.

The perception of brightness can be affected by the colour spectrum (Sawyer & Chamiliothori, 2019). The facade received a higher luminance with the lower light, so it is likely that it was perceived as brighter. A whiter light, like LED, may increase reassurance (Peña-Garcia et al., 2015). Still, the pink colour had a warm nuance, which was reflected in the light. The relationship between brightness, uniformity, light colour and reassurance is complex. One factor might take over in one context, but not in another.

5.2 Light Patterns – Emphasized Height

The question about direction of light in relation to perceived height was tested by adding light from beneath thin vertical elements in the facade. A clear majority perceived the Town Hall as higher with upward-directed light on the pilasters (see table 4).

Table 4
The pilasters (columns) on the pink Town Hall

Do you experience any difference regarding the height of the building when the columns are illuminated with up-directed light? The building as a whole becomes: lower, higher or is there no difference?	People n=201	Percentage
The building feels higher	147	73%
The building feels lower	34	17%
No difference	20	10%

A couple sitting on a bench was asked if they perceived any shift regarding building size when the Town Hall light went on or off:

I: Do you experience any difference in size regarding the town hall, when the pillars are dark?
M: Yes, they are obviously diminished when it is not illuminated.
W: Mm.
M: But it disappears in the background and gives other effects.
W: It looks less grand now because of the slightly lower light level.

There are several factors of light distribution that can add to an enlarged impression of the Town Hall. Firstly, just because the pillars were lit, they stood out from the background, in a figure-ground relationship (Wagemans et al., 2012). Secondly, pillars are traditionally a symbol for power, support and strength (Thiis-Evensen, 1989). Thirdly, they were thin vertical elements, which like a striped pattern emphasised height, according to earlier studies (Hård, 1995). Fourthly, the light was directed upwards, which gave something of a frog's perspective, diminishing the person on the ground.

The supporting theme of pillars carrying a roof is in itself a symbol for strength (Thiis-Evensen, 1989). Reinforced by light, they stand out as figures against a background, even more prominently than before. Only the pilasters were lit. Still, this light affects the whole impression of the building as larger; the contrast between them and the background was not too large to distort the coherence of the facade. We are used to pillars as symbols for powerful buildings, like municipality buildings, banks and universities. This Town Hall is normally a discrete, warm-pink, wooden building with just two storeys. Interestingly, the effect of added light clearly changed its appearance – and some interviewees called it "magnificent".

5.3 Light Patterns – Distance

One question dealt with how the perception of distance to a facade / the depth of the park was related to the illumination of a rear wall. The respondents were instructed that *depth* was in regard to the experienced distance from the respondent to the church facade. The illumination of the church facade changed every third minute between two, three and five illuminated facade sections. Many respondents who answered the questionnaire (53% of 207 responses) were of the opinion that the depth increased when the facade was least illuminated, with just two luminaires in the corners, whereas the facade seemed closer as more luminaires were added. It seemed closest with five luminaires (see table 5).

Table 5
Church facade: Largest perceived distance/depth

How do you experience the difference between five, three and two illuminated sections (the corners) at the church facade? Make a cross when you think the space becomes most distant.	People n=207	Percentage
2 sections	109	53%
3 sections	51	25%
5 sections	37	18%
No difference	10	4%

A middle-aged male respondent held a monologue, expounding on how lightness contrasts increased depth. He also described how darkness can make a space feel larger, since it may continue into infinity. Additionally, his opinion was that lit walls diminish the space, because it is clearer where the space stops:

> *I think three fields give more depth to the image. If it is three, because you then have dark parts, and you regard dark parts as deep, yes?*
> *Or the darkness, it is from here to infinity, yes?*
> *But if it is lit, bang! You have the wall there, the infinity ends and it becomes concretely defined, it will not come further. So, it is more an expression of the fantasy, if I say so.*

Another man explained why he experienced the church wall with five lit fields as closer. He refers to his observation that being more illuminated makes it brighter, compared to what it is like with fewer fields:

