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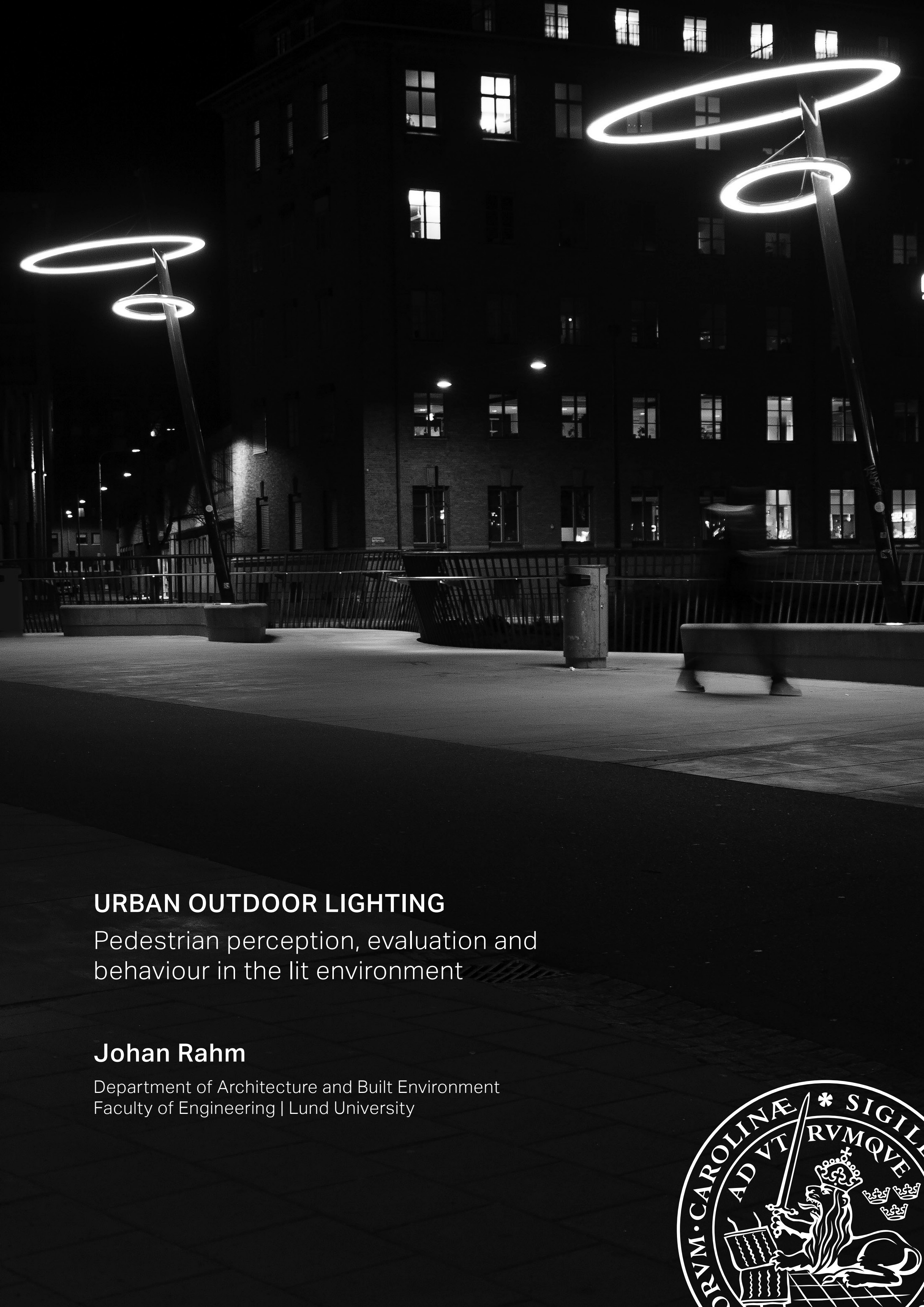

URBAN OUTDOOR LIGHTING

Pedestrian perception, evaluation and behaviour in the lit environment

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Abstract

Walking plays an essential role in sustainable transport systems, as nearly all journeys in the urban environment incorporate walking in one way or another. In parts of the world, for long periods of the year, seasonal variation in daylight hours means that pedestrians must rely on outdoor lighting to make cities accessible after dark. However, outdoor lighting is associated with considerable energy use, generating financial and environmental costs, so there is a need to develop energy-efficient outdoor lighting applications that also meet user needs. There are standard measures stipulated in national and international standards for the photometric properties of outdoor lighting but, to date, there is no consensus on methods for assessing how pedestrians respond to lighting.

This thesis aims to contribute to the understanding of the pedestrian response to outdoor lighting when walking after dark. A series of four studies explores what urban design qualities pedestrians consider important in relation to neighbourhood walkability (Paper I), evaluates a set of methods for assessing the pedestrian response (in terms of perception, evaluation and behaviour) to outdoor lighting (Paper II), evaluates the applicability of the methods in a field setting (Paper III), and tests a new behavioural method of assessing pedestrians' preferences for outdoor lighting applications (Paper IV).

The results suggest that outdoor lighting is considered an important urban design quality that pedestrians consider when assessing the walkability of their neighbourhoods. Outdoor lighting that caters to user needs and contributes to accessibility and perceived safety facilitates walking, whereas insufficient lighting has a negative influence on the perception of safety, and makes people avoid walking after dark.

The main finding from the evaluation of methods is that perceptual tasks (facial expression recognition and street sign reading) and evaluation instruments (perceived outdoor lighting quality scale and the composite affect measure) may be used to differentiate between lighting applications. The results also show that elderly people depend on outdoor lighting more for providing adequate seeing conditions. The results from the method development study indicate that the Random Environmental Walk method can be used for assessing the preference for different lighting applications, and that the results correspond to the results from self-rating scales.

The thesis suggests a theoretical framework that bridges walkability and lighting, which may inspire and benefit future research regarding outdoor lighting for pedestrians. Methods that can differentiate between lighting applications are identified and evaluated, which may be used to guide the decisions of municipalities before they undertake major upgrades or new installations of outdoor lighting on urban pedestrian paths. The methods may also be useful for lighting designers, as a way to obtain complementary perspectives to those provided by lighting simulation software.

Acknowledgements

Setting out on this journey, I was unaware of all the support I would receive from so many people along the way. Now, approaching the end of the journey, I would like to express my deep gratitude to everyone who helped and supported me during my doctoral research. I would like to direct special thanks to my main supervisor, Professor Maria Johansson, who has served both as an inspiration and a sparring partner during the thesis work. Her unfaltering enthusiasm and ability to deliver invaluable, pertinent feedback has not only been so useful in the writing of the thesis but has also contributed greatly to my development as a researcher.

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All studies were conducted in collaboration with Malmö municipality, and I would especially like to thank Johan Moritz and Johnny Clausen for their dedication to the project and their help with everything related to lighting applications. Per Tibbelin provided invaluable assistance in the full-scale laboratory, and Rifa Maliqi, Inês Ferreira, Lina Haremst and Dr Eja Pedersen were of great help during various parts of the studies. Thanks also to Serdar Kose for conducting energy measurements in the laboratory. Many thanks are also extended to all the participants, who, despite the dark and cold Swedish winter evenings, volunteered to spend time assessing outdoor lighting.

The environmental psychology research group has such a friendly and welcoming atmosphere and I have really enjoyed being part of the group. I would like to thank all my colleagues for being so generous with their time and for showing great interest in my work.

I thank my parents, Anders and Inger, for believing in my abilities to achieve whatever I set my mind to do, and for introducing me to the joy of reading early in life. Many thanks also to my good friend Lukas Råberg, who designed the cover of the thesis.

Finally, I would like to express my deepest gratitude to my beloved family. Gerda, I am so thankful for your love, patience and support. Through teamwork we somehow managed the busy periods. I am also very grateful to Elvira, Julie and Hilda for putting things in perspective and for bringing me such joy (and some grey hairs). This work is for you.

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List of original papers

Paper I

Rahm, J., Sternudd, C., & Johansson, M. (Submitted). “In the evening, I don’t walk in the park”: The interplay between street lighting and greenery in perceived safety.

Paper II

Rahm, J., & Johansson, M. (2018). Assessing the pedestrian response to urban outdoor lighting: A full-scale laboratory study. PLOS ONE, 13(10): e0204638. doi:10.1371/journal.pone.0204638

Paper III

Rahm, J., & Johansson, M. (Submitted). Assessment of outdoor lighting in the field: Methods for capturing the pedestrian experience.

Paper IV

Patching, G. R., Rahm, J., Jansson, M., & Johansson, M. (2017). A new method of random environmental walking for assessing behavioral preferences for different lighting applications. Frontiers in Psychology, 8(345). doi:10.3389/fpsyg.2017.00345

Author's contribution

Paper I

The author transcribed the focus group discussions and developed the code list in collaboration with Maria Johansson and Catharina Sternudd. The author coded the data, which was validated by Maria Johansson. The author conducted the thematic analysis and the reliability analysis. The author wrote the initial draft and Catharina Sternudd and Maria Johansson reviewed and edited the manuscript. Pimkamol Mattsson created the graphical visualisation of the results.

Paper II

The author designed and planned the study together with Maria Johansson. The author was responsible for the recruitment of participants and served as a contact person ahead of the experiment. The author conducted the data collection together with Maria Johansson, Eja Pedersen and Rifa Maliqi. The author processed the data and conducted the formal analysis. The author wrote the initial draft and created data visualisations, and Maria Johansson reviewed and edited the manuscript.

Paper III

The author designed and planned the study together with Maria Johansson. The author was responsible for the recruitment of participants and served as a contact person. The author conducted the data collection together with Maria Johansson, Lina Haremst and Rifa Maliqi. The author processed the data and conducted the formal analysis. The author wrote the initial draft and created the data visualisations and Maria Johansson reviewed and edited the manuscript.

