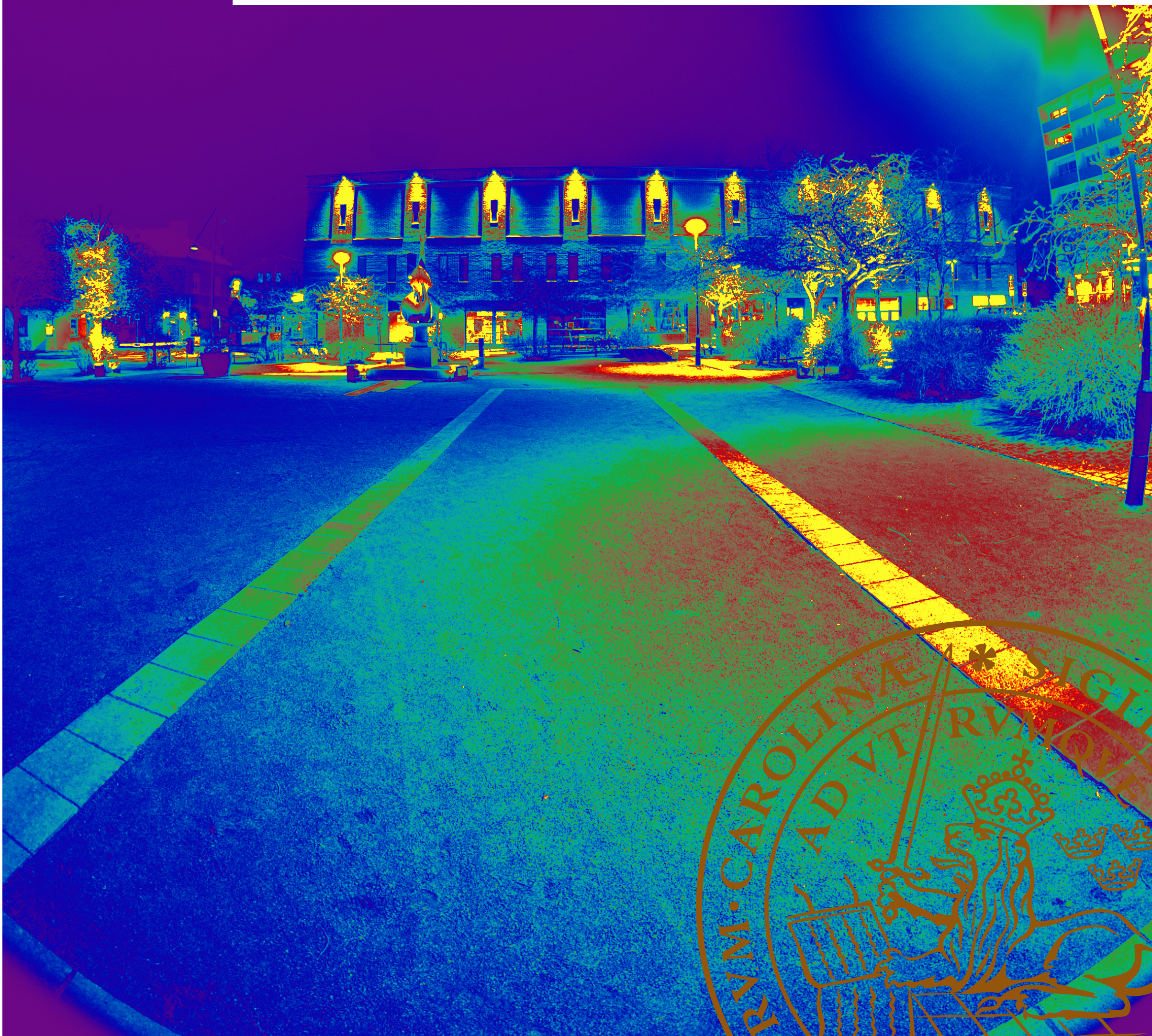
Sustaining Social Interaction in Public Squares After Dark

A socio-physical perspective on the lighting-behaviour relationship

VIVI KATARINA RUBERG HENNIG
DEPARTMENT OF ARCHITECTURE AND BUILT ENVIRONMENT | LUND UNIVERSITY



Public squares are essential everyday life spaces that support social interaction and contribute to people's wellbeing and quality of life.

This doctoral thesis explores the role of lighting in sustaining social interaction in public squares after dark. It proposes a socio-physical conceptual model to interpret the transactional relationship between the individual, the environmental setting, the environmental appraisal, and the behavioural outcome in terms of social interaction.

The thesis concludes that well-designed lighting can sustain social interaction in public squares after dark, and contribute positively to sustainable urban environments. It emphasizes that lighting design criteria must include the practice of attuning atmosphere after dark.

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DOCTORAL DISSERTATION

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Abstract

As everyday life-spaces, public squares are essential for supporting social interaction and thereby contributing to individuals' wellbeing and quality of life. The provision of safe, accessible, and inclusive public squares is imperative for sustainable urban development of cities and communities. After dark, electric lighting is necessary for sustaining activities, including social interactions, in public squares. Lighting may support user needs such as accessibility, reassurance, comfort, restorativeness, and atmosphere, all of which are essential for facilitating movement, enabling stationary activities, and encouraging social interaction in public squares after dark. In countries at northern latitudes, where daylight hours are limited in winter, lighting design is instrumental in sustaining social life in public squares after dark. However, the impact of lighting on people's experiences of public squares after dark, and how specific lighting characteristics may influence behavioural outcomes in such spaces, is poorly understood.

This thesis aims to investigate the relationship between spatial light characteristics, perceived atmosphere, and social interaction in public squares after dark.The thesis expands the knowledge on the role of lighting in sustaining social interaction in public squares after dark. By adopting a socio-physical perspective on the lighting-behaviour relationship, it proposes a conceptual model to further our understanding of human-environment transactions in public squares after dark.

The socio-physical conceptual model illustrates the transactional relationship between the individual, the environmental setting, the environmental appraisal, and the behavioural outcome. It stipulates that the individual's appraisal, and therefore her behaviour, are influenced by the lighting conditions. The model was applied in four empirical field studies that were conducted in two differently illuminated public squares (Kirseberg Square and Lindeborg Square) in Malmö, Sweden.

Study 1 (S1) and Study 2 (S2) focused on the behavioural outcome using direct, structured observations to compare user behaviour in daylight (DL) and in electric lighting (EL) after dark, in the two squares with dissimilar lighting conditions. S1 investigated movements and stationary activities and tested whether any change in these behaviours could be attributed to the effect of change in ambient light level. S2 investigated social interaction by comparing the occurrences of people visiting the squares alone, in pairs, or in groups of three or larger, in DL and in EL. The objective was to establish whether social interaction was sustained at the same time of day in EL after dark. Study 3 (S3), a survey, focused on the assessment of users' environmental appraisals (interpretation and evaluation) of the two squares, by comparing the appraisals in DL and in EL after dark. Furthermore, it investigated the possible correlation between appraisals of perceived atmosphere and self-reported social interaction after dark. Finally, Study 4 (S4), a lighting intervention, focused on the environmental setting in Kirseberg Square, investigating the influence of spatial light characteristics on users' environmental appraisals of this square after dark.

The findings of the observational studies (S1 and S2) suggest that electric lighting can sustain spatiotemporal patterns of user behaviour, including movements, stationary activities, and social interaction in public squares after dark. It was found that the change in behaviour in terms of stationary activities and social interaction could be attributed to the effect of change in ambient light level between DL and EL. The results suggest that the facilitation of stationary activities and social interaction requires that special attention is dedicated to perceptual attributes of light, specifically the level of uniformity and contrasts in the visual field. The results of the survey (S3) show that users' environmental appraisals of perceived lighting qualities, visual accessibility, reassurance and atmosphere were consistently assessed as higher in DL than in EL in both squares. Furthermore, the findings suggest that users' self-reported social interaction is associated with the perceived atmosphere in EL after dark. The results of the lighting intervention (S4) in Kirseberg Square suggest that spatial light characteristics are an important consideration for the appreciation of space and for the enhancement of atmosphere in public squares after dark. It is proposed that a balance of luminance in the visual field is beneficial to the appreciation of space and atmosphere enhancement.

The thesis concludes that social interaction in public squares after dark can be sustained with lighting, and emphasizes that lighting design criteria for public squares should extend beyond providing visual accessibility and reassurance to include the practice of attuning atmospheres. While appropriately designed lighting in public squares can sustain social interaction, lighting also entails negative consequences associated to energy use, light pollution and a negative impact on ecological systems. Future research on public spaces should thus address the spatial distribution of light, also with regards to how energy consumption may be lowered, costs reduced and obtrusive light avoided. In addition, research to advance knowledge on the influence of spatial as well as spectral characteristics is advocated.

Keywords Social Sustainability, Public Space, Social Interaction, Lighting

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MADE IN SWEDEN

To my beacon, my beloved grandma Vivi Ahlström; to my parents and guardian angels Ingrid and Christer Hennig; to my husband Allan Ruberg; to my son and sunshine Harald Hugo Ruberg Hennig; to my sisters Andrea Mäger and Michaela Hennig Brådhe, and to my friend Aleksandra Larsson

I owe you all my passion, strength, and dedication.

Table of Contents

Abstract

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The thesis concludes that social interaction in public squares after dark can be sustained with lighting, and it emphasizes that lighting design criteria for public squares should extend beyond providing visual accessibility and reassurance to include the practice of attuning atmospheres.

While appropriately designed lighting in public squares can sustain social interaction, lighting also entails negative consequences associated to energy use, light pollution, and a negative impact on ecological systems. Therefore, future research on public spaces should address the spatial distribution of light, also with regard to how energy consumption may be lowered, costs reduced, and obtrusive light avoided. In addition, research to advance knowledge on the influence of spatial as well as spectral characteristics is advocated.

Abbreviations

CIE	International Commission on Illumination
DL	Daylight
EL	Electric light
EP	Environmental psychology
H	Horizontal lighting mode
HDR	High dynamic range
HPS	High pressure sodium
HV	Horizontal and vertical lighting mode
HVA	Horizontal, vertical and accent lighting mode
IDs	Identification notes
RH	Reference horizontal lighting mode
LED	Light-emitting diode
M1	ID for ground-based luminaire for accent lighting
MH	Metal halide
P1	ID for lamppost with road-luminaire
P2	ID for lamppost with park-lantern
S1	Study 1
S2	Study 2
S3	Study 3
S4	Study 4
SPD	Spectral power distribution
T1	ID for top-mounted luminaire for façade lighting

Acknowledgments

This research was conducted as a cooperation between the research group in Environmental Psychology, Department of Architecture and Built Environment, Lund University, Lund, Sweden; the Division of Energy and Building Design, Department of Building & Environmental Technology, Lund University, Lund, Sweden; and the School of Architecture, The University of Sheffield, Sheffield, UK.

I would like to express my sincere gratitude to my supervisors, Professor Maria Johansson, Professor Steve Fotios, Dr Niko Gentile, Dr Catharina Sternudd, and Dr Pimkamol Mattsson for your guidance at various stages on the journey. To all my colleagues in the environmental psychology group, I would like to say thanks for keeping the spirit up, with special thanks to Dr Johan Rahm for his support with data collection and guidance, to Dr Ann Eklund and to Dr Eja Pedersen for their kind encouragements, and to Professor Thorbjörn Laike, who gave advice on the observational studies, provided support in the design of the intervention study and with data collection. Thanks also to Rifa Maliqi for her support. My gratitude goes to Dr Jan-Eric Englund, Department of Biosystems and Technology, Swedish University of Agricultural Sciences, who taught me statistics.

I would also like to thank Richard Jedon, Eindhoven University of Technology, who assisted in the data collection for the intervention study. Additional thanks to the master students Carl Laursen and Simon Borg, who assisted with data collection, and Fabrice Dufberg and Thea Johansson, who assisted with data coding of the questionnaires.

All studies were conducted in collaboration with Malmö Stad, Sweden. I would like to thank Johan Moritz for enabling the studies in real-life settings. Special thanks to Åsa Gullstrand for facilitating the studies and to Bertil Göransson, at Luxera, who assisted with the technical installation and programming.

My sincere thanks to all participants in the studies, i.e., the residents of the two neighbourhoods, Kirseberg and Lindeborg. I hope the findings of this project will contribute to the understanding of the socio-physical perspective on the lighting-behaviour relationship and provide insights on the association between lighting characteristics and social interaction in public squares after dark.

Finally, thanks to Professor Kevin Mansfield at the Bartlett School of Architecture, UCL, who inspired me to pursue doctoral studies, and who has supported me in every step of my career since the Light and Lighting MSc. I am deeply grateful to you.

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Preface

Observing and analysing light characteristics in nature and in the built environment has been a habit of mine since childhood, and it would seem that the apple did not fall far from the tree: recently, my seven-year-old son Harald Hugo noticed a reflection with a rainbow spectrum on the wall in our hallway. *Mummy, mummy, please come! – What is it? – You have to come! – Why? I asked. – I can't explain why. You have to come and see this; it's so beautiful! Mummy how come it looks like a rainbow?* We analysed the incident of the direct sunlight in the hallway and came to the conclusion that the light was being refracted into this colourful spectrum, and the mesmerizing reflection on the wall was thanks to a facet of the hallway mirror. Our most astonishing lighting experience, however, was a picture from a camera obscura, formed in the window frame of our son's bedroom. My son and I were literally inside the camera obscura, and our garden was projected upside down.

Children are open, intuitive and curious by nature. I believe that research requires the same intuition, curiosity and tenacity. My own curiosity has led to an insatiable passion for investigating the relationship between light and space – two inseparable entities, it seems. And yes, 'Curiosity killed the cat...but satisfaction brought it back'.

At the start of my professional journey, I was a building engineer with a passion for dance. Intrigued by the natural sciences, I studied to become a landscape architect and during my studies I was gradually drawn towards light. Eventually my next career path became clear, and I pursued a MSc in Light and Lighting at the Bartlett School of Architecture at UCL in London. I worked as a professional lighting designer for 20 years before embarking on my PhD journey. Looking back, the decision to pursue a research path was bold, driven by a desire to bridge the gap between science and practice. I would like to see a cross-pollination between these two parallel worlds.

Throughout my doctoral studies, I have observed a shift in the lighting industry. In fact, I would argue that professional lighting designers, urban planners, manufacturers, and other stakeholders in general are genuinely motivated to become informed about lighting research. It is my sincere belief that research should be conducted as a cooperation between academia and industry. The development of research design, methods, and theoretical framework needs to be informed by practice as well in order to ensure the relevance of research and potentially facilitate its implementation in practice.

Light and lighting shapes our life-spaces and the behavioural patterns of our lives. According to Böhme (Böhme 2017), atmosphere may be theorized as 'tuned space', i.e., space infused with a particular mood, produced by various agents, e.g. illumination. In elaborating with the spatial, spectral, intensity and temporal characteristics of light, lighting design professionals alter spatial perception, cognitive and affective connotations that mediate the after-dark experience of the built environment, or using Böhme's notion, 'produce atmospheres'.

Essentially, lighting design professionals strive to create luminous conditions that optimize wellbeing and behavioural outcomes, including social interaction, by supporting the needs and preferences of individuals.