> *Well, I just said that when it was five fields, it felt like it was closer than with three fields. In some way, it becomes whiter and it comes closer. Yes, it is less light, but it feels farther away, I think. It is remarkably darker.*

There seemed to be several factors adding to the likelihood of the answer that the facade tended to look farther away with just two illuminated sections, the corners. The finding that the perceived depth of the church facade increased with two illuminated sections and a darkened centre, while the depth decreased with five illuminated sections, indicates that illuminated surfaces in this context appear to approach, while dark surfaces alienate. When more of the facade was darker, it might have been difficult to detect the position of the dark parts – this could be the cause for a few interviewees saying the facade looked bent. With only the corners of the facade being lit, it might have been easier to interpret as a continuation of sides of the park, with the lit tree-trunks. Then, most of the facade became a dark background. One can either see the facade as a spatial boundary in the park space, focusing on the cavity, or see it as a body. All this relates to previous research about the ambivalence in the changing figure-ground relationship (Davoudian, 2013; Gibson, 1950). It also connects to the knowledge that bright surfaces either seem to approach (Coules, 1955) or look farther away (Flynn et al., 1973; Matusiak, 2006b).

Some respondents interpreted the question of depth as if it dealt with depth on only the facade surface, and that it did not refer to the space in front of it. They thought that the facade looked flatter when completely illuminated with five sections, but that it looked deeper with three sections; for example, when every second section was switched off, a play of light and shadow was established. The dark sections were perceived as deeper. Illuminated surfaces give a sense of materiality, especially when they are illuminated with raking light that enhances the texture, so that they become more distinct, while the dark surfaces fade away. Additional knowledge gained from this study is that it is much easier to talk about spatial depth by asking in which scenario the respondent perceived the building as nearest, rather than asking when the depth was greatest.

5.4 Light Patterns – Width

Most respondents judged the church facade with five illuminated sections as the broadest. Some answered that they perceived the facade with two illuminated sections, the corners, as being the broadest. Only a few considered the facade to be broadest when illuminated in three sections (see table 6).

Table 6
Church facade: Largest perceived width

How do you experience the difference between five, three and two illuminated sections (the corners) at the church facade? Make a cross when you think the space becomes widest!	People n=207	Percentage
5 sections	118	56%
2 sections	61	29%
3 sections	20	10%
No difference	11	5%

A middle-aged woman explains why she experienced the building as smaller with three illuminated fields, compared to two and five fields:

> *Because the field in the centre catches the gaze, the church wall and its length look shorter. But when it was only two lights, one at each corner, you see a longer church facade.*

The interviews provided more answers than asked for by the questions in the survey. For example, the collection of interviews shows that several respondents assessed the church facade with three lit fields as *higher* than the other ones. The scenario with only two lit fields was judged as both high and wide, while the five lit fields' facade was only considered to be wide.

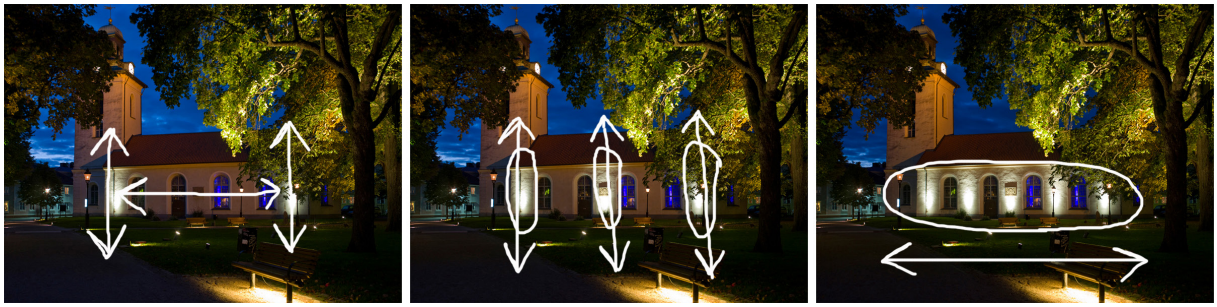

Figure 8
The illuminated sections form patterns that may affect perceived height and width.
PHOTO:PHOTO PATRIK GUNNAR HELIN, SKETCH ULRIKA WÄNSTRÖM LINDH