Paper IV

The author was involved in the design and planning of the study together with Maria Johansson, Geoffrey Patching and Märit Jansson. The author was responsible for the recruitment of participants and served as a contact person. The author participated in the writing of the paper in collaboration with Geoffrey Patching, Märit Jansson and Maria Johansson.

Table of contents

1. Introduction

Today, the majority of the world´s population lives in cities, and further urbanisation is expected globally (United Nations, 2014). This trend accentuates the need for developing sustainable cities, with safe and healthy living environments (United Nations, 2012). The United Nations Agenda 2030 highlights the importance of making cities available for all citizens, by providing access to safe, affordable, accessible and sustainable transport systems, with special attention to the needs of those in vulnerable situations (e.g. women, children, persons with disabilities, and older persons) (United Nations, 2015).

On a European and a national level, the European Commission's Sustainable Urban Mobility Plan (SUMP) (Wefering, Rupprecht, Bührmann, & Böhler-Baedeker, 2014) and the Swedish report, Traffic for an Attractive City (TRAST) (Swedish Transport Administration, 2015a), are guidelines aimed at helping decision-makers adopt strategies for creating sustainable cities, through a shift towards more sustainable modes of transport, such as public transport, cycling and walking.

Walking is an important link in sustainable intermodal transportation systems (Rastogi, 2011), as nearly all journeys in the urban environment incorporate walking in some way. Walking may also substitute short motor vehicle trips, thereby reducing energy usage and CO2 emissions, decreasing noise and air pollution, and improving living conditions on a local level (Wilson, Wilson, & Krizek, 2007; Xia et al., 2015). Walking is also an active mode of transportation that benefits public health, by reducing the risk of chronic diseases such as cancer, diabetes and heart disease (World Health Organization, 2009).

A lot of research has been conducted on the impact of neighbourhood-level built environment characteristics (such as density, diversity and design of the built environment) on people's travel mode choices and their level of physical activity (Badland & Schofield, 2005; Ewing & Cervero, 2010). However, less focus has been placed on the influence of people's perception of micro-level environmental features, such as vegetation and street lighting, and how such features may interact in influencing the choice to walk as a means of transportation in urban environments (Kim, Park, & Lee, 2014; Park, Choi, & Lee, 2015).

In some parts of the world, seasonal variation in daylight hours means that pedestrians must rely on outdoor lighting to provide functional outdoor environments for long periods of the year. During these periods, people get to and from work and go about their everyday activities in the dark, relying on outdoor lighting to provide functional levels of visual accessibility and perceived safety. Consequently, the presence of outdoor lighting is considered to improve neighbourhood quality (Bonaiuto, Fornara, & Bonnes, 2006) and has been shown to increase the amount of walking after dark among different age groups: adolescents (Jago, Baranowski, Zakeri, & Harris, 2005), adults (Addy et al., 2004; Eyler et al., 2002; Lee & Moudon, 2008) and elderly (Corseuil et al., 2011; Corseuil, Hallal, Corseuil, Schneider, & D'Orsi, 2012; Rosenberg, Huang, Simonovich, & Belza, 2013).

Unfortunately, the benefits of outdoor lighting must be balanced against considerable energy use, generating financial and environmental costs. One way of alleviating this impact is to replace or retro-fit existing outdoor lighting installations with light sources with greater energy efficiency (Boyce, Fotios, & Richards, 2009; Kuhn, Johansson, Laike, & Govén, 2013), bringing about an estimated energy-saving of between 30-50% of the total annual lighting energy use (International Energy Agency, 2006).

In Sweden, many municipalities are on the verge of updating their outdoor lighting infrastructure, due to the age and state of existing installations, as well as for energy conservation reasons (Jägerbrand, Robertson, Andersson, & Folkeson, 2013). New Light-Emitting Diode (LED) lighting applications may reduce the energy use, but have different photometric properties than previous lighting technologies, such as high-pressure sodium and ceramic metal halides, and may vary greatly depending on quality and design. Furthermore, economic considerations mean that it is likely that only the luminaire will be changed while the old lampposts are retained (J. Clausen, personal communication, 7 February 2019). This may result in suboptimal lighting designs, where the new luminaires are not placed at their intended height or at intended distances. All in all, this indicates the need for assessing how pedestrians experience the lighting applications in the field before initiating large-scale retrofits.

Both technical and human aspects of lighting need to be considered in order to find lighting solutions adapted to user needs while minimising energy use (Johansson, Pedersen, Maleetipwan-Mattsson, Kuhn, & Laike, 2014). Also, the needs of users from vulnerable groups, such as the elderly and the visually impaired, have to be considered (Bierings & Jansonius, 2019; Johansson, Rosén, & Küller, 2011), since the scotopic sensitivity declines as the eye ages (Jackson, Owsley, & McGwin, 1999; Jackson & Owsley, 2000). A set of standard measures regarding the technical aspects of lighting are stipulated in national and international standards (CIE, 2010; Swedish Transport Administration, 2015b). However, to date, there is no consensus on measures of pedestrians' response to outdoor lighting.

In view of the sheer scale of the investments, much is won if the human perspective is applied early in the decision-making process. There is therefore a need to develop methods for assessing the human response to outdoor lighting in a real-world setting.

1.1 Aim

The overarching aim of the thesis is to contribute to the understanding of the pedestrian response to outdoor lighting when walking, after dark, in an urban environment lit by energy-efficient lighting applications. More specifically, the thesis has the following objectives:

- O1. To explore what pedestrians emphasise as important with regard to perceived urban design qualities related to neighbourhood walkability.
- O2. To evaluate a set of methods for assessing the pedestrian response (in terms of perception, evaluation and behaviour) to outdoor lighting.
- O3. To evaluate whether the methods for assessing the pedestrian experience of outdoor lighting, previously evaluated in a full-scale laboratory, are applicable in a real-world setting.
- O4. To investigate whether young people (20-35 yrs.) respond differently to outdoor lighting than elderly (60-75 yrs.) and whether the assessed lighting installations provide sufficient lighting conditions for both age groups.
- O5. To test a new behavioural method of assessing pedestrians' preferences for outdoor lighting applications, as a way of complementing existing self-report scales.

1.2 Outline of empirical work

The five objectives (O1-O5) were addressed through four studies (S1-S4, presented in chronological order). The results from each study were reported in separate papers (Figure 1).

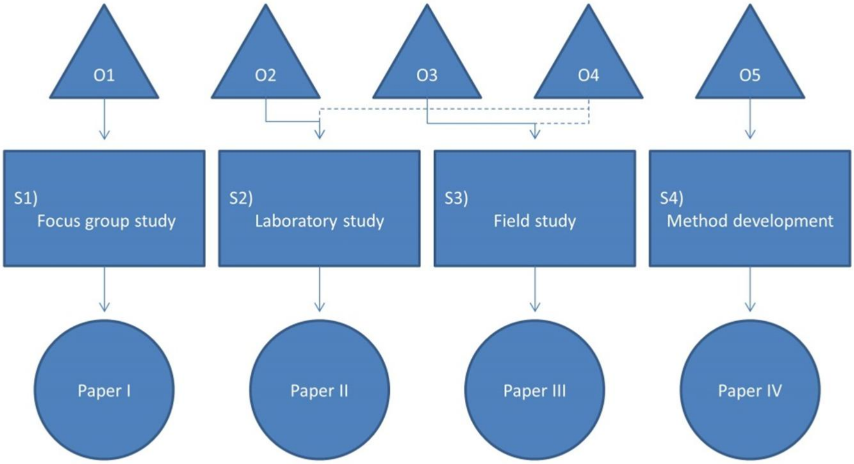

Figure 1.
An overview of the relations between the objectives (O1-O5), studies (S1-S4) and papers.

2. Theoretical framework

2.1 Walkability

The quality of the built environment with regard to walking is labelled walkability. It can be defined as "the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network" (Southworth, 2005, p. 248).

Walkability has been approached from different scientific disciplines, e.g. architecture and urban design (Ewing & Handy, 2009; Southworth, 2005; Sugiyama & Ward Thompson, 2008), health sciences (Frank et al., 2006; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Sundquist et al., 2011), transport research (Manaugh & El-Geneidy, 2011; Millward, Spinney, & Scott, 2013), and environmental psychology (Alfonzo, 2005; Brown, Werner, Amburgey, & Szalay, 2007; Johansson et al., 2011; Johansson, Sternudd, & Kärrholm, 2016). A common approach to investigating the relationship between the built environment and walkability has been to focus on the neighbourhood level of the built environment, in terms of one or several of its five Ds: density, diversity, design, destination accessibility and distance to transit (for an overview, see Ewing & Cervero, 2010). Others have attempted to capture micro-level factors influencing walkability, such as traffic, street width, slope, etc. (Handy, 2005).

A number of instruments have been developed for assessing micro-level characteristics considered important for walkability, such as the Systematic Pedestrian and Cycling Environmental Scan (Pikora et al., 2006), Neighborhood Environment Walkability Scale (Saelens, Sallis, Black, & Chen, 2003) and Active Commuting Route Environment Scale (Wahlgren, Stigell, & Schantz, 2010). However, the established measures of walkability either neglect outdoor lighting or treat it superficially as a dichotomous existing / non-existing variable.

An alternative approach is to use the pedestrian perspective as a starting point in order to understand how the experience of the environment impacts walking. As part of the social-ecological model of walking, Alfonzo (2005) suggests a hierarchical structure of pedestrian needs consisting of five levels (ranging from feasibility (relating to personal limits), via accessibility, safety and comfort, to pleasurability of the walking environment) that influence people's decision to walk (Figure 2). Within the hierarchical structure, a pedestrian would typically not consider a higher-ordered need if a lower-order need was not fulfilled. From this perspective, the presence, quality and characteristics of artificial outdoor lighting impacts the evaluation of how the environments support the pedestrian needs, so is fundamental for people's decisions whether to walk or not after dark.