This thesis investigates the role of lighting in sustaining social interaction in public squares and strives to further the understanding of the lighting-behaviour relationship.

I hope that you, the reader, will enjoy the content, and find that it resonates with you.

List of original papers

Paper I

Hennig, V.K.R., Gentile, N., Fotios, S., Sternudd, C., & Johansson, M. (2023). User behaviour in public squares after dark. *Lighting Research and Technology,* 55(7-8):621-642 2023. doi:10.1177/14771535231200390

Paper II

Hennig, V.K.R., Fotios, S., Gentile, N., Sternudd, C., & Johansson, M. (2022). Social interaction in local public squares after dark. *IOP Publishing Ltd. Earth and Environmental Science.* (1099 (2022) 012008). doi:10.1088/17551315/1099/1/012008

Paper III

Hennig, V.K.R., Gentile, N., & Johansson, M. (2024). Social Interaction in Public Squares: The role of users' environmental appraisals during daylight and after dark. *Submitted* (Under peer-review).

Paper IV

Hennig, V.K.R., Gentile, N., Fotios, S., & Johansson, M. (2024). Lighting Design Intervention in Kirseberg Square, Sweden: The influence of spatial light distribution on users' environmental appraisals (In manuscript).

Author’s contribution

Paper I

The author developed the study design and the observational method, including the coding scheme for data collection, with support from Maria Johansson (MJ). The author conducted the data collection. The author coded the observational data, which was validated by MJ and Niko Gentile (NG). The data analysis was conducted by the author with guidance from MJ, Steve Fotios (SF) and NG. The photometric assessment was conducted by NG with the author’s assistance. The author wrote the initial draft and finalized the manuscript. MJ, SF, NG and Catharina Sternudd (CS) reviewed and edited every version of the manuscript.

Paper II

The author designed the coding scheme for data collection with support from MJ. The author conducted the data collection and coded the data. NG and MJ validated the data. The data analysis was conducted by the author with the supervision of MJ and NG. The conceptual model was developed by the author. The initial draft was written by the author, and NG advised on the manuscript structure. The photometric assessment was conducted by NG with the author’s assistance. The drone photography was conducted by NG. The author wrote the initial draft and the final version of the manuscript. MJ, SF, NG and CS reviewed and edited the manuscript.

Paper III

The author planned the survey together with MJ. The questionnaire used was adapted for Study 3 by the author and MJ. In addition, the measurement of self-reported social interaction was developed by the author and MJ. The new measurement of perceived atmosphere was developed by the author. The data collection was conducted by the author with support from MJ. The author conducted the data analysis together with MJ. The author wrote the initial draft and the final version of the manuscript and created the visualizations. MJ and NG reviewed and edited the manuscript.

Paper IV

The study was designed by the author under the supervision of MJ and NG. SF offered advice regarding the design of the study. The data collection was conducted by the author, MJ and CS. The author and MJ carried out the data analysis. NG conducted the HDR-photography and photometric assessment. The author wrote the initial draft and created the visualizations. MJ, SF and NG reviewed and edited draft versions of the manuscript. The author and MJ edited the final version.

1 Introduction

The UN Sustainable Development Goal (SDG) 11 is to make cities and human settlements inclusive, safe, resilient and sustainable, and it targets the provision of universal access to safe inclusive and accessible public spaces by 2030 (UN 2015). A guiding principle envisions people's right to safe and healthy habitats, including the right 'to fully enjoy the city and its quality public spaces', which are participatory, enhance social interaction, promote civic engagement and foster social cohesion (UN 2017). This principle stems from 'Lefebvre's conceptual idea of "right to the city" which invokes the right of citizens to appropriate public spaces and to utilize these spaces for drama and fun' (Dovey 2016). A public space might thus be described as:

> The stage upon which the drama of communal life unfolds. The streets, squares, and parks of a city give form to the ebb and flow of human exchange. These dynamic spaces are an essential counterpart to the more settled places and routines of work and home life, providing the channels for movement, the nodes for communication and the common grounds for play and relaxation (Carr et al. 1992, p.3).

The implementation of SDG 11 arguably requires focus at the community level 'to make tangible differences in the everyday lives of people' (Vaidya and Chatterji 2020).

Urban theorists argue that the social and psychological health of modern communities requires quality public spaces, here defined as 'publicly accessible spaces' that are meaningful, responsive, democratic and protective of rights of different user groups' (Carr et al. 1992; Mehta 2007). Users are defined here as those who frequent public spaces and rely on them for passive and active social engagement (Francis 1989). Meaningful spaces allow individuals to make connections between the space and their personal lives and to relate to a larger socio-physical context. Responsive spaces support the needs of their users by providing comfort and facilitating relaxation, active and passive engagement, and discovery. Democratic spaces are accessible to everyone, thereby affording freedom of speech and action (Carr et al. 1992).

At their best, public spaces are 'sites of civic promise' that foster sociality and community engagement (Amin 2006). Well-designed shared physical space generates active and passive social interaction (Mehta 2014), enhances individuals' sense of belonging, and supports quality of life, social well-being and the health of individuals (Beck 2009; Cattell et al. 2008; Mouratidis 2021; Kent and Thompson 2014).

The provision of quality public spaces is therefore a key objective in socially sustainable urban development, and the relationship between public spaces and the quality of urban life rightly draws the attention of stakeholders, urban designers, and researchers from many disciplines (Altman and Zube 1989; Holland et al. 2017).

1.1 Public Space Contextualized

Let us contextualize 'public space'. As stated by Madanipour, '"[s]pace" can be seen as an abstract substitute for the world around us, for what we generally mean by our built and natural environment' (Madanipour 1996). For an architect or a lighting designer, space is also an artistic media 'a uniformly extended material to be modelled in various ways'. That is to say, space is an entity with spatial properties; i.e., dimensions, a certain shape, a scale, a lighting condition, etc. (Kärrholm 2004). Public spaces in the built environment encompass a variety of settings, including streets, parks, plazas, and squares, and more (Altman and Zube 1989).

The term 'public' – from the Latin 'publicus', meaning 'belonging to the people' (Dovey 2016) – connotes the idea that the space is accessible to everyone – people of a community, a nation, regardless of age, gender, ethnicity, physical variation or other characteristics (Carr et al. 1992). Whatever the differences in personal identity, public spaces are shared, in common.

'Public space' is related to the term 'public place', with 'space' becoming 'place', as it obtains psychological or symbolic meaning (Altman and Zube 1989). Space may thus be referred to as an abstract environment that transforms into a meaningful place when people use, change or give symbolic value to the specific setting (Altman and Zube 1989). Unlike 'space', 'place' implies an emotional link, positive or negative, between a person and a specific physical setting (Altman and Zube 1989). According to Dovey place is 'irreducible to characteristics or constituent parts' (Dovey 2016, p.106). The ways in which place makes sense in people's everyday lives is the primary understanding of the sense of place. Thus:

> place encompasses the ideas of interaction between people and a physical setting and incorporates a set of meanings that emerge from and inform the interaction (Altman and Zube 1989, p.2).

1.2 Public Squares within Neighbourhoods

This thesis focuses on public squares within neighbourhoods. Such squares constitute everyday life spaces of their users, and they may serve as social spaces after dark as well. Neighbourhood social life spans a continuum of social interactions, ranging from encounters between strangers to meetings between friends (Carr et al. 1992).

The sphere of social life in a neighbourhood may be defined as a parochial realm; that is, some may define it as public space, and others might call it home territory (Lofland 2009). Public squares where people regularly meet their friends or watch daily life are crucial public places for enriching people's lives (Low 2023; Mehta 2014).

1.3 Previous Research and Knowledge Gap

Research on squares is inherently multidisciplinary. Previous approaches have tended to focus either on the physical dimension, concerned with physical design qualities of space in relation to 'use', or on social dimensions, where public squares are discussed in the context of social dynamics (Mehta 2014). Literature on the qualities of urban design and their role in facilitating social life in public space (including squares) predominantly concerns daylight conditions (Gehl 2010; Jacobs 1992; Whyte 2001). Empirical research shows that well-frequented public squares that support social interaction possess certain key qualities, including accessibility, comfort, a variety of uses and activities, and sociability (Whyte 1980; Whyte 2001).

Lighting research with a social orientation argues that light, whether daylight or electric, provides a critical infrastructure by enabling people's daily routines of social interaction in public spaces after dark (Bordonaro, Entwistle, and Slater 2019; Casciani 2020a). However, empirical research on how lighting may support social interaction in public squares after dark is lacking.

In countries at northern latitudes in particular, where daylight hours are very limited for part of the year, lighting design is imperative for sustaining mobility (Rahm, Sternudd, and Johansson 2021) and for sustaining social life in public space (Boyce 2019). Previous lighting research has predominantly concerned mobility. Footpaths have been systematically examined with regard to pedestrians' movement (Boyce 2019; Rahm, Niska, and Johansson 2024); essentially, pedestrians' safe movement is a matter of visual performance and involves the visual tasks of orientation, obstacle detection, and facial recognition (Fotios and Cheal 2007a; Fotios and Johansson 2019; Johansson, Küller, and Rosén 2011). Pedestrian mobility after dark (Johansson, Küller, and Rosén 2011; Rahm 2019) and pedestrian reassurance, i.e., the confidence pedestrians might gain from lighting when walking along a footpath after dark (Boyce et al. 2000; Fotios, Unwin, and Farrall 2015; Unwin 2019), are prerequisites for access and thus for the potential use of a square (Whyte 2001). The focus of lighting research has been elsewhere than on how lighting may support stationary activities, for instance standing and sitting, or on how lighting may support social interaction in public squares after dark.

1.3.1 The role of lighting in sustaining social interaction in public squares after dark

Understanding the link between lighting and social behaviour demands further advancements in knowledge on how users experience public squares after dark (Cattell et al. 2008; Johansson, Küller, and Rosén 2011; Mehta 2007; Rahm 2019). There is thus a need for a comprehensive conceptual model to aid the interpretation of the relationship between lighting and behaviour in public squares. Studies conducted in real life settings are needed, with investigations of how different characteristics of light may influence social interaction.

Light provides us with visual cues that aid our cognitive interpretation of the physical environment, and it evokes affective responses and cognitive associations to the environment (de Vries et al. 2018). Luminous conditions have been associated to users' environmental appraisals of perceived outdoor lighting qualities, perceived visual accessibility (Johansson, Küller, and Rosén 2011; Rahm and Johansson 2021), reassurance (safety) (Boomsma and Steg 2014; Haans and de Kort 2012; Fotios, Unwin, and Farrall 2015), restorativeness (Nikunen and Korpela 2009; Nikunen and Korpela 2012), and atmosphere (Stokkermans et al. 2017, 2018).

Assessments of these environmental appraisals in the context of luminous conditions in public squares are rare, and the link to behavioural outcomes in this context has not yet been established.

Spatial distribution has been found to affect perceptual attributes of light. It has been proposed that brightness and perceived uniformity are salient features impacting the impression of public squares after dark (Casciani 2020c; Nasar and Bokharaei 2016, 2017). These conclusions are based on 3D-visualizations, however, and ascertaining ecological validity (Robson and McCartan 2016) requires empirical investigations of lighting interventions (that allow for photometric assessments) conducted in real life settings (Davoudian 2019).

In lighting design practice, the construct of atmosphere is essential for conveying lighting schemes for potential clients. Light significantly influences the visual appearance of a space, and it is linked to appraisals of atmosphere (Stokkermans et al. 2018). Previous attempts to assess atmosphere with validated scales concern indoor environments (Stokkermans et al. 2017, 2018; Vogels 2008). Research addressing this construct in relation to public squares is needed. While previous ethnographic methods describe atmosphere in public space, these methods do not employ photometric measurements for atmosphere assessment (Sumartojo, Edensor, and Pink 2019). Knowledge about the influence of lighting characteristics on environmental appraisals of atmosphere is necessary in order to advance lighting practice, and research methods should include technical assessments of the lighting conditions, as these are necessary for design development. The potential association between perceived atmosphere in public squares and social interaction should also be tested.

1.4 Aim of the Thesis

The overarching aim of this thesis is to provide knowledge on the role of lighting in sustaining social interaction in public squares after dark.

This thesis employs a socio-physical perspective on the relationship between lighting and behaviour, proposing a conceptual model aimed at advancing understanding of human-environment transactions in public squares after dark.

Specifically, the aim is to investigate any association between spatial light characteristics, perceived atmosphere, and self-reported social interaction in public squares after dark.

1.5 Research Question and Specific Objectives

The overarching research question of this thesis is:

Can lighting sustain social interaction in public squares after dark? The thesis focuses on public squares within neighbourhood communities, i.e., public spaces that that constitute ‘everyday life-spaces’ of users.

The empirical research of this thesis aims to fulfil the following objectives:

O1. To investigate *user behaviour* in terms of *movements and stationary activities* in daylight (DL) compared to in electric lighting (EL) after dark in two public squares with different lighting conditions, and to test whether any change in user behaviour may be attributed to the effect of change in ambient light level.

O2. To investigate *user behaviour* in terms of observed *social interaction*, in DL compared to in EL after dark in two public squares with different lighting conditions.

O3. To investigate the extent to which *environmental appraisals* are associated with self-reported social interaction in public squares after dark.

O4. To explore the influence of *spatial light distribution* on users' environmental appraisals in public squares after dark.

1.6 Outline of the Empirical Work

The four objectives (O1 – O4) were addressed in four empirical field studies (S1 – S4). The results of each study were reported in four scientific papers (Appendix I – Appendix IV). Figure 1 outlines the empirical work and illustrates the relationship between objectives, studies and papers.