Considering the church facade when illuminated with five sections, the illuminated areas together form a large, united, horizontal, nearly continuous band of light, while the scenarios with three, respectively two, illuminated sections are seen as separate illuminated areas with a more vertical emphasis (figure 8). This relates in a way to the praxis of vertical-horizontal patterns as reinforcing width or height (Hård, 1995; Neufert & Neufert, 2000), and to Matusiak's (2006b) study of window shapes. The finding that the church facade was seen as wider with more illuminated fields, and also that it had an increased brightness, follows the earlier research finding that a brighter object is usually seen as larger (Oberfeld et al., 2010). The five illuminated sections can appear closer because the total brightness of the facade is greater, or by the change in placement or by a combination of the two. With three light beams, the centre of the

facade was emphasised, while two light beams merely marked the corners of the building. An architectural student in one of the focus discussions observed that a dark section in the middle of the church facade created a black hole to "fall" into. But the student said this had no effect on perception of width. When three sections of the facade were illuminated, the centre was emphasised in a way that might attract the gaze. It reduced the viewing field from a wider view to a more focused viewing angle, which could create a narrower facade impression. If one sees the simplified light pattern of the façade, not as a large horizontal band in the scenario with five illuminated sections, but instead as separate illuminated sections with windows between, the vertical direction is emphasised. Accordingly, when the building appears higher, the width impression also changes, so the facade looks less broad. That surface proportions affect each other harkens back to the finding that room perception can be seen as a function of a relationship between depth and width (Holmberg et al., 1966). Height was not asked about in the questionnaire, but it was mentioned frequently in the quotations, and therefore it seems appropriate to keep it in the discussion, in that dimensions affect each other.

5.5 Illuminated Spatial Boundaries – Spaciousness

The final research question concerned whether the surrounding illuminated tree trunks had any effect on the perceived size of the park space. Most people answered that the space appears to be larger when the trunks are illuminated, yet there were also many of them who contrastingly said the spatial size diminished. Very few left this answer unmarked or answered that there was no difference (see table 7).

Table 7
The experience of the park with illuminated tree trunks

Do you experience any difference in spatial size when the tree trunks are illuminated? Does it become: smaller, larger or is there no difference?	People n=219	Percentage
The space feels larger	121	55%
The space feels smaller	72	33%
No difference	15	7%
No answers	11	5%

A similar explanation was usually given nevertheless: that if the unlit or the lit tree trunks made the space look larger, the interviewees referred to clear or unclear spatial boundaries. Either they referred to experiencing the park with lit tree trunks as larger because of the clear boundaries that displayed how big it really was, or they experienced the park without clear boundaries as larger because it seemed to continue further into dark infinity. Some also said it looked smaller with lit tree trunks, since it showed where the park ends.

A married couple in their 70s:

M: It was all gloomy and dead before the trees were lit.
W: The light makes it larger.
M: I think it is the opposite. Yes, but before, these trees were far away. Now it is, now you see.
W: Yes, but then there is a wall that one does not really know the limitation of. Here you can see the limitation.
M: Well, I think it encloses and comes closer, now when it is lit up.
W: I sense this form of the park much more when it is light all around, and I think the distance has increased while we moved ourselves a bit, when you watch the tree trunks.

The figure-ground relationship (Gibson, 1950; Wagemans et al., 2012) can help us understand why some people saw the lit trunks as approaching and making the space smaller, while others thought that the bright trunks enlarged the space. Like with the church facade, it may depend on whether one sees the lit zones on the trunks as single objects or as background. The choice may be related to the distance between the observer and the object in focus. As earlier research has shown, there is commonly a preference for light in a person's own immediate surroundings (Haans & De Kort, 2012), rather than for light at a distance. This could have impacted on where the respondents chose to stand when they were answering.