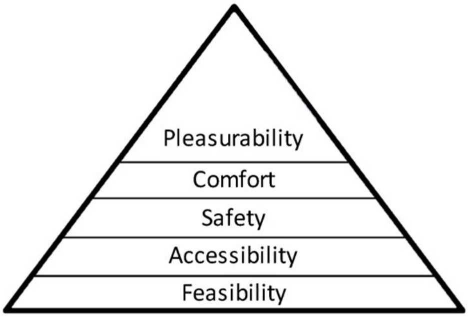

Figure 2.
The pedestrian needs hierarchy, adapted from Alfonzo (2005).

2.2 Human-environment interaction

The idea that the intention to walk and the act of walking are influenced by the physical environment may also be understood through the lens of the Human-Environment-Interaction (HEI) model shown in Figure 3 (Ferreira, Johansson, Sternudd, & Fornara, 2016; Fyhri & Hjorthol, 2009; Johansson, 2006; Küller, 1991). The model states that the interaction between the individual and the physical and social environments triggers a basic emotional process that influences how the situation is perceived and guides the reaction/behaviour of the individual.

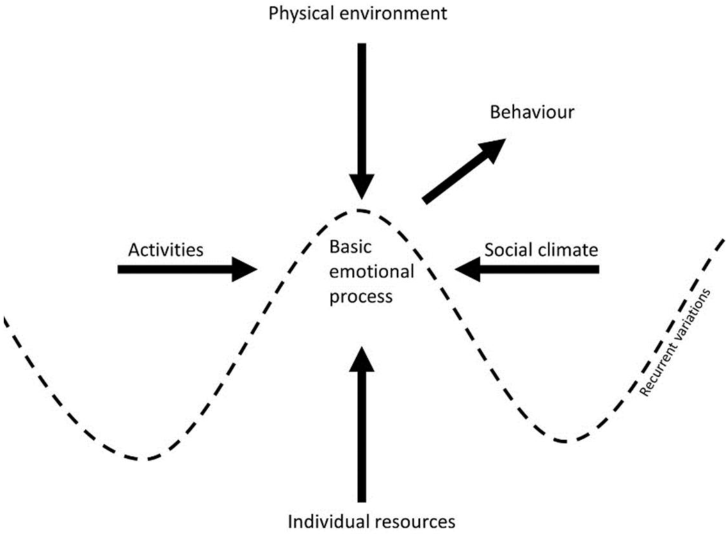

Figure 3.
The human-environment-interaction model. Adapted from Küller, 1991.

The basic emotional process consists of four stages: activation, orientation, evaluation and coping/control. A change in the physical or social environment activates the process, and the individual orientates the attention towards the change. The situation is evaluated and the evaluation process leads to the initiation of a coping response. The coping response aims at retaining control over the situation and will vary depending on the outcome of the evaluation. According to the HEI model, this basic emotional process is influenced by the activity the individual is engaged in, as well as by personal resources and previous experiences. The HEI model served as a conceptual framework that, in addition to the thematic structure presented in the next section, guided the design of Studies 2 and 3.

The following example applies the HEI model to the scenario of walking alone after dark: In the evening, an individual walks alone on an urban pedestrian path which is poorly lit, with no other people around. Suddenly, an unfamiliar person appears from around a bend 20 m further along the path. The individual becomes aroused, switches attention towards the person, makes a quick evaluation of the situation and the person's intent, and reacts in a way that aims to control the situation. Depending on the individual resources and prior experiences, the evaluation and coping response might be very different. Possible reactions may range from turning around and trying to withdraw from the setting as a way of coping with a situation perceived as unsafe, to continuing walking along the path and greeting the person when passing.

2.3 Outdoor lighting: Overarching themes of pedestrian response

As in the walkability research field, where outdoor lighting is treated superficially, walkability is overlooked in the lighting research field. A body of research investigates the human response to outdoor lighting, but without exploring its impact on the walkability of the lit environment. In an attempt to generate an overview of the diverse research field of the human response to outdoor lighting, Rahm and Johansson (2016) conducted a systematic literature review (Appendix V). The systematic search identified 48 relevant articles, and an inductive thematic analysis was conducted (Braun & Clarke, 2006), by which three overarching themes were identified. The themes were conceptualised based on the primary underlying process assessed by the tasks within each category.

The first theme, ‘Perception of the lit environment’, concerns how lighting applications are perceived differently in visual terms depending on individual factors, such as age and eyesight, and on the various characteristics of the light source, especially at mesopic vision. The second and third themes concern how the individual responds to the perceived environment, either on a cognitive/emotional level, ‘Evaluation of the lit environment’, or by an overt physical reaction, ‘Behaviour in the lit environment’ (Figure 4). The underlying categories relevant for the objectives of the thesis will be presented in detail in section 4.1, ‘Selection of methods’.

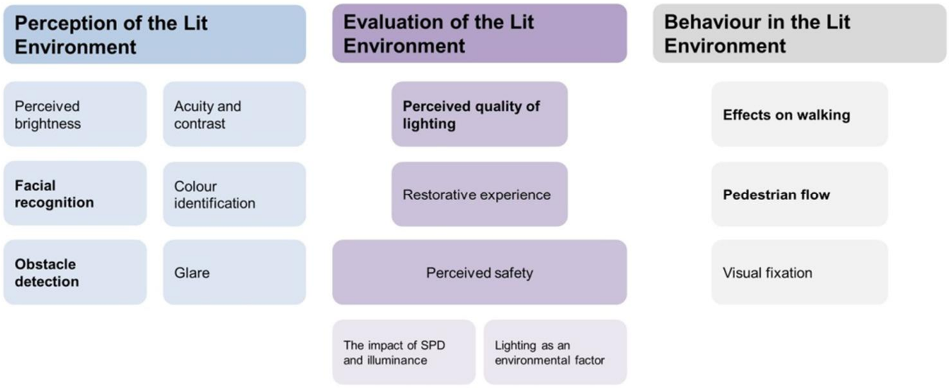

Figure 4.
Overarching themes and corresponding categories identified through the systematic literature review. Categories included in the thesis are marked in bold.

3. Scientific point of departure

In the tradition of the field of environmental psychology, this thesis takes a pluralistic, problem-centred, real-world oriented approach to research. Environmental psychology may be considered a multiple-paradigm discipline (Craik, 1977) and, in line with the pragmatic position proposed by Greene and Caracelli (1997) and Patton (1988), multiple paradigms are applied in the thesis: a constructivistic worldview underlies Study 1, whereas post-positivism underlies Studies 2-4. It is acknowledged that the different worldviews represent different stances on ontology (nature of reality), epistemology (how we gain knowledge of what we know), axiology (the roles of values in research), methodology and the language of research (Creswell & Plano Clark, 2007).

However, by adopting a pragmatic position, the paradigms are "viewed as descriptions of, not prescriptions for, research practice" (Greene & Caracelli, 1997, p. 8) and it is assumed that "methods can be combined on the basis of their practical utility" (Maxwell & Mittapalli, 2010, p. 146). Furthermore, within the field of environmental psychology, the use of multiple methods and approaches to gain knowledge is advocated, and multiple studies and methods are considered necessary for reaching full understanding (Gifford, 2014). A pluralistic approach was therefore employed to strengthen the overall exploration of the pedestrian response to outdoor lighting.

3.1 Ethical considerations

The studies underlying the thesis were carried out in accordance with the rules and regulations laid down by the Ethics Committee of the Swedish Research Council (Gustafsson, Hermerén, & Petterson, 2011). These guidelines state that a research project should be submitted to an ethics committee if it uses a method meant to influence the person physically or psychologically or causes obvious risk for physical or psychological harm to the participant. The Regional Ethical Review Board was consulted, but the Board concluded that approval according to the Swedish Ethical Review Act was not needed for the methods employed in the studies.

Before participation, information about the aim of the study was given and written informed consent was obtained from all participants in accordance with the Declaration of Helsinki (World Medical Association, 2013). The participants were also informed of their right to withdraw at any time without giving an explanation. Personal information was anonymised to retain the privacy of the participants, who received a small remuneration after their participation.

4. Methodological considerations

The thesis employs a mixed methods approach (Creswell & Plano Clark, 2007), where the individual studies were based on both qualitative (Study 1) and quantitative methods (Studies 2-4). The first study, being exploratory in nature, used focus groups to gather data concerning what pedestrians emphasise as important with regard to perceived urban design qualities related to neighbourhood walkability. Based on the transcribed interviews, an inductive thematic analysis was conducted (Braun & Clarke, 2006), to identify themes relevant for the decision to walk in the neighbourhood after dark.

The second and third studies employed a hypothetico-deductive approach (Mesly, 2015) to test the hypotheses regarding the methods used for assessing the luminaires. The fourth study, which tested the Random Environmental Walk (REW) method, relied on a hypothetico-deductive approach regarding the assessment of perceived lighting quality, while a Bayesian probabilistic approach was behind the model concerning the design of the REW procedure (Kruschke, 2015).

4.1 Selection of methods

The method applied in Study 1 was chosen to explore what pedestrians regard as important in terms of perceived urban design qualities relating to neighbourhood walkability. The use of focus groups (Greenbaum, 1998), with open, general questions about perceived urban design qualities as prompts for stimulating the focus group discussions, enabled the collection of data covering a variety of topics relating to the pedestrian experience. Focus group methodology was deemed appropriate for soliciting diverse and rich information, since it evens out the power imbalance between researcher and participants, and allows an interactive exchange of opinions between the participants (Liamputtong, 2011). The rich data obtained through the focus groups served as a basis for an inductive thematic analysis (Braun & Clarke, 2006), identifying patterns and themes in the discussions.