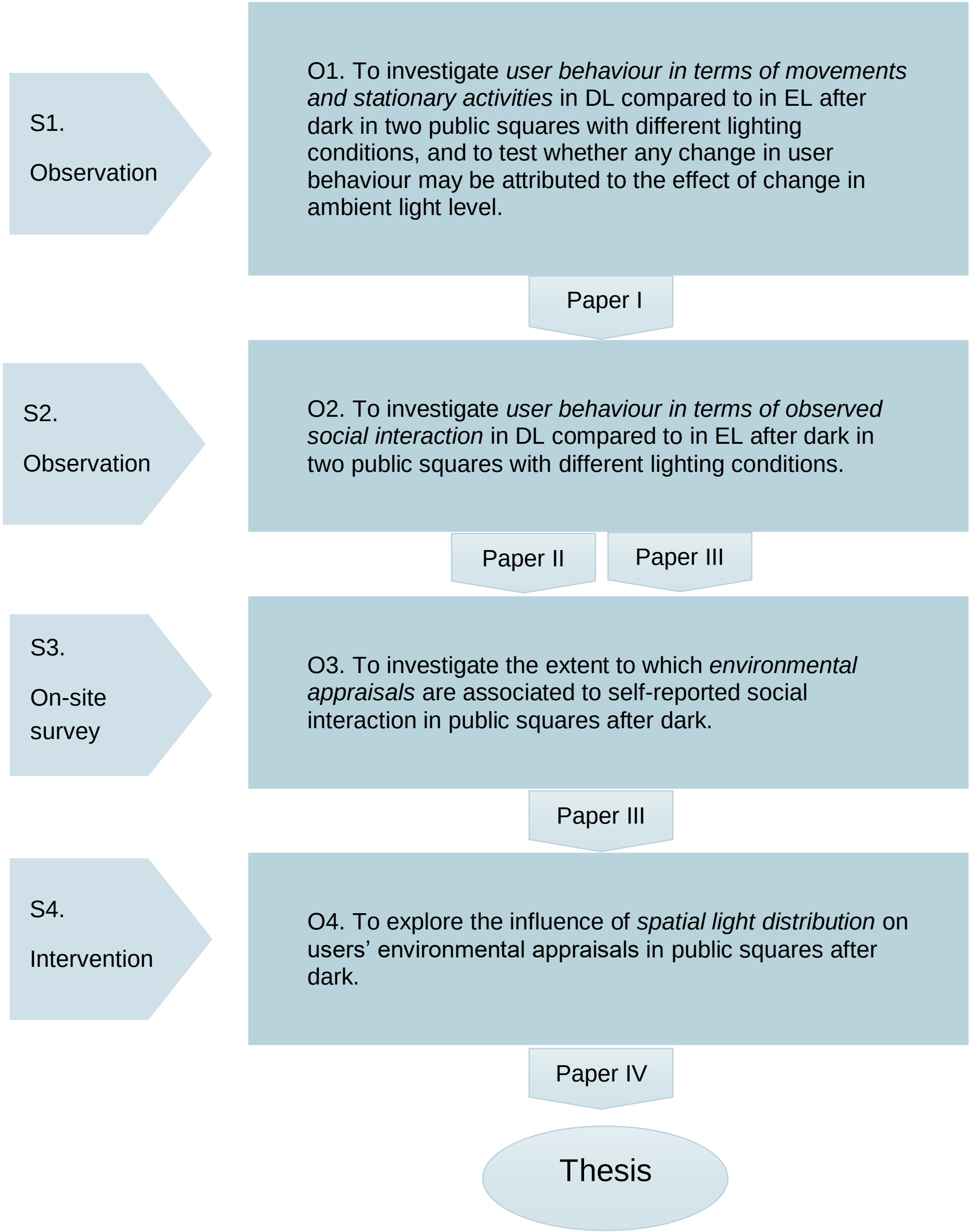

Figure 1. Outline of empirical work

The following two chapters describe the scientific point of departure and the theoretical underpinning of the research question.

2 Scientific Point of Departure

2.1 Environmental Psychology Approach

The scientific point of departure of this thesis lies in the field of environmental psychology (EP), which adopts a real-world-oriented and problem-centred approach for studying and improving people's relationships with their everyday environments (Gifford 2016). The tradition of EP advocates the use of multiple methods for investigating any research question or phenomenon, aiming to provide a holistic view of the complexity of the human-environment transaction.

As a research discipline, EP may be viewed 'as part of a multidisciplinary field of environment and behaviour, with the common focus on people's relationship with their socio-physical surroundings' (Stokols 1995, p.822; Giuliani and Scopelliti 2009). The author of this thesis is guided by this perspective. Public squares are truly multifaceted socio-physical spaces in the built environment, and thus a thesis on the role of lighting in sustaining social interaction in public squares requires a broad and open-minded perspective, especially in the initial phase of the investigation.

EP pertains to the study of the 'interface' between human behaviour and the socio-physical environment. Drawing on the work of Stokols, this thesis adopts a socio-physical stance to understand human-environment transactions in public squares. (Stokols 1978, p.253).

2.2 Lighting Design Practice

As a point of departure, this research draws on the practical and empirical knowhow gained from the author's professional experience as a lighting designer and landscape architect. Theories and methods employed are approached from a practical standpoint. The methodology of S3 and of the intervention study S4 in particular is informed by practice and lighting design research on the human- and social dimensions of urban lightscapes (Casciani 2020a; Wänström Lindh 2012).

3 Theoretical Framework

The theoretical framework of this thesis was established through a literature study spanning several research domains. It essentially integrates EP theories on modes of human-environment transactions and previous lighting research on pedestrian mobility after dark and draws on established frameworks on the performance of public squares from literature on public spaces, public life studies, and urban sociology. Table 1 provides an overview of the theories and topics that have been used to establish a theoretical framework for public squares after dark and to propose a socio-physical conceptual model for interpreting the lighting-behaviour relationship in public squares after dark. Figure 2 illustrates a flowchart of the development of the theoretical framework.

3.1 A Transactional-Contextual Framework

This thesis employs a transactional-contextual framework, which focuses on the dynamic interplay (transactions) between people and their everyday environmental settings (contexts) (Bonnes and Secchiaroli 1995). This perspective maintains that individuals' behaviour is influenced by their characteristics, abilities, preferences and needs, and also by the nature of the physical setting, the social opportunities, and the socio-cultural context. 'In any given environmental setting physical aspects are closely linked to socio-cultural ones, giving spatial and temporal regularity and consistency to the occurrences of behaviours' (Bonnes and Secchiaroli 1995, p.160).

The transactional-contextual perspective affirms a) that the relationship between individuals and their environment is characterized by continuous exchange and reciprocity, and b) the primarily active and intentional role (that is, planned and directed by goals) of the individual towards the environment (Bonnes and Secchiaroli 1995, p.65). Human-environment transactions are hence not merely characterized by the individual's adaptation to an environment, but by 'environmental optimization'.

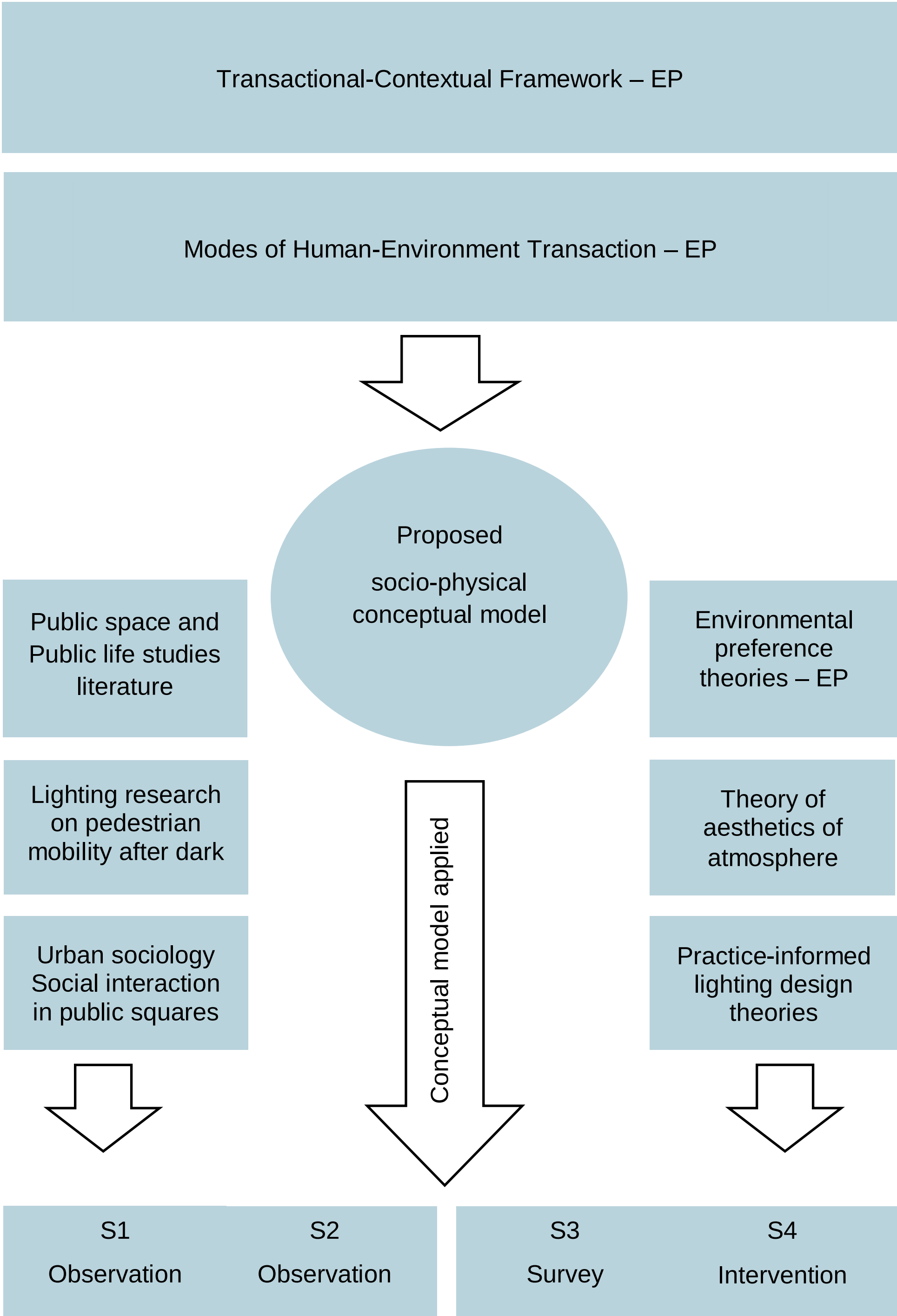

Figure 2. Flowchart of theoretical framework, socio-physical conceptual model, and studies

Table 1. Overview of theories and topics utilized and their respective research domains

	Main domains		Supporting domains			
THEORIES	EP	Lighting research	Philo-sophy	Public life studies	Public space literature	Urban sociology
Transactional-contextual framework	✓					
Modes of human-environment transaction	✓					
Environmental preference theories	✓	✓				
The aesthetics of atmospheres			✓			
Theory of visual spatial boundaries		✓				
TOPICS	EP	Lighting research	Philo-sophy	Public life studies	Public space literature	Urban sociology
The role of public squares				✓	✓	✓
Public space quality					✓	
Performance of public squares				✓	✓	
User needs	✓				✓	
Public life / User behaviour	✓			✓		✓
Pedestrian mobility after dark	✓	✓				
Social interaction in public squares				✓		✓
Perceptual attributes of light	✓	✓				
Environmental appraisals	✓	✓				
Social dimension of lighting		✓				

3.2 Modes of Human-Environment Transaction

According to Stokols (1978), people seek to optimize their relationships with the socio-physical environment through dynamic processes (a cyclic feedback model of human cognition and behaviour); presumably, this occurs within individuals, groups and communities, see Figure 3 (Bonnes and Secchiaroli 1995; Stokols 1978).

Stokols maintains (Stokols 1978, p.259) that the human-environment transaction is characterized in two dimensions: a) cognitive versus behavioural *form* of transaction, and b) an active versus reactive *phase* of transaction. These two dimensions yield four *modes* of human-environment transaction: 1. *Interpretive* (active-cognitive); 2. *Evaluative* (reactive-cognitive); 3. *Operative* (active-behavioural) and 4. *Responsive* (reactive-behavioural). The first mode involves the individual's cognitive representation of the socio-physical environment; the second, the individual's evaluation of the environment in relation to predefined standards of quality; the third, the individual's movement through or direct impact on the environment; and fourth, the environment's effects on the individual's behaviour and well-being.

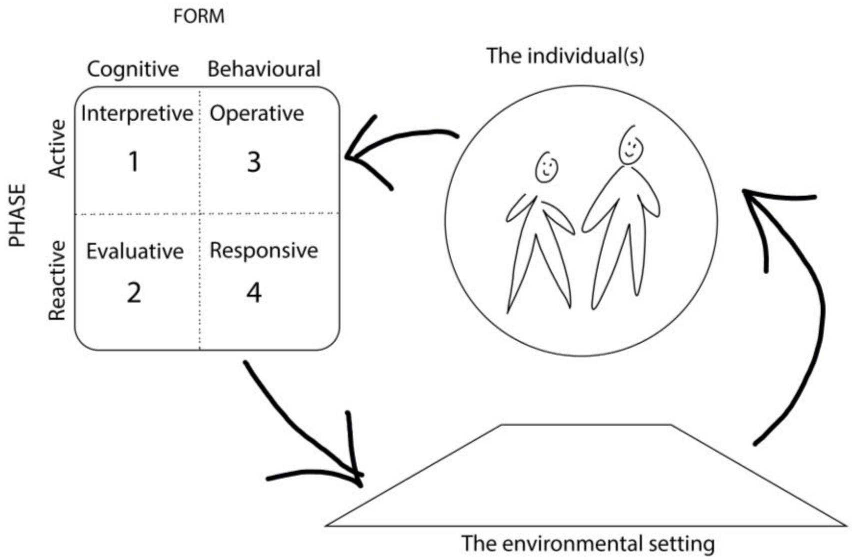

Figure 3. Modes of human-environment transaction. Adapted from (Stokols 1978)
This figure illustrates a goal-directed, cyclic feedback of the human-environment transaction. The two forms and the two phases of human-environment transaction yield four modes: the interpretative, the evaluative, the operative, and the responsive. In this diagram, the form 'cognitive' refers to both informational- and affective processes.

3.3 Environmental Preference Theories in EP

This thesis also draws on theories of environmental preference derived from the field of environmental psychology: prospect-refuge theory (Appleton 1975, 1984; Dosen and Ostwald 2016); theory of environmental preference (Kaplan 1987), and restorative potential of settings (Kaplan 1995). Prospect-refuge theory posits that the preference for a setting is dependent on the possibility to gain an overview of the setting (prospect) from a safe enclosure (refuge) (Appleton 1975, 1984). Previous studies argue that the impact of lighting on individuals' sense of reassurance/safety is mediated by proximate cues of prospect and refuge in an environmental setting (Blobaum and Hunecke 2005; Boomsma and Steg 2014; Fotios, Unwin, and Farrall 2015; Haans and de Kort 2012). It is argued that prospect-refuge characteristics of the setting are fundamental for individuals' preference as well as a feeling of reassurance. Site characteristics that extend the typology of reassurance/safety are: ease of ‘escape’ (for potential victims), and possibilities for ‘concealment’ (offering potential offenders a hiding place) (Fisher and Nasar 1992; van Rijswijk, Rooks, and Haans 2016).

Kaplan’s environmental preference model posits that the preference for a setting is a function of the individual’s need to make sense (coherence and legibility) of the setting and the need to be involved (complexity and mystery) in it (Kaplan 1987). The preference model has been applied in lighting research. Results of a study conducted in a lab environment that investigated the influence of lighting modes of different spatial light distribution and CCT suggested that spatial perception of the lit environment may be assessed with the preference model (using the evaluative descriptors legibility, coherence, complexity and mystery) (Casciani 2020b). One insight from the study regards the spatial distribution of light. The level of uniformity was correlated to coherence and complexity, and balance in luminance contrast ratio between light and darkness was identified as important for legibility (Casciani 2020b). Legibility and coherence are considered crucial design objectives in design practice (Casciani 2020a; Dovey 2016).

3.4 The Aesthetics of Atmospheres

The concept of ‘atmosphere’ is central to the investigation on how light and lighting may influence users’ appreciation of space, and it is therefore assumed that it is associated to users’ social interaction.

Atmosphere may be understood using Böhme’s theory ‘The Aesthetics of Atmospheres’ (Böhme 2017). ‘All what mediates objective factors of the environment with aesthetic feelings of the human being is what we call atmosphere [sic]’ (Böhme 2017, p.1). Atmosphere is *in between*, ‘or in the air’. Accordingly, atmosphere refers to the individual’s subjective, overall impression of a space, as well as the objective characteristics of that space. Atmospheres are thus both emotional and spatial (Böhme 2017).