A previous interior study gave similar findings – where the majority of the interviewees talked about darkness as diminishing, since the dark room made them see only the closest area around them. Yet, several respondents said the opposite: that the room felt larger in darkness, because one could not really see where it ended (Wänström Lindh, Billger, & Aries, 2020).

6. Method Discussion

All the illuminated objects contributed to the overall impression of the park space. It is possible that the spatial complexity, together with several objects to judge, made it harder to focus, even though the assessment was based on pair-wise comparison. We cannot take the results of this study as providing a complete picture of the subject at hand, but they can be used to generate new hypotheses for further study in this area. This study was structured within the concept of a lighting design festival. Accordingly, the design needed to be appealing and to encompass the whole site, and at the same time be experimental in generating answers to research questions. Thus, it was the case that treetops, benches and paths at the research site also were lit up, but not studied specifically. The more objects there are in the background, the harder it is to see the saliency of an object (Davoudian, 2013). The study-objects were

oriented in the outer boundaries of the park; when focusing on them, the respondent's back was turned towards the other objects. But the trees could not be observed without the whole surrounding context being visible. This was also the intention, since that question regarded the park-space as a whole.

Contrasts at different levels interfere with each other. That the findings in some cases show ambiguity is not negative; there is probably a similar diversity in most studies with rating scales, which are not revealed. Previous research shows that findings regarding relationship between brightness, uniformity, size and reassurance are not always consistent within a study, nor in relation to other studies (Brent Prozman & Houser, 2005; Durak et al., 2007; Gärling, 1969; Hesselgren, 1975; Houser, Tiller, Bernecker, & Mistrick, 2002; Matusiak, 2004; Stamps & Krishnan, 2006; Stokkermans et al., 2018; Thiel et al., 1986). Revealing different interpretations may even lead to the most interesting findings. Without the interviews, it would not have been clear that the respondents interpreted the concept of depth differently; some addressed the depth of the facade surface and some the distance from their position to the facade (see 5.4). It would be better if related to the concept of *distance (close-far)*. The interviews with architects indicated that they had a larger understanding of the *depth*-concept, compared to people in general.

The answering rate differed between 219 answers for the tree-question to 201 answers for the Town Hall. It is possible that the tree question caught more interest. The most likely reason for the dropout answers could be that most respondents were passers-by; they had already taken the one-hour light-walk before they came to the research site. They might have been restless or cold, and wanted to walk further to their friends. The luminaires at the Town Hall switched with the longest interval. It was lit by discharge lamps which took 15 minutes to cool down between the scenarios. Staying longer than 15 minutes enabled the respondents to see the changing of the lighting scenarios several times. During the video recorded interviews, talkative persons spent more time at the site. To the lessons learned from this study belongs that it would have been better if defined observer positions had been marked on the ground. The street lighting question was focused on assessing the higher luminaire height. The first question's alternative was if it looked higher; the presentation order of the answer's alternatives might have impacted on the result. Regarding the Town Hall light, it would have been beneficial if the question did not mention the upwardly directed light, but only the lit pilasters. The text can unintentionally have put focus on the increased height. To be able to retrieve answers that are possible to generalise, only one or two variables should be studied in a controlled environment. However, there are a lot of benefits with a qualitative and open study as well. This study raised many research questions and hypotheses for future research. With an inductive and explorative approach, findings

which were not even asked for show up. In this study, such findings are: the experienced height of the church facade, the possible relation between street luminaire height and uniformity for reassurance, and also the ambiguity in the tree light experiment – that both brightness and darkness can increase spatial size. Such findings may even be the most interesting.