The methods for assessing outdoor lighting in the laboratory (Study 2) and in the field (Studies 3 and 4) were chosen after identifying methods deemed feasible for use in a practical setting and that considered the three overarching themes of pedestrian response to outdoor lighting (perception of the lit environment, evaluation of the lit environment, and behaviour in the lit environment) produced by the systematic literature review (Appendix V). The reason for this was to identify methods that could differentiate between lighting applications based on different aspects of the pedestrian response. The REW method was inspired by the travelling politician problem, as detailed by Kruschke (2015). An overview of the methods applied in the different studies is presented in Table 1.

Table 1.
An overview of the methods applied in the four studies.

Method	Study 1	Study 2	Study 3	Study 4
Focus group discussions	ü			
Facial expression recognition task		ü	ü	
Obstacle detection task		ü		
Sign reading task		ü	ü	
POLQ scale		ü	ü	ü
Affect grid and scales		ü	ü	
Perceived seeing condition		ü	ü	
Visual accessibility scale			ü	
Walking speed measurement		ü		
Pedestrian flow observation			ü	
Random Environmental Walking				ü

4.1.1 Perception of the lit environment

Facial recognition is considered to be an important visual task for pedestrians after dark, since judging the intent of oncoming pedestrians from a safe distance is deemed to influence the perception of safety (Caminada & Van Bommel, 1980; CIE, 2010; Willis, Palermo, & Burke, 2011). Facial recognition has been investigated both in laboratory settings (Fotios, Yang, & Cheal, 2015; Yang & Fotios, 2015) and in the field (Knight, 2010; Lin & Fotios, 2015; Rea, Bullough, & Akashi, 2009; Yao, Sun, & Lin, 2009), using photographs, dummies or assistants as targets that should be recognised by the respondents.

A common technique has been to measure the distance at which the respondents are certain of the gender, can guess the identity, or make out facial features. It is suggested, however, that recognition of facial expressions may be a more relevant task for evaluating lighting quality, and more ecologically valid due to its greater relevance for judging the intent of oncoming strangers (Raynham & Fotios, 2011). Facial expression recognition was therefore chosen as the first method used for evaluating the perception of the lit environment, both in the laboratory and in the field. To ensure that the participants were presented with the intended facial expression, validated photographs depicting anger, fear and surprise were used (Ekman, 2007).

The second method, obstacle detection, is considered important, since uneven pavements and other obstacles are a common cause of outdoor fall accidents (Arvidsson, 2017; Berntman, 2015; Fothergill, O'Driscoll, & Hashemi, 1995). Obstacle detection has been explored in the laboratory using apparatus with adjustable obstacle heights (Fotios & Cheal, 2009, 2013) and by using a mock-up path with a false floor displaying obstacles at various heights (Fotios & Uttley, 2018; Uttley, Fotios, & Cheal, 2017). An inverse relationship has been found between illuminance level and the obstacle height needed for it to be detected, and at low light levels (0.2 lx) younger participants detected significantly lower obstacles than older participants (Fotios & Cheal, 2009; Uttley et al., 2017). Obstacle detection was used in the laboratory (Study 2), but was not deemed feasible for use in the field.

The importance of the third task, street sign reading, for orientation within the environment has been briefly discussed by Fotios and Cheal (2007), but to our knowledge has not previously been used for assessing outdoor lighting. It was deemed to have ecological validity and practical utility, and was therefore included both in the laboratory and in the field.

4.1.2 Evaluation of the lit environment

Within the second overarching theme, the evaluation of the lit environment, perceived lighting quality and the impact of lighting on the emotional state were deemed important topics. Perceived safety (a central theme of Study 1) was not considered feasible to include, since the experimental situations did not allow for an unbiased assessment due to the presence of the researchers, the safe setting in the laboratory, and the presence of the nearby group of participants in the field study.

Perceived lighting quality adds the human evaluation component to the assessment of lighting quality and complements the technical environmental assessment measures. It has been conceptualised in a variety of ways (Boyce, Eklund, Hamilton, & Bruno, 2000; Hanyu, 1997; Johansson et al., 2011; Johansson et al., 2014; Kuhn et al., 2013; Shikakura, Kikuchi, Tanaka, & Furuta, 1992; Viliūnas et al., 2014). In a recent effort to assess the perceived outdoor lighting quality, Johansson et al. (2011) and Kuhn et al. (2013) used the dimensions brightness and hedonic tone, previously used by Küller and Wetterberg (1993, 1996), to describe subjective impressions. Their concept has since been further developed by the development of the Perceived Outdoor Lighting Quality scale, POLQ (Johansson et al., 2014), which distinguishes between lighting applications on two indices, the Perceived Strength Quality (PSQ) and the Perceived Comfort Quality (PCQ) index.

It has also been found that lighting may affect the emotional state of the individual in terms of the level of arousal and pleasure (Hanyu, 1997; Park & Farr, 2007; Quartier, Vanrie, & Van Cleempoel, 2014). Since perceived lighting quality and emotional state influence the experience of walking in the lit environment, the POLQ scale (Johansson et al., 2014) and a composite measure consisting of the affect grid (Johansson et al., 2016; Russell, Weiss, & Mendelsohn, 1989) and two scales measuring levels of valence and arousal (Johansson et al., 2016) were selected as methods for assessing the evaluation of the lit environment, both in the laboratory and in the field.

The REW method was developed to capture pedestrians' behavioural preferences for outdoor lighting applications as an alternative to self-rating scales. This could be useful for gathering the opinions of people where the use of self-rating scales would be a challenge (e.g. children or people with insufficient language skills or with reading difficulties). In the REW method, a forced-choice technique is used, where the participants repeatedly have to choose between staying at their present lighting application or walking to a randomly selected lighting application (for a detailed description, see Appendix IV). The REW method was evaluated in Study 4.

4.1.3 Behaviour in the lit environment

Within the third overarching theme, behaviour in the lit environment, studies indicate that the illuminance level may have tangible effects on pedestrian behaviour. Walking speed was therefore deemed to be a measure with potential to differentiate between the three lighting applications in the laboratory, since insufficient lighting is suggested to decrease walking speed (Choi, Kang, Shin, & Tack, 2014; Pedersen & Johansson, 2018) and make people look at the ground more, compared to brighter conditions (Itoh, 2006). Also, some studies suggests that a change in lighting conditions may have an impact on the pedestrian flow (Herbert & Davidson, 1994; Painter, 1996; Unwin, Symonds, & Laike, 2017), and observations of pedestrian flow were therefore used to evaluate the impact of the lighting applications in the field.

4.2 Reliability and validity

The methods from Study 2 were also applied in Study 3, replicating Study 2 to some degree and giving an indication of the generalisability of the methods. The corresponding results for the perceptual tasks suggest they can be used also in the field. However, the lack of correspondence for the evaluation measures does not necessarily imply that the measures lack reliability, since the between-subjects design of Study 3 might have resulted in a statistical power too low to detect differences for the evaluation measures. Moreover, the reliability and validity have already been established for the POLQ scale (Johansson et al., 2014) and the composite measure of valence and arousal (Johansson et al., 2016; Russell et al., 1989; Västfjäll & Gärling, 2007).

In Study 4, the correspondence in the rankings of the lighting applications between the PCQ dimension of the POLQ scale and REW indicate the validity of the REW method in assessing the preference for the lighting applications, based on the extent to which the light is perceived as mild, soft, warm, natural and non-glaring. The perceptual tasks were assumed to have sufficiently high face validity to be perceived as relevant by pedestrians after dark. However, the facial expression recognition task used black and white photographs as stimuli, which might have had an impact on the realism of the task.

4.3 Settings

Studies 1, 3, and 4 were conducted in the field, while Study 2 was a full-scale laboratory study. Study 1 was conducted in three different neighbourhoods with mid-twentieth century design located in semi-central Malmö (a city of about 300,000 inhabitants), Sweden. The reason for conducting the first study in the field was to explore how pedestrians discuss perceived urban design qualities with regard to neighbourhood walkability, while being in the neighbourhood itself. This was assumed to elicit more relevant commentary than asking about recollections of outdoor environments while being in an indoor setting.

In order to reduce confounding factors such as traffic, other pedestrians and weather, a mock-up in a laboratory was used for Study 2. Also, being in a laboratory enabled a within-subjects design due to the ease by which the lighting application could be changed, and allowed more comfortable conditions for the participants.

The third and fourth studies were conducted in a field setting in Pildammsparken in Malmö. The move from the laboratory back to real-world settings in Studies 3 and 4 was in line with the problem-centred, real-world oriented approach of the thesis. Greater ecological validity was sought by applying the methods shown to differentiate in the laboratory in a field setting. A secluded urban park setting was used to minimise confounding factors, such as disturbing light sources and other pedestrians. Also, as the results from Study 1 indicated, parks tend to be avoided after dark, forcing pedestrians to make detours. An urban park was therefore deemed a relevant setting for assessing the pedestrian experience of outdoor lighting, in an attempt to contribute to an understanding of the accessibility of the city after dark.

Study 1 was conducted in early autumn with mild weather conditions, whereas Studies 3 and 4 were conducted during November and December, with temperatures ranging from 3 to 11 degrees Celsius. There was no snow on the ground during the data collections.

4.4 Lighting applications

A variety of lighting applications were used in the studies underlying the thesis. In Study 1, the lighting applications represented current lighting applications for pedestrians in three neighbourhoods of Malmö. In Studies 2-4 the lighting applications were selected by the municipality of Malmö on the basis of economic feasibility, fulfilment of technical specifications according to the national standards, and relevance for use on pedestrian paths in the city.