Atmospheres may be ‘tuned’ to a certain mood, and atmospheres ‘modify moods’. An atmosphere is produced by various agents, e.g. illumination. Böhme even suggests that ‘illuminations are perceived as atmospheres that unify the diverse elements within a space into a cohesive whole’ (Böhme 2017). Atmospheres can therefore be approached in two ways: they may be perceived; i.e., perceived by the individual in a specific setting, or produced (either intentionally according to the design objectives of an architect or lighting designer, or unintentionally, unexpectedly). In elaborating with the different characteristics of light – spatial, spectral, intensity and temporal variations – lighting designers may mediate the after-dark experience, or using Böhme's notion, 'produce atmosphere' (Casciani 2020a; Stokkermans et al. 2018).

3.5 Theory of Visual Spatial Boundaries

This thesis also draws on a theory of visual spatial boundaries (Wänström Lindh 2012), which posits that visual spatial boundaries made visible by vertical illumination are beneficial for appreciation of space, enhancement of atmosphere, and for a feeling of safety/reassurance (see Section 4.1.3) in urban environments (Wänström Lindh 2013). It is stipulated that the distribution of light mediates 'a tangible experience of space' (Wänström Lindh 2012), e.g., that vertical illuminance on walls and structural elements is important for the individuals' cognitive interpretation (interpretative mode) and for appraisals (evaluative mode) of a public square after dark. This aligns with EP theories of environmental preference described above, and it is also corroborated by experience from lighting design practice, which advocates vertical illuminance in careful balance with horizontal to support cognitive interpretation of the urban environment (Olaisen and Bredal 2022).

The following chapter integrates the theoretical framework presented in Chapter 3 and draws on the work by Stokols (Stokols 1978) to propose a socio-physical conceptual model for interpreting human-environment transactions in public squares after dark.

4 A Socio-Physical Perspective on the Lighting-Behaviour relationship

4.1 A Socio-Physical Conceptual Model

This chapter presents a socio-physical conceptual model, illustrated in Figure 4, that offers an interpretation of the transactional relationship between individuals (with their characteristics, abilities, preferences and needs), the environmental setting (with social opportunities and physical properties, including lighting conditions), the environmental appraisal (interpretative and evaluative processes), the behavioural (operative) outcome in terms of movements, stationary activities and social interaction, and the responsive mode (social well-being).

The configuration of the model departs from Stokols' modes of the human-environment transaction: the interpretive, the evaluative, the operative and the responsive mode (Stokols 1978); see Section 3.2. The conceptual model stipulates that the individual's environmental appraisal – and therefore her behaviour – is impacted by the lighting condition in terms of spatial, spectral, intensity and temporal characteristics (Veitch 2001; Veitch, Fotios, and Houser 2019).

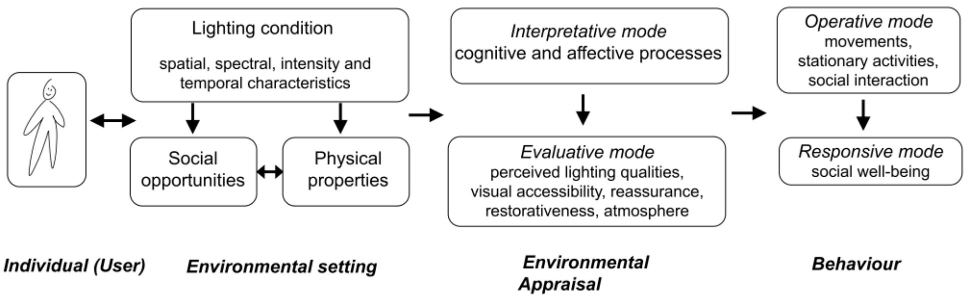

Figure 4. Socio-physical conceptual model of human-environment transactions in public squares after dark
This conceptual model illustrates the transactional relationship between the individual, the environmental setting, the environmental appraisal and the behavioural outcome. The configuration of the model departs from Stokols' modes of human-environment transaction (Stokols 1978).

4.1.1 The individual (user)

Whom is the public space for? In reality, a public square is 'a meeting ground of the interest of many diverse groups' (Francis 1989, p.150). Users may be defined as those who frequent public squares and who rely on them for active and passive engagement (Francis 1989). Local residents are the predominant users of a local public square within a neighbourhood.

Studying users' needs and preferences is crucial to the understanding of how public squares are used and valued, and therefore an important prerequisite for urban design and the management of public squares (Francis 1989). User needs associated to the use of public squares include e.g. access, safety, comfort, 'pleasurability' and inclusiveness (Casciani 2020a; Mehta 2014; Mehan 2017; Whyte 2001). Essentially, the lighting conditions must also accommodate these user needs after dark by ensuring visibility, way-finding, safety and comfort, and by enhancing the atmosphere (Veitch 2001).

4.1.2 The environmental setting

Physical properties

The 'programming' of a an environmental setting – in our case a public square – relates the design (physical properties) to the intended function and use of the square (Dovey 2016). Hence public squares are proposed, built and assessed with assumptions about their use and activities (Carr et al. 1992).

Aligning the physical layout of a public square with its intended activities is imperative for facilitating social interaction (Gaver 1996; Mehta 2007, 2009). The greater the congruence between a particular layout of the physical environment and the activities, the better the setting will accommodate human behaviour and needs (Mehta 2007, 2009). This implies that lighting needs to be integral in the programming to support user needs and to sustain social interaction in squares after dark, and across seasons.

Squares have physical properties, spatial limits and characteristics that can either impede or facilitate user behaviour, including social interaction (Carr et al. 1992; Whyte 1980; Whyte 2001). User activities tend to grow in number, duration and scope in squares with appropriate physical properties (Gehl 2006, 2010). Well-frequented squares are distinguished by their legibility and coherence (Kaplan 1987; Lynch 1960), possessing physical properties that resonate with user needs – both with regard to movements and to stationary activities and social interaction (Carr et al. 1992; Mehta 2014); for instance, they provide adequate seating and incorporate trees and favourable wind and light conditions (Whyte 1980).

Social opportunities

Social space is defined here using Lefebvre's notion. Social spaces are produced and shaped by social relations and cultural practices (Lefebvre 1991). Thus, we may understand the social space of a public square within a neighbourhood by interpreting the types of social relations and the opportunities for social interactions that the square accommodates. Social space, with social opportunities, is perceived by the individual, or, in Lefebvre's terminology, by a 'social subject':

> The notion of space is at first empty, but later filled by a social life and modified by it. […] Social space is conceived as being transformed into 'lived experience' by a social 'subject' (Lefebvre 1991, p.190).

A public square set within a neighbourhood may thus provide opportunities for 'interrelatedness with other human beings' (Crowhurst Lennard and Lennard 1987). Potential social interactions range from those between strangers to people categorically known to each other, acquaintances, and friends (Lofland 2009; Simões Aelbrecht 2016). The social relations and types of social interactions in a public square within a neighbourhood exist along a continuum; the space is experienced as public by some and as private place, 'a home-turf' by those belonging to an 'intimate face-to-face community' (Lofland 2009; Madanipour 2010).

Important social aspects of a public square include accessibility, inclusivity, and opportunities for social interaction (Madanipour 2010). According to Madanipour:

> The most essential aspect is its accessibility, the more open and unconditional the access, the more public it becomes. This openness should include physical as well as social accessibility – access to the place and to the activities within it; without free and open access, a public space is not quite public.

Lighting conditions

Light provides visual information, and as a result, light is essential to most human activities, including social interaction (Boyce 2019; de Kort and Veitch 2014). Lighting conditions may both support or obstruct individual's perceptions and appraisals (i.e., interpretations and evaluations) of spaces (Baron, Rea, and Daniels 1992; de Kort and Veitch 2014; de Kort 2019; Küller 1991).

The lighting condition described by its specific spatial, spectral, intensity and temporal characteristics supposedly impact the behavioural outcome in a public square. The spatial characteristics concern the relative geometric patterns of optical radiation in an observer's field of view. The spectral characteristics concern the relative wavelength distribution of optical radiation, and is described by a light source's SPD. The intensity characteristics concerns the quantity of optical radiation weighted by the appropriate spectral weighing function. Lastly, the temporal characteristics concern both the timing and duration of exposure to optical radiation as well as the temporal pattern of the output (Veitch, Fotios, and Houser 2019). This thesis primarily focuses on the lighting conditions spatial light characteristics.

With the setting of the sun, the portrayal of physical properties and social opportunities of a public square changes. The individual's behaviour is conditioned by the electric lighting condition (Veitch 2001). Light influences visibility, visual performance and visual comfort, the visual impression of spaces and the perception of persons and objects in the space (Boyce 2014; de Kort 2019).

The 'performance of a square after dark', i.e., the facilitation of user behaviour, might differ from daylight conditions in terms of sustained mobility, stationary activities, and social interaction. Important user criteria such as access, links to and from the square, accommodation of use and activities, and social opportunities are likely affected by the change in ambient light level.

Users' perception of a square in daylight, which typically implies photopic conditions of vision, allows for both colour vision and fine resolution. Daylight's critical characteristics include variability in illuminance (in the approximate range from 1000 lx to 100000 lx); variability in cloud cover (from entirely overcast skies to cloudless skies; this changes depending on latitude, season and time of day) and solar geometry; and thus also variability in directionality, varying correlated colour temperature (CCT), and spatial distribution (Boyce 2014). Appreciation of a square in daylight conditions is thus highly dynamic, as it changes with light's spatial, spectral, intensity and temporal characteristics.

Illuminances are far lower in electric light, and the visual system typically operates in mesopic conditions with reduced colour vision and resolution (Boyce 2014). Temporal variations in spatial distribution and directionality are largely absent. The features of a square – with trees, sculptures or the features of people within the square – are thus modelled differently in daylight and electric light and in electric lighting designs of different after-dark uniformity. How users perceive, interpret and behave in a square after dark may thus be impacted by electric lighting design choices (Veitch 2001).

It has been proposed that two perceptual attributes of light in particular – brightness and perceived uniformity – are salient features that impact the impression given by public squares after dark (Nasar and Bokharaei 2016, 2017).

CIE defines brightness as an attribute of visual perception according to which an area appears to emit, transmit or reflect, more or less light (CIE 2020). Brightness has been approached in a variety of ways in the literature over time. There exists an apparent consensus that the spatial distribution of light and luminance in the field of view may alter how brightness is perceived (Boyce 2014). Some scholars have suggested that brightness correlates with the logarithm of the vertical illuminance on the eye of the observer (Hawkes, Loe, and Rowlands 1979), whilst others posit that the location of luminance in space is important for measuring brightness, suggesting that the mean luminance within a 40° degree vertical band about the horizontal line of sight (i.e., emphasizing the luminance of the walls relative to the ground in a public square) is adequate for the perception of brightness (Loe, Mansfield, and Rowlands 2000).

The relationship between brightness and luminance also changes depending on context (Rea, Radetsky, and Bullough 2011). An important consideration for an outdoor space, such as a public square after dark, is that the perception of brightness at different light-levels (between approximately 2 and 20 lx) exhibits a shift in spectral sensitivity, i.e., an increased short-wavelength spectral sensitivity, at higher light levels (Bullough et al. 2014). Brightness also depends on the state of adaptation of the visual system (Stokkermans et al. 2017).

The term 'spatial brightness' is related to brightness. A consensual definition by CIE is 'an attribute of a visual perception according to which a luminous environment appears to contain more or less light'. Spatial brightness can be perceived while immersed within a space or when a space is observed remotely but fills a large part of the visual field (CIE 2020). Spatial brightness encompasses the overall sensation based on the response of a large part of the visual field extending beyond the fovea. 'Spatial brightness describes a visual sensation to the magnitude of the ambient lighting within an environment' (Fotios and Atli 2013).

Uniformity of illuminance is defined as quotient of minimum illuminance and average illuminance of a surface (CIE 2020). While illuminance refers to the amount of light falling on a surface, the magnitude of luminance depends on to the intensity of light from a surface in the direction of the viewer and the projected area of the surface emitting or reflecting this light (Tregenza and Loe 2013). The uniformity of luminance is defined as quotient of minimum luminance and average luminance of a surface (CIE 2020). The spatial lighting condition is dependent on the luminance distribution on all visible surfaces in the space (Veitch, Fotios, and Houser 2019). Aspects of the visual field depends not only on light sources and their optics but on light distribution of the luminaires, the three dimensional geometry of the setting, surface reflectance and finishes, the viewing position, movement of visual tasks, size and shape of field of view, size and shapes of visual targets, and eccentricity of visual targets which may be foveal or parafoveal (Veitch, Fotios, and Houser 2019).

The individual's perceived uniformity is affected by spatial light distribution (Veitch 2001). Different degrees of uniformity are desirable in different locations (Boyce 2014). 'The visual system is very tolerant of variations in luminance in the visual field, indeed it is such variation that makes vision possible' (Boyce 2014, p.165). 'Illuminance uniformity measured as minimum/average ratio is not the complete story, in every setting it is necessary to consider where the maximum and minimum illuminances occur and the rate of change of illuminances between them' (Boyce 2014, p.169). The level of perceived uniformity will determine whether a space is experienced as monotonous (uniform) or if it offers variability/interest (non-uniform) (Veitch 2001).

A study of the impression of squares (conducted using visualizations) suggested a greater preference for uniform and bright than for uniform and dim lighting conditions (Nasar and Bokharaei 2017).

4.1.3 Environmental appraisals

Environmental appraisals are cognitive, affective and emotional psychological processes through which an individual interprets and evaluates an environmental setting's characteristics (Gifford 2014). In psychology, the concept of appraisal is rooted in an understanding of the intrinsic interconnectedness of cognitive and affective processes (Del Aguila, Ghavampour, and Vale 2019; Kappas 2006), and that these occur at 'different levels of psychological processing': on a psycho-physiological 'direct, immediate and intuitive level', and on other more conscious and cognitively elaborated levels (Johansson, Gyllin, et al. 2014; Kappas 2006; Leventhal and Scherer 1987).

The environmental appraisals investigated in this thesis are hypothesized to be of importance for facilitating social interaction in public squares; this will be outlined in the following (Rahm, Niska, and Johansson 2024; Johansson, Tsiakiris, and Rahm 2024).

Perceived outdoor lighting quality

Two dimensions may be used to describe perceived lighting quality in outdoor conditions: 1) strength quality, which captures brightness perception, and 2) comfort quality, which captures hedonic tone, i.e., the extent to which light is perceived as soft, natural and warm (Johansson, Pedersen, et al. 2014). These two dimensions have implications for perceived visual accessibility and perceived reassurance (Johansson, Küller, and Rosén 2011).

Perceived visual accessibility

Perceived visual accessibility refers to an individual's subjective experience of seeing, for example, performing visual tasks such as way-finding, detecting obstacles on the ground and recognizing the faces of others (Johansson, Küller, and Rosén 2011). Lighting facilitates way-finding as it reveals 'the immediate world in detail and the distant world in form' (Boyce 2014, p. 427). Facial recognition is an important visual task that allows assessment of the intentions of others (Fotios and Johansson 2019) and enables social interactions such as 'face engagement' (i.e., a mutual glance of recognition). It is hypothesized that perceived visual accessibility is a prerequisite for social interaction.