7. Conclusion

Light distribution, with its play of light and shadows, affects perception of spatial size. However, the effect of light on size is not easy to predict, since contrast effects and figure-background relationships are complicated in authentic spaces. Brightness may have an enlarging and approaching effect in some situations, but not in others where we find it actually has the opposite effect (Hesselgren, 1975). A corresponding ambiguity is seen in a research study about atmosphere (Stokkermans et al., 2018). The experiments with the tree trunks and the church facade show an example of the ambiguity related to perception of brightness and size. It is interesting that the interviewees used the same explanation as to whether the lit tree trunks created a larger space or a smaller space – it was because the light emphasised the spatial boundaries.

The perceived size of the street space was found to correspond to the height of the placement of luminaires. The lower placement of luminaires emphasised the walls and created a more clearly defined space. The concept of light topography, and the awareness of the effect of the placement of luminaires in terms of height on spatial experience, is an important contribution of this research. It is far from assumed that lighting planners in general consider the effect of the perception of spatial height and size according to luminaire position. Often luminaire position is higher than necessary as a way of defraying costs, as it increases the distance between luminaires, and thus allows for the use of fewer luminaires. By planning for variations in lighting topography, we may be able to support visual guidance, stimulate social interaction, create rhythm and attention, comfort and reassurance. Rhythm does not necessarily mean time-scheduled light changes. The movement of the pedestrian, when he or she passes by variously placed luminaires, can be experienced as a rhythm, a static rhythm (Bülow, 2013; Lefebvre, 2004; Wänström Lindh, 2013b; 2018). Social interaction, here, concerns especially the experience of an urban space having a private or public character. Light topography can be used for visual guidance, to clarify the functions of different urban spaces. If a luminaire position is lower, it may indicate the pedestrian scale, to call for the drivers' attention. In this experimental study, there are several parts which relate to light topography, and not only the street luminaire's height. The building with emphasized pilasters, illuminated from below, was experienced as higher, and the church facade lit with separated lit fields was also regarded as

higher, while an emphasized width simultaneously gave a lower impression. To sum this up, light topography can both consider luminaires' position of height, and also the height and shape of lit fields. And we shall not forget that also shadows can affect the perceived height of a space. From this study there are several raised questions, which need further studies:

- The experience of size and distance in relation to brightness / darkness. This regards differently sized objects compared to spaces, in interiors compared to exteriors, and in many different contexts with shifting in surrounding contrasts of light, shadow and colour.
- The relation between street lighting's height, brightness, uniformity and experienced room size, in relation to reassurance.
- The possibilities and benefits of using the concept of light topography in city planning.
- The effect of legible, lit spatial boundaries on comfort and reassurance.
- The light patterns and their relation to spatial size and shape.
- The effect on different observer positions when assessing depth / distance.

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Biographical information

Ulrika Wänström Lindh, PhD,
Senior lecturer
School of Engineering, Jönköping University, Department of Construction Engineering and Lighting Science
Address: Box 1026, SE 551 11. Jönköping, Sweden
Phone: + 46 (0) 739 10 16 70
E-mail: ulrika.wanstrom-lindh@ju.se
Research gate:
https://www.researchgate.net/profile/Ulrika_Lindh

Ulrika Wänström Lindh is an Assistant Professor, with a background as an interior architect and lighting designer. She works at the School of Engineering at Jönköping University, in Sweden. She teaches about spatial experience at a bachelor program in Lighting design. Ulrika's research focuses spatial experience and distribution of light, in interior as well as exterior spaces. Of special concern are questions about perceived depth, size, shape and enclosure, as well as the experienced atmosphere of illuminated spaces. A current research project focus on relationships between light distribution and visual experience at pedestrian roads.

Biographical information

Monica Billger, PhD, Full professorb
Department of Architectural theory and methods, Chalmers University of Technology, Gothenburg
Address: SE-412 96 Gothenburg, Sweden
Phone: +46 317722383
E-mail: monica.billger@chalmers.se

Monica Billger is a full Professor in Architecture and Visualization at Chalmers, in Sweden. She has a background in multi-disciplinary research on simulation of colour and light in three-dimensional spaces, with the objective to develop assessment techniques to compare physical spaces to virtual environments.