In Study 1, at the time of the study, Rönneholm had high-pressure sodium applications (Correlated Colour Temperature (CCT): 2060 K), Dammfri had ceramic metal halide (CMH) applications (CCT: 2821 K), and in Lorensborg the lighting applications had recently been replaced with white LED applications (CCT: 4098 K). For Study 2, the laboratory study, Malmö municipality picked three lighting applications. Lighting applications A (CMH, CCT = 2890) and B (LED, CCT = 2912) were already being used on various paths in the city, while application C (LED, CCT = 3810) was a new luminaire considered for future use (for photometric properties see Appendix II, Table 1, Figures 3 & 4). In Study 3, Malmö municipality wanted to further evaluate lighting application B from Study 2 along with an updated version of lighting application C , with a warmer, more yellow colour (CCT = 2930 K; for photometric properties see Appendix III, Table 2 & Figure 2). For Study 4, Malmö municipality selected four different lighting applications: Lighting application 1 (CMH, CCT = 2832), 2 (CMH, CCT = 2981), 3 (LED, CCT = 3912) and 4 (LED, CCT = 4051; for photometric properties see Appendix IV).

4.5 Participants

The studies underlying the thesis used different groups of participants. The participants of Study 1 were recruited from the areas in Malmö where the focus group interviews were conducted. The reason for this was to ensure that the participants were familiar with the neighbourhoods both during the day and after dark. In Study 2, the participants were recruited from two different age groups (20-35 yrs. and 60-75 yrs.), to investigate whether people from different age groups respond differently to outdoor lighting and whether the assessed lighting installations were sufficient to discern obstacles, to read street signs, and to correctly identify facial expressions for both age groups. The participants were recruited at organisations for the elderly, in public places, on the university campus and through the researchers' personal networks. Studies 3 and 4 were conducted in conjunction with each other, but in different parts of the park. They therefore shared participants, recruited from two different age groups (20-35 yrs. and 60-75 yrs.) for the same reason and followed the same procedure as for Study 2. The majority of the participants in Studies 3 and 4 visited the park once a year or less frequently.

5. Summary of the papers

5.1 Paper I

5.1.1 Aim

Study 1 was aimed at exploring what pedestrians emphasised as important in terms of perceived urban design qualities relating to neighbourhood walkability. The main focus of the analysis was on the topics of greenery, outdoor lighting and perceived safety in relation to walking in an urban context, and how the perception of safety affected how the participants used the neighbourhood for walking.

5.1.2 Method

Participants and settings

The study involved 106 participants, between 18 and 84 years of age, of which 51% were female.

Procedure and analysis

All participants were informed about the overarching aim of the study, to explore how they perceived their neighbourhood with regard to walking for transport (without mentioning specific neighbourhood qualities related to walking). In each district, the participants first took part in a structured walk following a route of approximately 300 m, representing the pedestrian planning strategy of the district. Immediately after the structured walk, the participants gathered for focus group discussions.

These discussions were led by a researcher, using a semi-structured interview guide containing open questions about the qualities of the neighbourhood and suggestions on how to improve the neighbourhood in relation to walking (see Appendix I, Table 1). Twenty-four focus group discussions were held, all during daylight hours, each taking approximately 15 minutes. The recorded and transcribed interviews were coded on a line-by-line basis using a code-list consisting of 16 codes. Three codes (outdoor lighting, greenery and perceived safety) frequently occurred together and a decision was made to focus on those three topics in the further analysis. The paragraphs where the codes co-occurred, as identified by the ATLAS.ti query tool, were compiled, analysed for similarities and differences, and thematically categorised (Braun & Clarke, 2006).

5.1.3 Results

Four clear themes were identified in the compiled quotations from the co-occurring codes (see Appendix I, Table 2). A common theme found for greenery and lighting was the avoidance of certain areas after dark. Greenery tended to be considered a positive environmental factor during daytime, but environments with greenery (especially the municipal parks) were avoided after dark, which seemed to be reinforced by inadequate street lighting. A second theme was the feeling of entrapment, i.e. not being able to escape from a potentially dangerous situation, which was associated with feeling unsafe. If dense and too close to the path, greenery contributed to the feeling of entrapment. Entrapment was also mentioned as a reason for avoiding certain areas after dark. Not only the municipal parks were avoided; passages with mesh fences and dense greenery close to the path created a sense of entrapment which, in turn, deterred pedestrians from using them after dark. In the neighbourhoods of this study, some of the paths with dense greenery are the only option for walking in a certain direction, which forced some pedestrians to make lengthy detours.

A third theme was the presence of others, which contributed to the perceived safety and seemed to keep environments inviting also after dark. Finally, quotations related to prospect were identified for both lighting and greenery in relation to perceived safety. For greenery, this was expressed as concern with neglected upkeep resulting in large bushes and excessive undergrowth obstructing the views of pedestrians. For lighting, the reasons for concern related to overview were low light levels and unlit areas. The results point to the complexity of pedestrians' perception of safety and indicate that, after dark, perceived safety is influenced both by urban greenery and street lighting. Also, the themes seem to be inter-related, at least to some degree (see Figure 5).

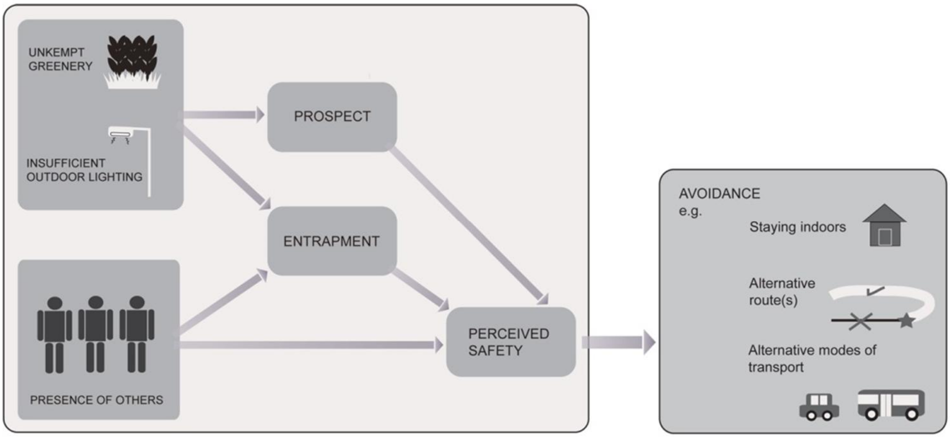

Figure 5.
Overview of the suggested relations between perceived safety, urban greenery, outdoor lighting and the identified themes.

5.2 Paper II

5.2.1 Aim

The aim of Study 2 was to assess differences between three lighting applications fulfilling requirements for current Swedish standards on illuminance levels at pedestrian paths, but differing in photometric qualities. A further aim was to test whether people from different age groups responded differently to the three lighting applications.

5.2.2 Method

Participants and settings

The study comprised 89 participants divided into two age groups: one group of young people (N: 43, aged 19-31 yrs., mean age: 22, 47% female) and one group of elderly (N: 46, aged 62-77, mean age: 69, 54% female).

The study was carried out in a laboratory (14.5 x 18.5 x 4.5 m) where a 23 m long and 2.5 m wide pedestrian path was constructed along the diagonal axis, with two lampposts 4 m high placed 16 m apart. The walls were covered in black cloth and the floor had a graphite-grey carpet with a reflection factor of 5%. The three lamps were one CMH (Lighting application A) and two LEDs (Lighting applications B and C) (for photometric data, see Appendix II, Table 1).

Measurements

Three tasks were used to evaluate the perception of the lit environment: obstacle detection, facial expression recognition, and sign reading. For the obstacle detection task, the participants were placed at a specific viewing point and instructed to focus straight ahead while simultaneously stating the number of obstacles (10 x 10 x 2.5 cm, made of the same carpet as was covering the floor) they could discern on the ground on their right-hand side. In the facial expression recognition task, the participants were instructed to walk towards a photograph of a woman´s face (175 x 200 mm; positioned at a height of 1.65 m; printed on non-glossy paper), placed on the right-hand side of the path 12 m from the first lamppost, and to stop when they could discern the facial expression. In the sign reading task, the participants were asked to walk along the path towards a street signpost (placed 4 m to the right of the path and 13.6 m from the starting point, at a height of 2.10 m) and to stop when the text on the street signpost became legible.

In order to assess the emotional state of the participants immediately after they had finished walking down the path, a composite measure consisting of the affect grid (Johansson et al., 2016; Russell et al., 1989), and two scales measuring levels of valence and arousal were administered (Johansson et al., 2016). To capture how the participants experienced the lighting and the lit environment, the POLQ scale (Johansson et al., 2014) was used. The participants were also asked to rate how well they could see under the present lighting application using a 7-point Likert scale (1 = very poorly, to 7 = very well).

Behaviour was assessed in terms of walking speed. Before entering the laboratory, the baseline walking speed of the participants was measured over a 33.3 m distance in a corridor under well-lit conditions ($\bar{E}_H$= 195 lx). In the laboratory, at the start and end of the path, motion sensors connected to a stopwatch measured the time it took the participants to walk the path, and walking speed was calculated. The impact of lighting on walking speed was then calculated for each lighting application by subtracting the walking speeds from the laboratory from the baseline walking speed.

Procedure

The study employed a mixed design, with a within-subjects repeated measures design for evaluating differences due to the different lighting applications, and a between-groups design for exploring differences due to age. Each participant performed the test procedure three times, once for each lighting application. The luminaires were shifted by rotating the top of the lamppost, and the presentation order was counterbalanced. The participants entered the laboratory one at a time, while the rest of the group remained in the waiting room. First, the participants rated their emotional state and the perceived lighting quality. When all participants were finished, they entered the laboratory a second time and walked to the obstacle detection point 5.5 m down the path from the first lamppost and performed the obstacle detection task. The participants returned to the starting point before starting the facial expression recognition task, after which they returned to the starting point. Lastly, the participants performed the sign reading task.