Perceived reassurance

Perceived reassurance encompasses perceived safety as well as fear of crime. Reassurance is what provides the comfort that makes an individual feel less worried and afraid and that restores confidence (Fotios, Unwin, and Farrall 2015). Here, reassurance is used to describe the confidence an individual might gain from lighting, i.e., feeling safe and at ease when visiting a square. Several studies on lighting's impact on reassurance/safety (Blobaum and Hunecke 2005; Boomsma and Steg 2014; Haans and de Kort 2012) (including the present) share a common denominator, utilizing prospect- and refuge theory (Appleton 1975). This theory posits that the preference for a setting is contingent on being able to gain an overview (prospect) from a vantage point (refuge) (see Section 3.3). It is hypothesized that a greater sense of reassurance after dark increases the support of social interaction.

Perceived restorativeness

The perceived restorativeness of a setting refers to the extent to which the setting is perceived as compatible, fascinating, extent, and providing 'a sense of being away' (thereby offering relief from the demands and routines of the everyday life) (Kaplan 1995). Lighting that enhances restorative elements, e.g. greenery, may increase perceived restorativeness after dark (Nikunen and Korpela 2012). It is argued that lighting that improves the visual experience after dark by enhancing 'scene content' may provide restorativeness (Nikunen et al. 2014).

Perceived atmosphere

Perceived atmosphere refers here to affective qualities attributed to an environment (Stokkermans et al. 2017). Light significantly influences a space's visual appearance and is also linked to how atmosphere is appraised (Stokkermans et al. 2018). Flynn et al. (1973) distinguished three main factors to differentiate impressions of an illuminated room: perceptual clarity, spaciousness, and pleasantness. Pleasantness was identified as an evaluative factor. Two perceptual attributes of light in particular – brightness and perceived uniformity – have been found to influence the atmosphere of a space (de Kort 2019). In turn, these attributes depend on intensity characteristics and on the spatial distribution of light (Stokkermans et al. 2018; Veitch, Stokkermans, and Newsham 2011). Stokkermans et al. (2018) suggested four dimensions for the description of atmosphere (cosiness, liveliness, tenseness and detachment) and also demonstrated a clear relationship between these dimensions and the perceived brightness and uniformity of light. Spectral power distribution of the light is also shown to affect brightness and how a scene is appreciated (Bullough et al. 2014; Fotios and Cheal 2007b).

This thesis considers 'perceived atmosphere' to be an overarching construct and presumes that it is associated with perceived lighting quality, visual accessibility, and reassurance. It is hypothesized that an atmosphere appraised as pleasant is a prerequisite for social interaction.

4.1.4 Behavioural outcome

Behavioural outcome (user behaviour) is viewed in its socio-physical and spatiotemporal context (Bonnes and Secchiaroli 1995); in this case, this is a local public square situated within the social realm of a neighbourhood with its associated behavioural patterns.

The connections between environmental setting and behaviour are explored based on the hypothesis that the anticipated behaviour in a public square is affected by the individual's (user's) environmental appraisal of both the social opportunities and physical properties of the setting (Del Aguila, Ghavampour, and Vale 2019; Francis et al. 2012). Furthermore, that behaviour (both operative mode and responsive mode) is mediated by past experiences and expectations (Küller 1991). Behaviours are mediated by the individual's 'pre-recognition' or 'mental image' of the square (Del Aguila, Ghavampour, and Vale 2019). A goal-directed behaviour (operative mode) is expected to be derived in part from social opportunities and physical properties of the environment that satisfy the goal-directed behaviour (Del Aguila, Ghavampour, and Vale 2019).

This thesis focuses on the users' operative mode, i.e., observable behaviour (Stokols 1978; Sussman 2016) operationalized as observed movements, stationary activities and social interaction (as depicted in Figures 5 and 18), and captured as self-reported social interaction (as depicted in Figure 6). Social interactions generally take place in the co-presence of others. They may be passive, that is, direct participation may be absent, and offer an opportunity 'to see and be seen' whilst generating a sense of belonging (Cattell et al. 2008); or active, expressed as e.g., face engagement and 'chance encounters', encompassing greetings, chats with others or even socializing with friends (Goffman 1966). The responsive mode in a public square after dark refers to outcomes such as mood and social wellbeing when visiting the square. A positive experience would reinforce and lead to more frequent visits, whilst a negative experience would instead lead to avoidance of the square after dark or of being alone there after dark.

Behavioural outcomes may also be understood using the typology of 'necessary', 'optional' and 'social activities', introduced by Gehl (Gehl 2006, 2010). Necessary activities are fairly compulsory – an example is food shopping – and optional activities are voluntary – for instance taking a stroll or sunbathing – and thus more likely to be impacted by physical conditions (Gehl 2006). Whenever conditions are improved for necessary and optional activities in a public space, 'social' activities are also indirectly supported (Gehl 2006). Previous studies concerning daylight conditions suggest that optional and social activities are largely dependent on the physical properties, mediated by appropriate design. This implies that they are also more likely to be affected by the electric lighting condition after dark.

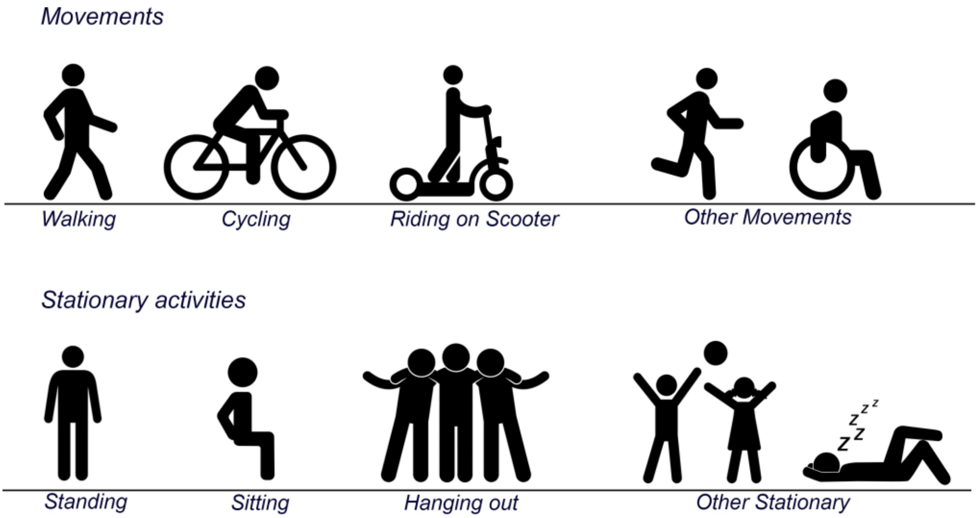

Figure 5. User behaviour in two behavioural categories: Movements and stationary activities
Movements comprise walking, cycling, riding on a scooter and other movements. Stationary activities comprise standing, sitting, hanging out and other stationary activities

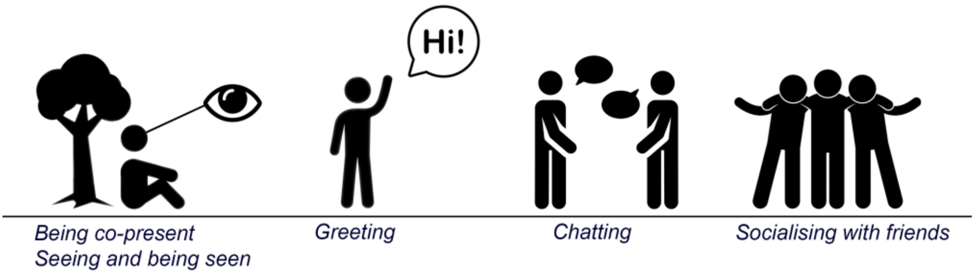

Figure 6. Social interaction in public squares
The continuum of social interaction from passive to active; including being co-present with others, greeting others, chatting or socializing with friends

5 Methodology

This chapter reports on methodology, study design and methods.

5.1 Mixed Methods Approach

A mixed methods approach integrating quantitative and qualitative methods was employed throughout the studies, to explore the transactions between individuals and their environments. Such an approach enables the researcher to gain a deeper understanding of the complexity of human-environment transactions (Gifford 2016; Robson and McCartan 2016). Mixed method research may be defined as 'research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both quantitative and qualitative approaches or methods in a single study or a program of inquiry' (Tashakkori and Creswell 2007, p.4). The theoretical underpinning of mixed-methods approach is pragmatic; it 'recognizes the existence and importance of the physical (or natural) world as well as the social and psychological world' (Robson and McCartan 2016, p.29). With a pragmatic worldview, theories are viewed as instrumental and become 'true' on the basis of predictability and applicability (Robson and McCartan 2016).

5.2 Conceptual Model Applied

The socio-physical conceptual model (see Figure 4) was a basis for the design of four empirical field studies. It was operationalized in the study design and guided the choice of methods. It was used as an analytic tool to investigate the lighting-behaviour relationship in public squares after dark.

The four studies were conducted in real life settings in two neighbourhood squares in Malmö, Sweden.

The different elements of the conceptual model were systematically applied in each of the four studies to investigate the influence of light on human-environment transactions in public squares.

S1 applied the behavioural outcome element (the operative mode) of the conceptual model by comparing user behaviour in the two categories – movements and stationary activities – in daylight and in electric lighting after dark, in the two squares.

S2 applied the behavioural outcome element (the operative mode) of the conceptual model by comparing social interaction in daylight and in electric lighting after dark in the two squares.

S3 applied the environmental appraisal element (the interpretative mode and the evaluative mode) of the conceptual model by comparing environmental appraisals in daylight and in electric lighting after dark. Furthermore, it investigated the association between environmental appraisals and users' self-reported social interaction after dark (the operative mode) in the two squares.

S4 applied the environmental setting element by exploring the influence of spatial characteristics of light on users' environmental appraisals (the interpretative mode and the evaluative mode) after dark in Kirseberg Square.

5.3 Study Design and Methods

An overview of the study design and employed methods in the four studies is provided in Table 2.

The studies S1 and S2 were descriptive observational studies in which direct, structured observations were conducted to investigate user behaviour in the respective squares in daylight and in electric lighting conditions. In this method, the observer adopts – to the furthest extent feasible – a non-participant, pure observer role to avoid reactivity of those under observation (Sussman 2016). The observations were carried out onsite in three functional zones (sampling units): A, B and C, which enabled observations of individuals from a visible and audible distance.

Observations were reported in a coding scheme that used predefined types of behaviour. An advantage of using a coding scheme is that observational biases are circumvented (Gifford 2016). A pilot study was conducted prior to S1 and S2. This was an exploratory phase of the research project, during which unstructured observations were conducted to identify behaviours in the respective squares. The coding schemes for S1 and S2 were developed during this phase using predefined types of behaviour, drawing on and with inspiration from Public Life Studies (Gehl and Svarre 2013; Jacobs 1992). The method for developing the coding schemes was adapted from Sussman (Sussman 2016, p.22).

In S2, qualitative field notes were taken prior to sampling sessions, as were notes on social interaction with IDs, to complement findings based on the quantitative data.

This allowed for a richer interpretation of spatiotemporal patterns of social interaction in the two squares. Technical assessments of the electric lighting condition in both squares were conducted in S1. These assessments included High-Dynamic Range (HDR) photography, photometric measurements, and drone photography to evaluate and compare the respective electric lighting conditions.

The two squares, Kirseberg Square and Lindeborg Square were selected due to the two squares' common features: function (both are local centres with services and amenities); size (the squares have a comparable surface area); physical setting and spatial arrangement (both include design features such as benches, trees and planting). In other words, the squares share similar design 'programming' (Dovey 2016). However, the electrical lighting installations and lighting conditions are dissimilar in terms of spatial light distribution, intensity, uniformity, levels of contrast in the visual field, spectral power distribution (SPD), correlated colour temperature (CCT), CIE general colour rendering index (CRI), and differences in scotopic/photopic (S/P) ratios. The appearances and ambience of the squares after dark are thus different, enabling comparison.

The neighbourhoods have an equal number of inhabitants: approximately 5300 in Kirsebergsstaden in northern Malmö, and approximately 5000 in Lindeborg in southern Malmö. Chapter 6 gives a detailed description of the neighbourhoods, the two public squares, and of the lighting installations, including photometric assessments of after-dark appearance.

The two squares investigated thus offered two parallel and comparable cases for observations of user behaviour and for cross-sectional analyses between Zones A, B and C per square. The lighting conditions DL/EL were compared in order to discern any spatiotemporal pattern in the respective lighting condition in the respective squares and to investigate whether user behaviour was sustained after dark.

The two squares are representative and comparable cases for typical small municipalities in Sweden; generalization of the findings to similar contexts is thus also plausible.

The observations in S1 and S2 were used as a point of departure for the subsequent, S3, a cross-sectional, onsite survey conducted in both squares that investigated environmental appraisals and users' self-reported social interaction in DL and EL after dark. A set of validated scales for the assessment of environmental appraisals was used in S3. The assessment of self-reported social interaction used a scale developed in the pilot study. The scale to assess atmosphere was adopted from interior studies (Stokkermans et al. 2017, 2018), and 'adapted to squares' using factor analyses into two dimensions. The internal reliability of all scales was tested for both DL and EL.

The final study, S4, an intervention study, employed a transdisciplinary approach.

The lighting design intervention was conducted in Kirseberg Square. The square in which to carry out the intervention was selected based on the findings of S1 and S2: these suggested that neither stationary activities nor social interaction were sustained after dark in the zone designed for these activities (Zone A). A presumed improvement to the original lighting condition (see the photometric assessment in Section 6.2.3) in this zone was expected to significantly affect users' environmental appraisals.

The setup of S4 emanates from lighting practice, while the methods of assessing environmental appraisals used the validated scales from EP, mimicking S3, to investigate the influence of spatial light distribution on users' environmental appraisals. In addition to a quantitative assessment using validated scales, a qualitative assessment was conducted using participants' own narratives. The technical assessment of the lighting intervention employed simulations, High-Dynamic Range (HDR) photography and photometric measurements to objectively describe the different lighting modes.