5.2.3 Results

The data was analysed using a Repeated Measures ANOVA with age as between-subjects factor.

Perception

Statistically significant differences were found between the different lighting applications for obstacle detection, facial expression distance, and sign reading distance (Appendix II, Table 3 & Figure 7). For obstacle detection, participants were most successful in detecting obstacles under lighting application C, on average detecting 42% of the obstacles, followed by lighting application A (26%), and then lighting application B (19%) ($p < .001$, $\eta_p^2 = .304$). Similar results were found for the distances needed to recognise a facial expression ($p < .001$, $\eta_p^2 = .085$) and the distance to read the street signpost ($p < .001$, $\eta_p^2 = .268$). Lighting application C enabled the participants to identify facial expressions and read a street signpost at significantly greater distances (mean distance: 4.6 and 11.3 m) than lighting applications A (4.0 and 10.1 m) and B (4.2 and 9.9 m).

For obstacle detection, there were significant differences between the two age groups, where the younger group performed significantly better on average (36%) than the older group (24%) ($p = .002$, $\eta_p^2 = .105$). Also, the younger group could both identify facial expressions (4.7 m) and read the street signpost (12.1 m) at greater distances on average than the older group (4.1 and 8.6 m). For facial expression distance there was also a weak interaction effect, indicating that the older group needed to be closest for lighting application B ($p = .041$, $\eta_p^2 = .036$), whereas the younger group had their shortest distance for lighting application A. The younger participants were also more accurate in their assessment of facial expressions ($p = .008$, $\eta_p^2 = .079$).

Evaluation

Significant differences were also found for the instruments used for evaluating the lighting and the lit environment. For the perceived lighting quality indices from the POLQ scale, PSQ and PCQ, there were significant differences between the three lighting applications (PSQ, $p < .001$, $\eta_p^2 = .337$; PCQ, $p < .001$, $\eta_p^2 = .279$). Lighting application C was rated highest on perceived strength quality (mean PSQ: 5.6) and lowest on perceived comfort quality (mean PCQ: 3.2). For the emotional state measurement, the different lighting applications differed on level of arousal ($p < .001$, $\eta_p^2 = .104$), where lighting application C was experienced as more arousing than lighting application A, but not significantly different from B.

Lighting application C was deemed to give significantly better seeing conditions ($p < .001$, $\eta_p^2 = .129$) (Appendix II, Table 3). There were significant differences between the age groups for PCQ ($p < .001$, $\eta_p^2 = .192$), where the younger group had lower average ratings (3.59 compared to 4.9), but not for PSQ ($p = .766$). However, for both indices there were interaction effects (PSQ, $p = .009$, $\eta_p^2 = .053$; PCQ, $p = .019$, $\eta_p^2 = .045$). For PSQ, both lighting application A and B were rated lower by the younger group, while application C was rated higher than by the elderly. For PCQ, lighting applications A and B were evaluated similarly by the young group, whereas the elderly rated lighting application A higher than lighting application B. Differences between the age groups were also found for emotional state. The older group was both more aroused ($p = .001$, $\eta_p^2 = .128$) and felt more positive ($p < .001$, $\eta_p^2 = .241$) than the younger group.

Behaviour

Relative walking speed did not differ between the three lighting applications ($p = .243$), and there were no significant differences between the different age groups ($p = .208$) and no significant interaction effects ($p = .877$).

5.3 Paper III

5.3.1 Aim

Study 3 aimed at evaluating whether the methods for assessing the pedestrian experience of outdoor lighting, previously evaluated in the full-scale laboratory (Study 2), were applicable in a real-world setting. A second aim was to investigate whether the elderly experienced the lit environment differently to the young, and whether the lighting installations were sufficient for both age groups.

5.3.2 Method

Participants and settings

The sample consisted of 81 participants (mean age: 43, 64% women), divided into a younger group (n: 48, mean age: 26, 63% women) and an older group (n: 33, mean age: 69, 67% women). The study was carried out after sunset in Pildammsparken, an urban park in the centre of Malmö, Sweden. The participants walked a 90 m long and 3.4 m wide pedestrian gravel path. On the right-hand side of the path, lampposts were placed at intervals of 21.5 m, with luminaires at a height of 4 m.

Measurements

In the facial expression recognition task, the participants were instructed to walk along the path towards a photograph of a woman´s face (175 x 200 mm; positioned at a height of 1.65 m; printed on non-glossy paper), placed on the right-hand side of the path 17.5 m from the first lamppost, and to stop when they could discern the facial expression. For the sign reading task, the participants were asked to continue along the path towards a street sign (placed 2 m to the left of the path and 5 m from the next lamppost in the walking direction, at a height of 2.10 m) and to stop when the text became legible. The street sign was of similar type and with equivalent number of syllables as in the laboratory study (Appendix II).

The participants assessed their emotional state (arousal and valence) at the time when they had walked halfway down the path, using a composite measure consisting of the affect grid (Johansson et al., 2016; Russell et al., 1989), and two scales measuring levels of valence and arousal (Johansson et al., 2016). Also, after the participants had walked down the path, they responded to the POLQ scale (Johansson et al., 2014). The participants also rated how well they could see under the present lighting application, using a 7-point scale (1 = very poorly, to 7 = very well) and they rated the perceived visual accessibility by the following statements: I would have been able to a) detect objects on the ground; b) read a street sign and c) recognise the people’s faces. Responses were given on 5-point scales (1= totally disagree, to 5 = totally agree).

To evaluate the potential impact of lighting conditions on pedestrian flow (as a result of a hypothetical change to the attractiveness of the path for walking), a structured observation was conducted between 7 and 8 pm on four different occasions (Sunday, Tuesday, Wednesday and Thursday) for each lighting application. The pedestrian path was observed from a secluded spot some distance away and the number of pedestrians, whether they were alone or in company, and whether they were walking or jogging, was recorded.

Procedure

The study employed a between-subjects design, where the first group conducted the tasks under lighting application I and the second group under lighting application II. The participants arrived in groups of five at the meeting point, located a short distance from the starting point of the path. Before starting, the participants were instructed on how to use the POLQ scale and the affect grid. For the POLQ scale, the participants were asked to assess the perceived lighting quality of a pedestrian path depicted in a photo (17 x 21 cm) with the objective of establishing a common starting point, as well as giving an opportunity to ask questions about how to use the scale.

The participants were then asked to complete questionnaires surveying background data and individual characteristics.

The next step was to, one by one, walk to the starting point and then walk along the footpath. The procedure was based on the structured walk methodology developed by Johansson et al. (2016). The participants stopped approximately halfway down the path to fill in the affect grid and at the end of the path completed the POLQ scale, rated how well they could see, and responded to the visual accessibility items. When all were done, they returned to the meeting point. Next, the participants individually returned to the starting point and performed the facial expression recognition task, followed by the sign reading task.

5.3.3 Results

The data was analysed using 2-way independent ANOVA for analysing differences between the lighting applications and age groups, and Mann-Whitney U-test for differences in pedestrian flow between the two lighting applications.

Perception

The results from the visual tasks used to assess perception of the lit environment differed significantly between the lighting applications. For facial expression recognition, lighting application I enabled the participants to feel confident of recognising the facial expression at a distance of approximately 1.5 m greater than for lighting application II ($p = .025$, $\eta_p^2 = .064$) (Appendix III, Table 3). Similarly, for sign reading, lighting application I enabled the participants to read the street sign at a greater distance (15.79 m) compared to lighting application II (12.24 m) ($p < .001$, $\eta_p^2 = .192$). For sign reading, there were also significant age differences ($p < .001$, $\eta_p^2 = .324$). The young group were able to read the street sign at a distance of about 16 m, whereas the older group averaged at about 11 m. There were also significant interaction effects between age and lighting application for the sign reading task ($p = .009$, $\eta_p^2 = .086$), where the younger group managed to read the street sign at a relatively greater distance for lighting application I compared to application II.

Evaluation

The two lighting applications were evaluated similarly for emotional state, seeing conditions, the POLQ scale and perceived visual accessibility (Appendix III, Table 4). The results from the composite arousal measure showed that the younger group was significantly less aroused than the elderly ($p = .031$, $\eta_p^2 = .059$) and for perceived visual accessibility, there were significant interaction effects ($p = .040$, $\eta_p^2 = .053$). The young group rated lighting application I as providing the best visual accessibility, whereas the elderly rated lighting application II as better (Appendix III, Tables 3 & 4).

Behaviour

The behaviour measure, observations of pedestrian flow, did not detect any differences in number of people walking on the path under the two lighting conditions (Appendix III, Table 4 & Figure 3).

5.4 Paper IV

5.4.1 Aim

The aim of Study 4 was to develop a new behavioural method of assessing participants' preferences for outdoor lighting applications. This would complement existing self-report scales and more easily gather the opinions of people where the use of self-rating scales would be difficult.

5.4.2 Method

Participants and settings

Eighty participants (the same group as in Study 3) took part in the study – 51 women aged between 20 and 76 (mean = 44 yrs.), and 29 men aged between 21 and 76 (mean = 42 yrs.). The lighting applications tenable for use in the City of Malmö were selected by Malmö Streets and Park Department and installed in a small formal garden (area = 500 m^2). The spacing between the four lighting applications was about equal and all lighting applications were within short walking distance of each other (mean distance = 20.5 m).

Measurements and procedure

All participants undertook the study in small groups of 5-8 participants. Participants were first shown around the site by the study administrator, without requiring them to complete any task. Instructions about how to complete each part of the study were explained verbally, and the REW procedure was demonstrated practically. Perceived outdoor lighting quality was assessed using the POLQ scale (Johansson et al., 2014). For the REW, a tetrahedral die in a clear plastic pot was used by each participant to select randomly a lighting application on each repetition of Step 3 of the REW procedure, as described below. A paper form was provided for each participant to write down the number of the lighting application they walked to on each repetition of Step 3, in total 40 times per participant.

Instructions

Step 1. Throw the die.

Step 2. Walk to the lighting application as indicated by the number on the die.

Step 3. Throw the die again.

A. If you prefer the lighting application indicated by the die as compared to your current lighting application, walk to the lighting application indicated by the die and note the number of the lighting application in the protocol. If the lighting application indicated by the die is your current lighting application, stay at that location and repeat Step 3.

B. Alternatively, you can choose to throw the die again, walk to the lighting application indicated by the die and note the number of the lighting application in the protocol. If the lighting application indicated by the die is the same as your current location, stay at that location and repeat step 3.

5.4.3 Results

The lighting applications had a statistically significant effect on ratings of PCQ ($p < 0.001$). Overall, the rank order of PCQ ratings, from highest to lowest, for the four lighting applications was #3, #2, #4, and #1, indicating that lighting application #3 was perceived to provide the best visual comfort and lighting application #1 the worst. Statistical analysis failed to show any statistically significant difference between ratings of PSQ ($p = .35$), implying that the lighting applications were perceived as being similarly bright. The lighting applications also had a statistically significant effect on the number of times participants walked to each lighting application ($p < .001$). The overall rank order of the number of times participants walked to each lighting application, from most to least, is #3, #4, #2, and #1, indicating that the participants preferred lighting application #3 the most, and lighting application #1, the least.

6. Discussion

6.1 General discussion

The global urbanisation trend accentuates the need to develop sustainable cities, with the development of sustainable transport systems as one important piece to the puzzle. Walking plays an essential role in sustainable transport systems, as nearly all journeys in the urban environment incorporate walking in one way or another. Future urban environments should therefore to be designed with the pedestrian in mind, to facilitate walking. To make cities accessible to pedestrians also after dark, there is also a need to consider outdoor lighting applications and lighting design.

The findings presented in this thesis may contribute towards the development of sustainable cities in two ways. Both directly, by helping municipalities with the process of replacing old lighting applications with new pedestrian-friendly energy-efficient alternatives, and indirectly, by the increase in physically active transport that may result from urban lit environments being better aligned with pedestrian needs.

This thesis shows that outdoor lighting is considered an important urban design quality that pedestrians consider when judging the walkability of their neighbourhoods. Outdoor lighting that caters to user needs and contributes to accessibility and perceived safety promotes walking, whereas unkempt greenery and insufficient lighting influence the perception of safety negatively, due to feelings of entrapment and a decrease in prospect, and make people avoid walking after dark.

The results presented highlight the elderly's greater need for outdoor lighting. When choosing lighting applications, it is therefore necessary to take the context, the users, and the purpose of the lighting into account, and weigh the advantages and disadvantages of lighting applications, to find optimal solutions. The set of methods evaluated in the thesis can differentiate between lighting applications with regard to the human response and provide a complementary perspective to that of photometrical measurements. The Random Environmental Walk method can be used for triangulating the results from self-report scales, and for assessing the preferences of people who would have difficulties with responding to questionnaires.

This thesis bridges the gap between the research fields of walkability and outdoor lighting, by using theories from environmental psychology. The Human-Environment-Interaction model (Küller, 1991) and the pedestrian needs hierarchy (Alfonzo, 2005) serve as a theoretical framework. The HEI model highlights the different environmental variables that influence the pedestrian in every given moment, while the pedestrian needs hierarchy (feasibility, accessibility, safety, comfort, pleasurability) can be directly translated into functions that outdoor lighting has to provide in order to encourage walking after sunset.

Other, more specific, theories may be added to further elucidate specific aspects of the pedestrian response to the lit environment. For instance, as discussed in Paper I (Appendix I), the prospect-refuge theory (Appleton, 1975) may be applied in relation to perceived safety of the urban environment (Blöbaum & Hunecke, 2005; Boomsma & Steg, 2014; Loewen, Steel, & Suedfeld, 1993; Nasar & Fisher, 1993) and the social-psychological model of fear of crime (van der Wurff, van Staalduinen, & Stringer, 1989) may be applied to further illuminate the influence of the physical environment, as well as the social environment, on the pedestrians' perceived safety after dark.

6.2 Outdoor lighting as a perceived urban design quality

The findings from Study 1, the exploratory focus group study, show that outdoor lighting surfaces as an important urban design quality that pedestrians consider when contemplating the walkability of their neighbourhoods. A journey can be seen as a trip through a chain of different settings, where the overall accessibility is as strong as its weakest link. In the focus group discussions, insufficient outdoor lighting is portrayed as producing such 'weak links' that are perceived unsafe and therefore avoided, resulting in considerable detours. This is in line with two criteria considered important for a walkable neighbourhood: connectivity of the path network (defined as path continuity and absence of barriers) and safety (from both traffic and crime) (Southworth, 2005).

The thematic analysis revealed that unkempt greenery and insufficient lighting affected the level of prospect and the feelings of entrapment, which in turn influenced the perception of safety (similar to results found by Blöbaum & Hunecke, 2005). An example of the avoidance of insufficiently lit environments expressed in the interviews was that municipal parks switched from functioning as assets during the day to becoming barriers to walking after sunset. This is in line with the social-psychological model of fear of crime (van der Wurff et al., 1989), which suggests that, at certain times, physical and social environmental factors interact and make the place seem unsafe and better avoided, while at other times the factors are not aligned in a way that will trigger avoidance.

The benefits of outdoor lighting align well with the pedestrian needs hierarchy (Alfonzo, 2005), which may explain the importance given to outdoor lighting in the focus group discussions. Outdoor lighting contributes to accessibility and perceived safety, increases the comfort level and may, in some cases, provide a pleasurable visual experience by artistic lighting design, all of which promote walking (Alfonzo, 2005).

The relevance of the findings from the focus group discussions concerning outdoor lighting in relation to walkability is strengthened by the fact that the participants were not asked about outdoor lighting explicitly (see Fotios, Unwin, & Farrall, 2015) and that the discussions were conducted during daytime, well before sunset.

6.3 Methods for differentiating between lighting applications

The selected set of methods differentiated between the lighting applications with regard to the human response, and thereby provides a complementary perspective to that of technical measurements of photometric properties. In the laboratory study, most methods capturing perception and evaluation (obstacle detection, facial recognition distance, sign reading distance, arousal, PSQ, PCQ and seeing condition) identified one lighting application as superior to the other two. In the field study, the visual tasks differentiated significantly between the two lighting applications, and an interaction effect was found for perceived visual accessibility. However, no significant differences were found for the other evaluation measures.

In the laboratory, the lighting applications differed in terms of the underlying technology and consequently also on several photometric properties. The lighting application providing the best conditions for the visual tasks also used the most power and was perceived as less pleasant than the other two. In the field study, the lighting applications also differed with regard to the photometric properties. However, in the field, the lighting application providing the best conditions for the visual tasks was in this case perceived as equally pleasant, and had greater luminous efficacy than the other lighting application. In contrast, the results from Study 2 highlight the fact that there may be no lighting application that is preferable in every given situation.

Decision makers therefore need to take the context, as well as the purpose of the lighting, into account and weigh the advantages and disadvantages of lighting applications to find optimal solutions. In addition to energy efficiency and road lighting standards, it is therefore relevant to consider the human response when choosing between outdoor lighting applications for pedestrians. The methods evaluated in Studies 2 and 3 could be applied during such a process as a way to differentiate between different lighting applications based on the human response to the lighting.

Further, the results from the REW indicate that a repeated forced-choice method can be used for assessing pedestrians' relative preferences for outdoor lighting applications. The REW method can be used to triangulate the results from self-report scales, and for assessing the preferences of people whose language skills are insufficient to respond to questionnaires.

6.4 The assessment of behaviour

The methods for assessing the impact of outdoor lighting on walking did not detect any significant differences, neither in the laboratory (measuring walking speed), nor in the field (observing pedestrian flow).

In the laboratory, it is plausible that the illuminance levels for all lighting applications were sufficient to deliver the visual cues needed for walking at normal pace. The walking speed may also have been influenced by the study being conducted indoors, where participants walked towards the opposite wall and did not have to scan the ground for obstacles. However, another study, using a similar setting but with only one lighting application at different levels of dimming, did find significant differences, with walking speed declining with lower illuminances (Pedersen & Johansson, 2018). A reason for the different findings could be that the differences between the lighting conditions in the dimming study exceeded those in Study 2, since the greatest difference between lighting applications in Study 2 was equivalent to the scenario with the least difference in the dimming study.

In the field, it is plausible that something other than perceived lighting quality determined where people walked. There may be many reasons why people choose a specific path, and possibly habit or preference for the most direct route to the destination outweighed the impact of the differences in uniformity and illuminance between the two lighting applications. The lighting applications might also have been too similar to generate significant differences in pedestrian flow.

A plausible alternative to direct observation could be to use video technology currently used for surveillance purposes, or possibly infrared cameras, which intrude less on privacy since faces cannot be recognised (Johansson, Laureshyn, Nilsson, & Patching, 2017). The use of video technology could provide observational data for longer periods than is feasible with direct observation. Additionally, video technology could cast light on where pedestrians place themselves on the path and which strategies are employed with regard to other pedestrians and cyclists. This could in turn help answer questions relating to lighting design and traffic safety.

6.5 Differences between age groups

In Studies 2 and 3, participants were recruited from two age groups (young: 20-35 yrs. and elderly: 60-75 yrs.) to assess potential age differences in the response to outdoor lighting, and to test whether the lighting installations provided sufficient conditions to enable both age groups to perform tasks important to pedestrians, such as navigation, detecting obstacles and seeing other pedestrians' facial expressions.