Table 2. Overview of methods in the empirical field studies

Study	Study Design	Instruments and Measurement	Data	Scope
Pilot	Unsystematic, unconstrained observation	Field notes	Qualitative	Sense of place, Sense of neighbourhood
	Direct, structured observation	Coding scheme for user behaviour (trials)	Quantitative	Coding scheme for S1 and S2
	Survey	Self-reported social interaction (pilot)	Quantitative	Scale of self-reported social interaction
S1	Direct, structured observation	Coding scheme for movements and stationary activities	Quantitative	Description of user behaviour in DL/EL
	Technical assessment	HDR photography	Photometry	Description of EL condition in both squares
		Photometric measurements	Photometry	
		Drone photography	Visuals	
S2	Direct, structured observation	Coding scheme for social interaction	Quantitative	Description of user behaviour in DL/EL
	Unconstrained observation	Field notes	Qualitative	Sense of social interaction
S3	Survey (cross-sectional, on-site)	Self-reported social interaction scale	Quantitative	Correlation between environmental appraisals and self-reported social interaction after dark. Adapting atmosphere scale
		POLQ scale	Quantitative	
		Visual accessibility scale	Quantitative	
		Reassurance scale	Quantitative	
		Atmosphere scale	Quantitative	
S4	Intervention study	POLQ scale	Quantitative	Environmental appraisals of lighting modes with different spatial distribution
		Visual accessibility scale	Quantitative	
		Reassurance scale	Quantitative	
		Restorativeness scale	Quantitative	
		Atmosphere scale	Quantitative	
		Participant narratives	Qualitative	
	Technical assessment	Simulations	Photometry	Description of lighting modes with different spatial distribution
		HDR photography	Photometry	
		Photometric measurements	Photometry	

5.4 Validity and Reliability

All four empirical studies were conducted in real life settings, which arguably ensures ecological validity (Robson and McCartan 2016). The realistic conditions and authentic physical settings increase the likelihood that the results will be applicable in other, comparable settings with similar populations and contexts. Findings from the studies in this case may be generalized to similar neighbourhoods, or even to typical small municipalities in Sweden. This, however, requires the sample of participants studied to be representative of a wider population.

In the observational studies S1 and S2, visitors present at the square were studied in their 'natural setting', which ensures behavioural relevance. The sample included all age groups, that is, those age groups present in the squares during sample sessions. Thus, the sample is presumed representative of the neighbourhood population.

In studies S3 and S4, the sample of participants of each neighbourhood were aged 18 years and above. Children and teens were not represented.

Observations in S1 and S2 were direct and structured (Robson and McCartan 2016) and conducted using coding schemes. This is a formal approach for measuring behaviours that arguably reduces subjective bias and increases the reliability of the dataset. Inter-observer reliability was ensured by testing the coding scheme, revising it and verifying it again by three observers (Sussman 2016).

Validity refers to the extent to which a research study accurately measures or assesses the concept or phenomenon it claims to measure. It thus refers to whether the findings truly reflect the construct being investigated or not.

Accuracy – i.e., whether the method accurately captured the behaviours – was ensured by the pilot for the movements and stationary activities. The operationalization of social interaction in S2 was selected as a quantitative, objective way to observe social interaction; the aim was to establish quantitatively whether behavioural patterns were sustained after dark. In S2, social interaction was operationalized as being in pairs or in groups of three or larger. The studied behaviour (visitors to the square being accompanied by others) could also relate to safety, that is, that there might be a preference for not being alone after dark.

The method for capturing verbal- and non-verbal interaction was deemed inaccurate during the sampling, as capturing such interactions quantitatively at the square at rush-hour was not feasible.

'The act of observing may affect the state of the reality being observed' (Goldsmith and Elizabeth 2010). In studies S1 and S2, the observer adopted a passive role, 'watching' without interfering in any other way.

Coding schemes enable the researcher to convert qualitative observations into quantitative data and analyse this data statistically (Robson and McCartan 2016).

This method facilitated identification of spatiotemporal patterns of user behaviour in public squares and arguably allows for generalization of the findings. The coding scheme was tested and retested, validating the method.

During the pilot study in the initial phase of the project, the author spent a considerable amount of time (ca. 40h) in each of the two squares. Unconstrained observations and field notes gave an in-depth sense and an understanding of the squares as ‘social spaces’ and of the population of the neighbourhoods. The studied behaviours drew from the field of public life studies, and the inquiries that guided the research process and choice of methods were based on this initial phase of investigation.

In the studies S3 and S4, external reliability was achieved by utilizing established (validated) scales in the questionnaire. The scale for self-reported social interaction was validated in the preceding pilot study. Tests of the internal reliability, Cronbach’s alpha, of all employed scales were conducted for both DL and EL conditions. The scale for assessing perceived atmosphere in S3 was based on indoor studies but adapted for outdoors using factor analysis.

The intervention study S4, which investigated the influence of spatial light distribution on users’ environmental appraisals, was conducted in a real-life setting, ensuring high ecological validity. Moreover, the sample of participants was representative of the neighbourhood population. However, a larger sample size would have been preferable and enhanced the robustness of the results. With regard to the technical assessment, instrument reliability was ensured through the calibration of each instrument used (see Appendix IV), thus ensuring accuracy in the description of the lighting conditions.

The transparency of procedures and methods in the studies allows for replicability in similar settings and contexts.

Participants

The four studies underlying this thesis used different samples. While the studies S1 and S2 included observed individuals, S3 and S4 included invited participants. The observational studies, S1 and S2, included individuals present in the squares during the data collection sampling sessions. These individuals represented all age groups. In S1, a total of 5296 observations of behaviour in the categories movements and stationary activities were sampled in both squares. In S2, a total of 2522 observations of users’ active social interaction were sampled. These individuals were visually classified according to their apparent age group and their apparent gender. The demographics of the sample of S2, as assessed by the observer, are shown in Table 3.In the survey S3 and in the intervention S4, participants were recruited from the respective neighbourhoods, Kirseberg and Lindeborg. All participants were 18 years and above. Table 4 shows the demographics of the participants in the four groups that participated in S3. The sample comprised a total of 158 participants, 68% of them female and 32 % male, aged between 18 years and 85 years, with a mean age of 54 years. Table 5 shows the demographics of the participants who took part in the different lighting modes in the intervention study S4. The sample comprised four groups with a total of 177 participants, of which 86% resided locally in Kirseberg. 49 participants assessed lighting mode RH, 39 assessed lighting mode H, 42 assessed lighting mode HV, and 47 assessed lighting mode HVA.

Table 3. Demographic data of sample in S2: Mean age and gender representation

The demographics are based on visual classification during data collection.

Kirseberg Square													
Age group									Gender				
0-12 yrs		13-19 yrs		20-64 yrs		> 65 yrs		Total	Female		Male		Not id.
N	%	N	%	N	%	N	%	N	N	%	N	%	%
147	10.7	140	10.2	867	63.0	222	16.1	1376	743	54.0	627	45.6	0.4
Lindeborg Square													
Age group									Gender				
0-12 yrs		13-19 yrs		20-64 yrs		> 65 yrs		Total	Female		Male		Not id.
N	%	N	%	N	%	N	%	N	N	%	N	%	%
94	8.2	294	25.7	558	48.7	200	17.5	1146	606	52.9	538	46.9	0.2

Table 4. Demographic data of participants in S3: Mean age and gender representation

Participants		Age (yr.)	Female		Male	
	N	Mean	N	%	N	%
Total	158	54	107	68	51	32
Kirseberg Square in DL	37	55	26	70	11	30
Kirseberg Square in EL	49	48	31	63	18	37
Lindeborg Square in DL	38	62	26	68	12	32
Lindeborg Square in EL	34	52	24	71	10	29

Table 5. Demographic data of participants in S4: Mean age, gender representation, and the proportion who were local residents in Kirseberg and mean years of residence

Participants		Age (yr.)		Female		Male		Residents	
	N	Mean	SD	N	%	N	%	%	Mean yrs
Total	177	50	17	68	39	107	61	86	14
Lighting mode RH	49	48	16	18	37	31	63	96	15
Lighting mode H	39	52	19	16	42	22	58	90	17
Lighting mode HV	42	48	17	17	40	24	57	90	11
Lighting mode HVA	47	53	18	17	36	30	64	70	14

5.5 Ethical Considerations

This research was carried out in accordance with the ethical codes and guidelines of the Swedish Ethical Review Authority (Etikprövningsmyndigheten 2023) to ensure the rights and welfare of the human subjects in the respective studies.

No ethical approval was required for any of the studies, as neither involved any sensitive personal data, as defined by the Swedish Ethical Review Authority (Etikprövningsmyndigheten 2023). Nevertheless, all studies involved human subjects (visitors to the squares during the observations and participants in the survey and in the intervention), and ethical considerations were thus made at several stages of the research process.

Informative signs were posted at the site during each of the four field studies. These signs informed the public about the ongoing studies, explaining their purpose and identifying Lund University in cooperation with Malmö Stad as the responsible institutions. Contact details for the project manager were provided in case of enquiries from the public.

Ethical considerations included the following measures:

All data collected remained anonymous and no sensitive information regarding observed visitors or participants was included. Confidentiality was ensured (e.g. questionnaires in the survey remained anonymous, and observed visitors could not be identified from the coding scheme). Processing of personal data was in accordance with the EU's general data protection regulation, GDPR (EU 2016/679) and current legislation, the Swedish Data Protection Act.

The two observational studies (S1 and S2) were non-intrusive; the observer did not interfere with the visitors' activities in the squares in any way. The observer maintained a non-participant stance, staying in the background while coding user behaviour with pen and paper. On the few occasions when questions arose regarding the observer's presence, the observer explained the purpose of the study.

Participation in the survey (S3) and in the intervention (S4) was voluntary and based on informed consent. Participants were briefed on the purpose of the research, and of general ethical principles including their right to withdraw at any time. Written informed consent was obtained from all participants prior to distribution of questionnaires.

The lighting conditions in the intervention study posed no potential risks to participants.

After completing the questionnaires, participants had the opportunity to provide feedback, and they were informed that they could contact the project manager with any further questions, or if they would like to receive information regarding the findings of the studies. All participants received a small reimbursement: a gift card in the amount of 100 SEK.

6 Two Public Squares

This chapter presents the environmental settings, i.e., the two public squares investigated, Kirseberg Square and Lindeborg Square. A number of shared features make these squares comparable cases: their physical properties and spatial layout are similar, with functional zones intentionally designed (or programmed) for movements, stationary activities, and social interaction. Both squares serve as local centres, offering necessity-based commerce, services and amenities to residents of their respective neighbourhoods.

However, the lighting installations in each square differ in their spatial, spectral, intensity, and temporal characteristics. This results in different lighting conditions and dissimilar appearances after dark. The two neighbourhoods and the two squares in their respective lighting conditions – daylight and after dark – are further described below.

6.1 The Neighbourhoods

The neighbourhood Kirsebergsstaden is situated in northern Malmö, Sweden and has approximately 5300 inhabitants. It is part of the larger northern district with approximately 16 000 inhabitants ("Statistikunderlag för Malmö 2022"). Topographically, Kirseberg – unlike the rest of Malmö – is hilly, earning the area the nickname 'Backarna', or 'the hills', and its inhabitants 'Vi på backarna', or 'us on the hills'. The name Kirseberg is commonly thought to come from the Danish *kirsebær*, or cherry, as cherry trees were historically grown there. Originally largely inhabited by the working class, Kirseberg became a growing suburb of Malmö for those who could not afford to live within the city limits. In many ways, the neighbourhood has retained the character and appearance of a little town in its own right (Riksantikvariämbetets BeBR).

During the data collection phases, the author spent considerable time at the squares in the two neighbourhoods (six weeks of direct observations during the studies S1 and S2, and an additional six weeks during S3 and S4). The author's impression of Kirseberg is that there is a strong sense of community in the neighbourhood.

Lindeborg is situated in southern Malmö and has approximately 5000 inhabitants. It is part of the city district Hyllie, which has approximately 15 000 inhabitants ("Statistikunderlag för Malmö 2022").

Until 1970, the residential area of Lindeborg was still agricultural land with a few farming units. The development of the new residential area started in the 1970s and was named after one of the original farms. The western part of Lindeborg mainly comprises large-scale, eight-storey blocks of flats with generous green gardens. The eastern part has lower building blocks with two-to-three-storey houses and detached, single-family houses. Lindeborg consists primarily of co-operative units and, to a lesser extent, rental flats.

The author's impression of Lindeborg is that the locals are regularly present in Lindeborg Square, with teens in particular having a strong presence.

Table 6 presents demographics and socio-economic facts about the two neighbourhoods ("Statistikunderlag för Malmö 2022"), including that there is a lower average income in Kirsebergsstaden than in Lindeborg, and than in Malmö at large. The age group above 65 years is relatively larger in Lindeborg than in Kirsebergsstaden, and the level of education in Kirsebergsstaden is higher than in Lindeborg.

Table 6. Demographic and socio-economic profiles of the two neighbourhoods

	Age						
	0-19 yrs		20-64 yrs		> 65 yrs		Total
Kirsebergsstaden	997	19%	3661	69%	651	12%	5309
Lindeborg	1107	22%	2636	53%	1227	25%	4970
	Education (in age group 20-64 years)						
	Primary		Secondary		Post-secondary or higher		Other
Kirsebergsstaden	12%		36%		48%		4%
Lindeborg	11%		47%		38%		4%
	Economic facts						
	Average income		On welfare aid				
Kirsebergsstaden	249 000 SEK		8%				
Lindeborg	289 000 SEK		1%				
Malmö	297 000 SEK		7%				

6.2 Kirseberg Square

Kirseberg Square (Figure 7) is situated at the centre of the neighbourhood Kirsebergsstaden ("Statistikunderlag för Malmö 2022"). The square is surrounded on three sides (to the east, south and west) by buildings constructed in the 1960s, and to the north, along Vattenverksvägen, it is bordered by the small-scale residential houses that were typical in Kirseberg in the early 1900s (Riksantikvarieämbetet 2021a).

A children's day-care centre and a pharmacy are housed in a three-storey dark brick building (a former telephone exchange station) to the east. A grocery store is located in a one-storey building to the south. To the west, a four-storey residential building with balconies on each floor faces the square.

The square's approximate size is 3100m^2, with the area designed for stationary activities and social interaction (Zone A) accounting for around 700 m^2. Cherry trees, lime trees and rose bushes enclose this area. Benches in each corner provide sunny and shady seating during daylight hours, and a boule court offers opportunities for socializing among locals. Additionally, a bronze sculpture catches the eye and invites children to play.

Zones B and C are predominant areas for movements. A pedestrian route to the south gives access to the frequented grocery store, and a pedestrian route along the residential building to the west accommodates pedestrian movements on the north-south axis (Zone B). A one-way street (mixed traffic, with motorised vehicles, cyclists and pedestrians) to the east gives access to the parking area and to services including the pharmacy and the children's day-care.