In the laboratory there was a difference between the two age groups on the visual tasks, where the younger group performed significantly better. This result was in line with expectations due to the decline in night vision associated with increasing age (Jackson et al., 1999; Jackson & Owsley, 2000). There were also differences in perceived lighting quality, where the younger group rated the lighting applications lower on perceived comfort quality. The lower ratings of the younger group may represent a greater sensitivity, or stricter standards in the assessment of outdoor lighting. The older group may have been more indulgent towards the lighting applications due to their experience of older technologies, such as low-pressure sodium lighting.

In the field, the age differences were less obvious. The young group could read street signs at significantly greater distances, but there were no significant differences in the distance required for recognising facial expressions, despite the different luminance levels of the photographs for the two lighting applications (I: .26 cd/m^2; II: .19 cd/m^2). However, the highest luminance level in the field was equal to the lowest luminance level in the laboratory (.28 - .55 cd/m^2). A comparison between the distances in the field (young: 5.96 and 3.46 m; elderly: 3.74 and 3.24) and in the laboratory (young: 4.28-5.08 m; elderly: 3.53-4.07 m) suggests that the low luminance level in the field might have made the task too difficult for lighting application II, thereby masking possible differences between the group of elderly and the young. Due to the between-subjects design, potential differences between the groups experiencing the two lighting applications might have confounded the results. The significant interaction effect for perceived visual accessibility shows that the young group experiencing lighting application I rated the perceived visual accessibility higher than the group experiencing lighting application II. The opposite was true for the two groups of elderly. Unfortunately, the participants did not perform a baseline measurement under equal conditions, which might otherwise have clarified the issue.

Both in the laboratory and in the field the participants rated the lighting applications as providing sufficiently good lighting conditions. Also, the results on the visual task, sign reading distance, can be considered adequate. However, for the visual tasks obstacle detection and facial expression recognition, the results indicate that the lighting conditions were not sufficient. For obstacle detection, the detection rate ranged from 24% to 51% for the younger group and from 16% to 35% for the elderly. This may be a sign of insufficient lighting conditions, or of the task being too difficult. Still, it is an indication that it would have been difficult to detect trip hazards on the path, lit by any of the three lighting applications used in the lab. The results on facial expression recognition distance also suggest that the lighting conditions were insufficient. The mean distance for the younger group ranged from 4.28 to 5.08 m in the lab and from 3.46 to 5.96 m in the field. For the elderly the corresponding distances were 3.53 to 4.07 m in the lab and 3.24 to 3.74 m in the field. Caminada and van Bommel (1980) recommended four metres as the minimum distance for facial recognition, but more recent research (based on eye-tracking methodology) suggests that 15 m is the average distance for pedestrians to fixate on other pedestrians (Fotios & Johansson, 2019; Fotios, Uttley, & Fox, 2018). Both suggestions indicate that the lighting conditions did not meet the expectations. In retrospect, a baseline measurement under daylight conditions would have given an estimation of the distance required for the facial expression recognition task under optimal conditions, and thereby an indication of the adequacy of the assessed lighting conditions.

6.6 Limitations

All studies included in the thesis were conducted in collaboration with Malmö municipality to various degrees. For Studies 2-4, the lighting designers at Malmö municipality selected which lighting applications to use based on relevance for current and future practice, which contributed to the ecological validity of the research. However, the aspiration to maximise ecological validity brought difficulties in systematically controlling variables related to the lighting, such as CCT and illuminance levels. Naturally, the fact that the variables were not kept constant made it difficult to discriminate which factors were most significant for the differences in perception and evaluation of the lit environment. However, this was never the intention of the studies, as the focus was on evaluating lighting applications considered for future use and to test a set of methods with practical relevance for municipalities in their evaluation of outdoor lighting solutions.

In Study 3, due to the harsh weather conditions under which the data was collected and the difficulties with shifting the luminaires in the field, a between-subjects design was used. This may have resulted in lower power, and a greater risk of committing a type II error (i.e. not detecting existing differences), which could have been countered by the recruitment of a larger sample for Study 3. Another limitation to Study 3 was the number of observations conducted in order to estimate pedestrian flow. In hindsight, a longer observation period might better have captured potential differences in pedestrian flow.

6.7 Implications for practice

This thesis identifies and evaluates methods that can differentiate between lighting applications and that may therefore be used to guide the decisions of municipalities before they undertake major upgrades or new installations of outdoor lighting on urban pedestrian paths. Another target group is lighting designers, who may use these methods as a way to obtain complementing perspectives to those given by lighting simulation software. Pilot studies assessing how pedestrians experience the lighting in a real setting can help avoid installing lighting applications with unwanted characteristics, thereby finding a better solution early in the planning process.

The visual tasks (facial expression recognition distance and sign reading distance), along with the evaluation measures (the POLQ scale and the composite emotional state measure), are relatively easy to administer and have potential for use by municipalities in a real-world context. However, further validation and identification of minimum performance thresholds would be desirable before considering them to be standardised measures. The studies comprising the thesis employed large groups of participants (106, 89, 81 and 80 for Studies 1-4, respectively) but, for pilot tests conducted by municipalities, smaller groups of participants may be sufficient to learn about the participants' preferences. Further, the use of several methods in parallel, such as POLQ, REW and focus group discussions, would result in more solid conclusions due to the triangulation of methods.

6.8 Implications for research

Although this thesis has covered many aspects of outdoor lighting relevant for pedestrians, there are still many questions unanswered relating to the transaction between the pedestrian and the lit environment. Further research is therefore needed in order to advance the understanding of how LED outdoor lighting impacts walking in an urban context with special consideration to the elderly and the visually impaired, to identify lighting solutions that cater to user needs while minimising energy use. Another area of interest would be to isolate the effect of illuminance by evaluating the methods using only one type of lighting application, but at different levels of dimming. For the visual tasks, using daylight conditions as a baseline reference could be useful for determining how close the lighting applications come to optimal conditions.

This thesis puts forward a theoretical framework that bridges walkability and lighting, which could assist future research regarding outdoor lighting for pedestrians. By connecting the pedestrian needs hierarchy to the functions provided by outdoor lighting, the impact of outdoor lighting on the mobility of pedestrians in an urban environment after dark is emphasised. In the future, it would be desirable if the outdoor lighting research field would place greater focus on the pedestrian perspective, and if the walkability research field would apply a more nuanced approach to outdoor lighting, acknowledging the need for assessing the walkability of environments both during the day and after dark.

7. Sammanfattning

Idag bor majoriteten av jordens befolkning i städer, och den globala urbaniseringen förväntas fortsätta framöver. Omställning till hållbara städer, med trygga och hälsosamma livsmiljöer, är därför av största vikt. Hållbara transportsystem är en central del av denna omställning och goda förutsättningar för fotgängare är en viktig komponent i hållbara transportsystem. I Skandinavien medför den stora variationen i antal timmar dagsljus över året att fotgängare under långa perioder måste förlita sig på utomhusbelysning för att få tillräckliga synförhållanden.

Utomhusbelysning kräver en omfattande energianvändning, vilket medför miljömässiga och monetära kostnader. Nuvarande belysningslösningar behöver därför uppdateras till mer energieffektiva alternativ, som samtidigt möter fotgängarnas behov. Det finns i dagsläget inga standardiserade metoder för att utvärdera hur fotgängare upplever utomhusbelysningens kvalitet eller hur väl de ser i den belysta miljön, vilket gör det svårt att jämföra olika belysningslösningar i dessa avseenden.

Avhandlingen syftar till att belysa hur fotgängare upplever och responderar på energieffektiv utomhusbelysning i stadsmiljöer. Avhandlingen består av fyra delstudier som 1) utforskar vilka urbana designkvaliteter fotgängare upplever underlätta respektive hindra gående, 2) utvärderar metoder för att mäta fotgängares perception, värdering och beteende i en kontrollerad laboratoriemiljö, 3) applicerar de metoder med potential att differentiera mellan olika belysningslösningar i en verklig miljö, samt, 4) utvärderar en ny beteendebaserad metod för att undersöka fotgängares relativa preferenser för olika utomhusbelysningar.

Avhandlingen visar på belysningens betydelse för att människor ska vistas utomhus i stadsmiljön efter mörkrets inbrott. I avhandlingen lyfts otillräcklig utomhusbelysning fram som en orsak till otrygghet, vilket i sin tur medför att människor undviker att gå i vissa miljöer eller väljer bort att gå till fördel för andra transportmedel. Vidare identifieras perceptions- och värderingsmetoder som kan användas för att särskilja mellan olika belysningslösningar. Resultaten från laboratoriestudien och fältstudien visade också att gruppen med unga deltagare (20-35 år) var mindre emotionellt aktiverade samt presterade bättre på perceptionsuppgifterna än gruppen med äldre deltagare (60-75 år). Resultaten från perceptionsuppgifterna visar på äldres behov av högre belysningsstyrka, alternativt utomhusbelysning av bättre kvalitet, för att skapa tillräckligt goda synförhållanden. Resultaten från metodutvecklingsstudien indikerar att metoden kan användas för att utvärdera fotgängares preferens för olika belysningslösningar, och att resultaten är samstämmiga med resultat från självskattningsformulär.

Avhandlingen presenterar ett teoretiskt ramverk som kopplar samman forskning om belysning och mobilitet, vilket kan bidra till ett bättre helhetsperspektiv i framtida forskning om utomhusbelysning för fotgängare. Avhandlingen identifierar och utvärderar metoder som kan särskilja mellan belysningslösningar. Dessa metoder kan användas av kommuner som underlag vid nyinstallationer eller vid uppgradering av belysningslösningar. Metoderna kan också ge ljusdesigners nya perspektiv som kompletterar dagens datorsimuleringar.

8. References

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