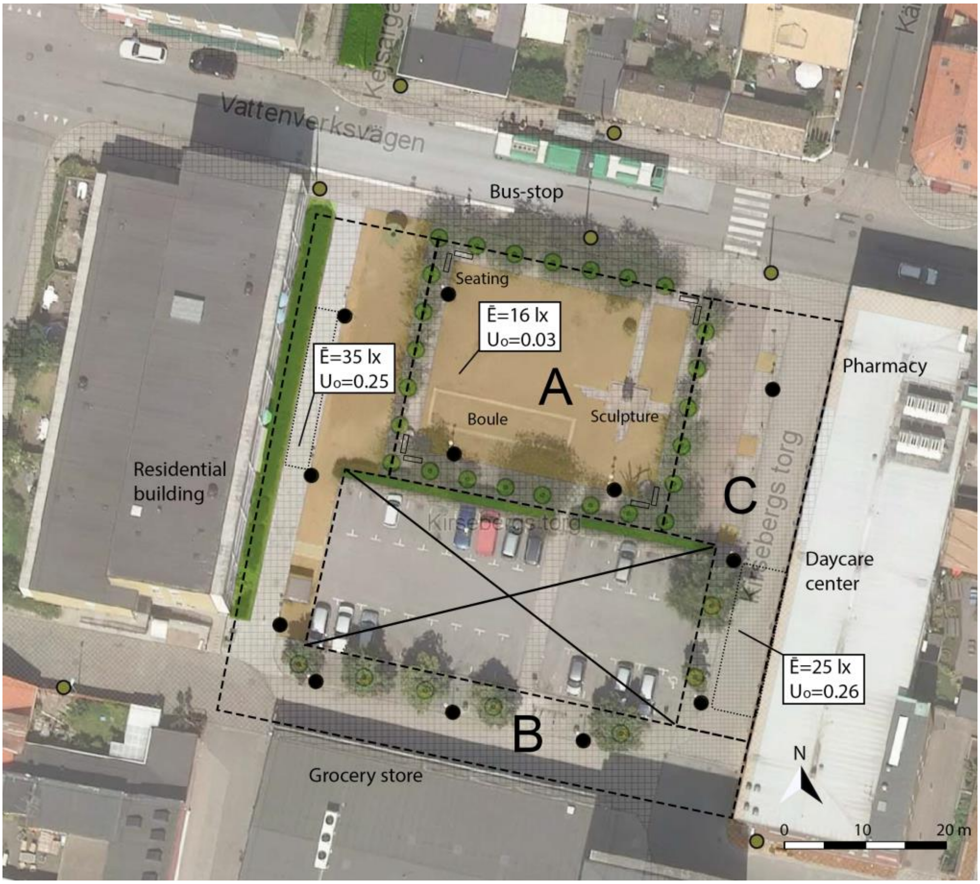

Figure 7. Plan of Kirseberg Square

Functional zones are indicated with A, B and C. The black dots represent lamp posts. Horizontal illumination measurements after dark are shown in callouts with average illuminance (Ē) and uniformity of illuminance (U_o).

Figure 8. Kirseberg Square in daylight
From the top left: Zone A – afternoon showing a shadow sequence (1-3); Zone B – pedestrian route (4); Zone B – commercial area (5). Below right: Zone C – one-way street (6).

6.2.1 Daylight appearance

Figure 8 shows Kirseberg Square in daylight. The shadow sequence in Zone A illustrates how the residential building situated to the west casts its shadow over this zone. Around the autumn and spring equinox (the time of data collection for the studies), direct sunlight lingers in the northeast corner of the square from late afternoon until early evening, at which point the entire zone is fully in the shade of the residential building.

It should be noted that data collection in daylight was conducted under all sky conditions, i.e., from completely overcast to clear skies. However, no data collection was conducted during heavy rain or snowfall.

6.2.2 Lighting installation

A technical overview of the lighting installation in Kirseberg Square is shown in Table 7 and Table 8. The square has 12 lamp posts (3.7m high) with double asymmetric reflector luminaires, each fitted with 70 W metal halide (MH) lamps. The low mounting height in combination with the high luminous output of the lamp result in substantial contrasts between bright and dark areas; see the photometric assessment in Section 6.2.3. The layout of the lampposts is shown in Figure 7, and the light distribution across the square is depicted in Figure 9.

Table 7. Specification of luminaire types

Square	Luminaire types						
	Type	Name	Light distribution	Optics	Shield	Height	Qty.
Kirseberg	Road luminaire	Philips, Copenhagen	asymmetric	reflector	upwards	3.7 m	2x12
	Spotlight	SILL, Plane projector	rot. symmetric	reflector	lamels	6 m	1
Lindeborg	Park lantern	DEFA, Helena	omni-directional	opal diffuser	glare rings	4.2 m	11

Table 8. Specification of lamp types

Square	Lamp types						
	Type	Name	Luminous flux (lm)	CCT (K)	CRI (Ra)	S/P ratio	Qty.
Kirseberg	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x12
	HPS	HST-DE 150W	1500	2000	25	0.5	1
Lindeborg	HPS	SON Pia Plus 70W	6000	2000	25	0.5	9
	MH	CDO-ET 70W/828	7030	2800	84	1.3	2

Figure 9. Kirseberg Square after dark

Top: Layout and distribution of light across the square (1). Below left: Zone A – north-east corner with benches (2). Below right: Lamp post with double asymmetric reflector luminaires, fitted with MH 70W (3).

6.2.3 Photometric assessment and after-dark appearance

A photometric assessment of horizontal illuminances on ground level in the three zones in Kirseberg Square is shown in Figure 10 and further described in Appendix I, Section 3.1, and Table 4. The horizontal illuminances across the square have an average of $\bar{E} = 23.4$ lx and a uniformity of $U_o = 0.03$. On the paths in Zones B and C, the average horizontal illuminances are above the required maintained levels of class P1, in standard SS-EN 13201-2:2016 for pedestrians and cyclists. The uniformity is lower than required, however, with the average illuminance exceeding 1.5 times the minimum for this class; see Appendix I, Table 4.

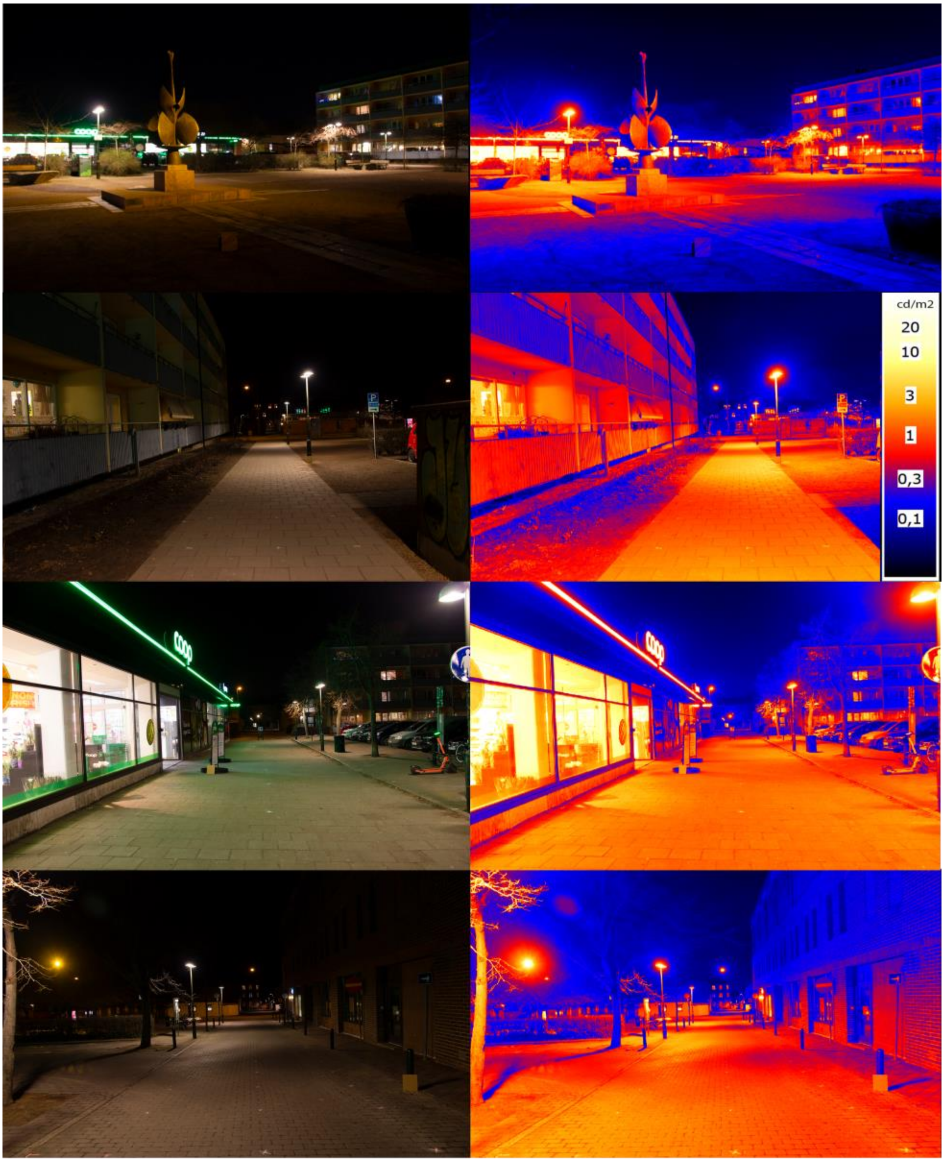

Figure 10. Kirseberg Square: HDR images with corresponding luminance maps
From above: Zone A, Zone B – pedestrian route; Zone B – commercial area; Zone C – one-way street.

Figure 10 shows HDR images converted into luminance maps, capturing the luminance levels in the visual scenes. An assessment of Zone A shows a large contrast at ground level, with luminance ranging from 0.1 cd/m² to 20 cd/m². The level of contrast is lower in Zones B and C. The hardscape in Zones B and C, with concrete slabs and stones reflecting the light, contributes to the bright appearance of the paths after dark. On the contrary, the low vertical luminance levels in Zone C are evident (see Figure 10), with the brick building left in darkness and reflecting light poorly. A spatial analysis after dark concludes that the areas with benches (for stationary activities and social interaction) become isolated, fragmented, bright islands after dark, Figure 10. The peripheral spatial limits of the square – the vertical walls – vanish after dark.

6.3 Lindeborg Square

Lindeborg Square (Figure 11) is located in southern Malmö, at the centre of the neighbourhood Lindeborg, which has approximately 5000 inhabitants ("Statistikunderlag för Malmö 2022"). The square and its surrounding buildings were constructed in the 1970s (Riksantikvarieämbetet 2021b). The commercial building to the north houses a grocery store, a florist, a gym, a pharmacy, and a pizzeria. To the south is an elementary school, and there is a church to the west.

Similar to Kirseberg Square, Lindeborg Square is approximately 3100m2. The area designed for stationary activities and social interaction (Zone A) comprises approximately 1300 m2. The design of Zone A subjectively suits its purpose well, with benches in every cardinal direction, a hardscape of red bricks and gravel, a softscape of lime trees, cherry trees, trimmed beech hedges, well-composed perennial flowerbeds, a water feature, and a small sculpture (Figure 12). A pedestrian- and bicycle path to the north (Zone B) provides access to the commercial destinations. This zone also accommodates seating across the building. A pedestrian- and bicycle path to the west (Zone C) provides access to and from the centre and connects the southern part of the neighbourhood to the square.

6.3.1 Daylight appearance

Figure 12 shows Lindeborg Square with clear skies and direct sunlight in early autumn. In the late afternoon, the school building to the south casts a shadow that partly covers Zone A. Unlike in Kirseberg Square however, there is still plenty of seat in the sun at Lindeborg Square, and most of Zone A remains un-shadowed.

In daylight, the red brick façades of the church and the school along with the red brick hardscape on the ground in Zone A give the square a warm impression.

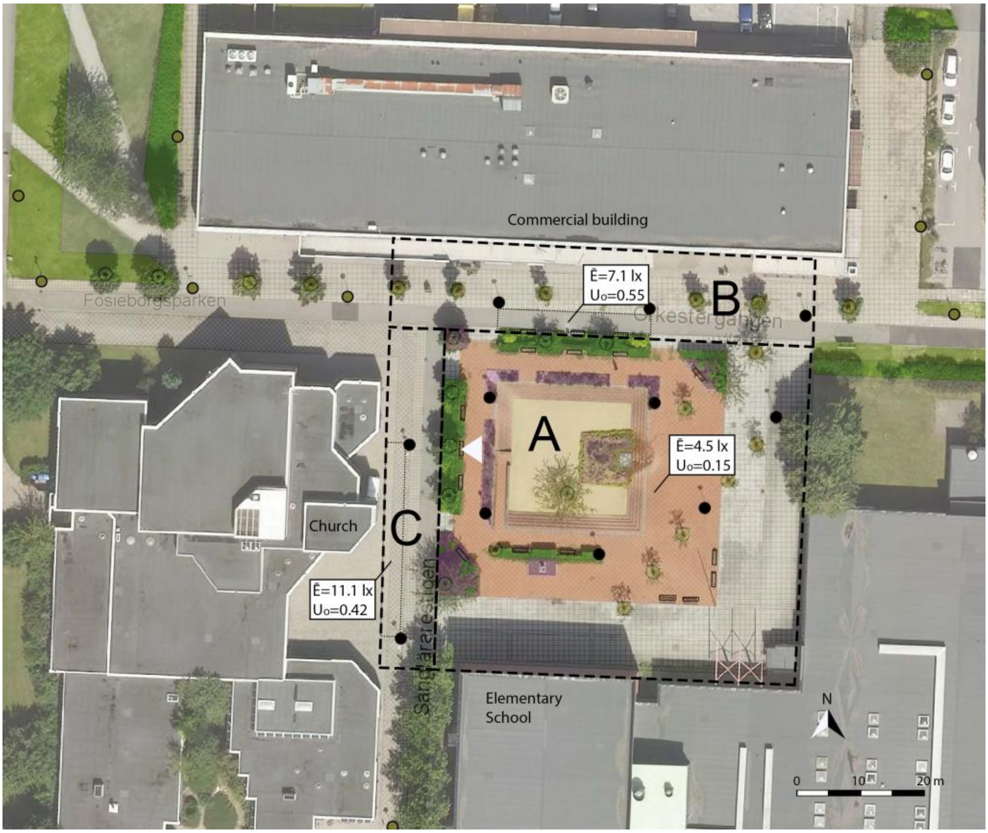

Figure 11. Plan of Lindeborg Square

Functional zones are indicated with A, B and C. The black dots represent lamp posts. Horizontal illumination measurements after dark are shown in callouts with average illuminance ($\bar{E}$) and uniformity of illuminance (U_o).

6.3.2 Lighting installation

A technical overview of the lighting installation in Lindeborg Square is given in Table 7 and Table 8. The square has 11 lamp posts (4.2m high) spaced at 20m intervals along paths in Zones B and C, and arranged to accompany seating and flowerbeds in Zone A. The park lanterns, shown in Figure 12, have a diffuse omnidirectional light distribution. Zone A and Zone B are fitted with 70 W high pressure sodium (HPS) lamps. The connecting bicycle path in Zone C is fitted with 70 W MH lamps.

The layout of the lamp posts is shown in Figure 11, and the light distribution across the square is depicted in Figure 13.

Figure 12. Lindeborg Square in daylight

From the top left: Zone A in early afternoon with clear skies and direct sunlight (1 - 3). Middle right: Zone A in late afternoon with shadow from the school building (4). Below left: Zone B – pedestrian- and cycle path to the east (5). Below right: Zone C – pedestrian- and cycle path towards the grocery store (6).

6.3.3 Photometric assessment and after-dark appearance

A photometric assessment of horizontal illuminances at ground level in the three zones in Lindeborg Square is shown in Figure 14 and described further in Appendix I, Section 3.1 and Table 4. The horizontal illuminances across the square have an average of $\bar{E}$ = 5.8 lx and a uniformity of U_o = 0.07. The light levels in Lindeborg Square are substantially lower than in Kirseberg Square. Moreover, the contrasts between bright and dark areas are less evident. The paths in Zone B and Zone C both comply with P2 and P4 classes in SS-EN 13201-2.2016, both in terms of horizontal illuminance levels and uniformity.

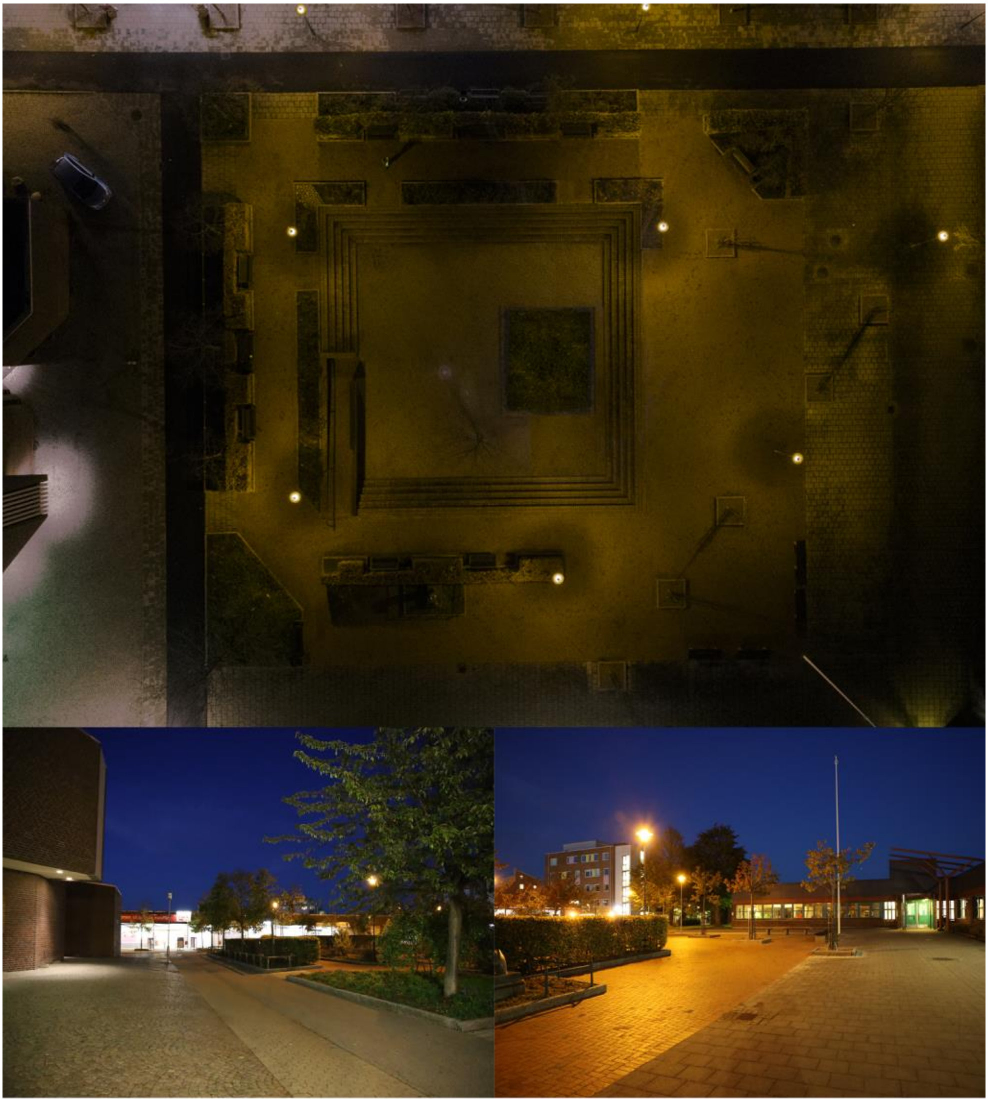

Figure 13. Lindeborg Square after dark

Top: Illustration of the layout and distribution of light across the square (1). Below left: Zone C – the park lanterns are fitted with MH 70W (2). Below right: Zone A – at the school, the park lanterns are fitted with HPS 70W (3).

Figure 14 shows HDR images converted into luminance maps, capturing the luminance levels in the visual scenes. An assessment of Zone A portrays a setting with a warm ambiance, diffuse light distribution from the lanterns, poor modelling of hedges, kerbstones and objects, and poor colour rendering due to HPS lamps that distort the colour of plant materials. In Zone B, the hardscape with asphalt in combination with low horizontal light levels on the path and high vertical light levels from the shop windows causes substantial contrasts. In Zone C, where park lanterns are fitted with MH lamps (Figure 13) and the hardscape is dark asphalt and granite, the impression is cooler. Façade lighting on the church contributes to a vertical luminance of 1 cd/m².

Figure 14. Lindeborg Square: HDR images with corresponding luminance maps
From the top: Zone A, Zone B – pedestrian- and cyclist route; Zone C – pedestrian- and cyclist route.

7 Intervention at Kirseberg Square

This chapter presents the applied lighting modes of a lighting intervention (S4) conducted at Kirseberg Square. Guided by the proposed socio-physical conceptual model (see Figure 4, Section 4.1), the intervention specifically targeted spatial characteristics of light as important for environmental appraisals – for both the interpretative and the evaluative mode – after dark. The intervention was carried out in Zone A of Kirseberg Square. Based on the technical assessment of the lighting condition in Kirseberg Square after dark (Chapter 6), which showed low uniformity in horizontal illuminances and substantial luminance contrasts between bright and dark areas in the visual scene in Zone A, it was deemed most appropriate to conduct an intervention in this square.

The intervention study was conducted in two phases. The first phase examined an intervention carried out by Malmö Stad, i.e. a 'municipality intervention', that aimed to provide a more uniform horizontal (H) illumination in Zone A than the pre-existing lighting condition described in Chapter 6, hereafter referred to as reference horizontal (RH). The second phase was conducted by the research team and investigated a spatial intervention with three lighting modes with different spatial distribution: horizontal (H), horizontal and vertical (HV), and horizontal, vertical and accent lighting (HVA).

7.1 Municipality Intervention

Malmö Stad upgraded the pre-existing permanent lighting in Zone A, Kirseberg, based on the findings of studies S1 and S2, which suggested that neither stationary activities nor social interaction were sustained in Zone A after dark (see Sections 8.1.3. and 8.2.3). The intent was to sustain the spatio-temporal behaviours observed in daylight in the after-dark condition. This was to be achieved by shifting from a lighting layout in Zone A (Figure 7) with three luminaires with an asymmetric direct distribution fitted with MH (RH) to a layout with four park lanterns with rotational-symmetric distribution fitted with LED (H) (Figure 15). The objective of the update was to achieve a light distribution with increased horizontal uniformity and less luminance contrast in the visual field, and at the same time to reduce energy consumption.

A technical description of the lighting installations with specifications of luminaire types and lamp types utilized for lighting mode, RH, and the intervention mode, H, are provided in Tables 9 and 10. Table 11 shows the horizontal illuminances on the ground level across Zone A and vertical illuminances on the adjacent façade in the respective lighting mode. The horizontal illuminances across Zone A of RH have an average of $\bar{E}$= 20.1 lx and a uniformity of U_o = 0.01, while the horizontal illuminances across Zone A of H have an average of $\bar{E}$ = 12 lx and a uniformity of U_o = 0.07.
The assessment of users' environmental appraisals of the two lighting modes with different horizontal light distribution, RH and H, is presented in Section 8.4 and Appendix IV, Tables 6 and 7.

Table 9. Specification of luminaire types utilized in the respective lighting mode

	Luminaire types						
Lighting Mode	Function	ID	Type	Light Distribution	Optics	Mounting height	Qty.
RH	Horizontal	P1	Road-luminaire Philips, Copenhagen	Asymmetric	Reflector	Top-mounted 3.7 m	2x12
H, HV, HVA	Horizontal	P1	Road-luminaire Philips, Copenhagen	Asymmetric	Reflector	Top-mounted 3.7 m	2x9
H, HV, HVA	Horizontal	P2	Park lantern Ateljé Lyktan, Linx	Rot. symmetric	Lens + opal diffuser	Top-mounted 4.0 m	4
HV, HVA	Façade lighting-Vertical	T1	Compact flood Meyer, Monocube 4	16° x 33° Linear horizontal	Narrow beam + linear lens	Top of façade 10m	11
HVA	Accent lighting Trees, sculpture	M1	Flood light Cameo, FLOOD 600	40°	Lens optic	Ground-based	12

Table 10. Specification of lamp types utilized in the respective lighting mode

	Lamp types							
Lighting Mode	ID	Type	Name	Luminous flux (lm)	CCT (K)	CRI (Ra)	S/P ratio	Qty.
RH	P1	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x12
H, HV, HVA	P1	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x9
H, HV, HVA	P2	LED	LED, 37 W, 830	3800	3000	80		4
HV, HVA	T1	LED	LED, RGBW, 20-50W	1500-2500	RGBW (3000)			11
HVA	M1	LED	LED, RGBWA, 9 x12 W	2042	RGBWA			12

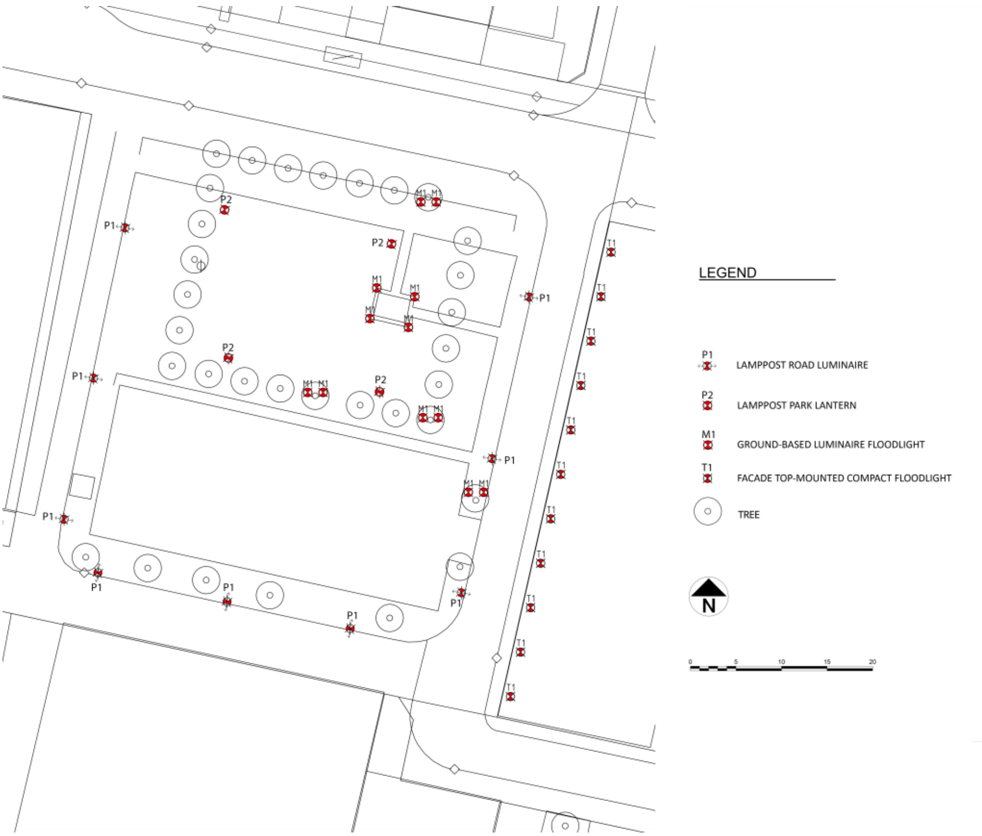

Figure 15. Lighting installation H, HV, HVA

Luminaire types and lamp types for the respective ID (P1, P2, M1 and T1) are specified in Tables 9 and 10. The lampposts (with ID P1 and ID P2) are utilized for all lighting modes (H, HV and HVA). Façade lighting with ID T1 is utilized for vertical lighting (HV and HVA), and ground-based luminaires with ID M1 for accent lighting are utilized in HVA.

Table 11. Horizontal illuminances and vertical illuminances

Representation of the horizontal illuminances and uniformity on the ground level in Zone A and vertical illuminances and uniformity on the adjacent façade for the respective lighting mode RH, H, HV and HVA.

	Horizontal illuminances			Vertical illuminances		
Lighting mode	$\bar{E}_h$ (lx)	$E_{h\,min}$ (lx)	U_o	$\bar{E}_v$ (lx)	$E_{v\,min}$ (lx)	U_o
RH	20.1	0.38	0.01	1.08	0	0
H	12.0	0.87	0.07	0.99	0	0
HV	12.0	0.87	0.07	12.1	1.00	0.08
HVA	12.4	0.91	0.07	12.1	1.00	0.08

7.2 Spatial Intervention

In the second phase temporary ‘spatial interventions’ were introduced by the research team. The design of the applied lighting modes derives from lighting design practice and lighting design research, emphasizing the importance of visual spatial boundaries as beneficial for appreciation of space (Section 3.5), while the assessment of the users’ environmental appraisals (Section 8.4) draws on environmental preference theories in EP (Section 3.3).

The research design (setup) of the spatial intervention derives from an investigation on spaciousness and sociability by Casciani (Casciani 2020c), in which lighting modes are added incrementally, i.e., from an isolated horizontal mode (H) to a combined mode with added vertical illumination (HV), and to a ‘complete mode’ with added accent lighting (HVA). The horizontal light distribution is held more or less constant across the respective modes, with a minor contribution expected from reflected light in the HVA mode.

The three lighting modes are expected to achieve the following design criteria to varying degrees:

- Ensure users’ visual performance and visual comfort, i.e., supporting users’ perceived visual accessibility and cognitive perception of the space (cf. *interpretative mode* of the human-environment transaction).
- Provide an overview of the square, i.e., supporting users’ sense of reassurance (cf. *evaluative mode*).
- Enhance the visual spatial boundaries of the square (by illuminating/not illuminating the adjacent façade) following Wänström (Wänström Lindh 2013); presumed beneficial to users’ perception of atmosphere (cf. *evaluative mode*).
- Provide restorativeness (by accentuating or not accentuating ‘scene content’, organic elements, trees, and sculpture) following Nikunen and Korpela (Nikunen and Korpela 2009; Nikunen and Korpela 2012) (cf. *evaluative mode*).
- Enhance ‘a cohesive sense’ (Böhme 2017) of a pleasant atmosphere, following work by Böhme (Böhme 2017), Stokkermans et al. (Stokkermans et al. 2018) and de Kort (de Kort 2019), due to differences in perceptual attributes of light (spatial brightness, perceived uniformity), and in the balance of brightness levels (Hvass and Hansen 2022) (cf. *evaluative mode*).

More specifically, the lighting mode HV, as compared to H, intends to balance light levels in the vertical plane relative to the horizontal plane and to balance the luminance of the lamppost luminaires relative to the luminance of the background (the adjacent façade), thus intending to reduce any uncomfortable contrast in the visual field. Compared to lighting mode H, a combination of horizontal and vertical illumination, HV, intends to increase the perceived brightness of the setting (Boyce 2014, pp 197-201). Furthermore, HV intends to define visual spatial boundaries. In lighting mode HVA, the accent lighting intends to focus the users' attention on scene content and greenery after dark. Lighting mode HVA also intends to enhance Zone A as a 'refuge' (here interpreted as a zone aimed at enhancing social interaction) (Appleton 1984). Lighting on the sculpture spatially creates a foreground, middle ground and background, which may enhance appreciation of the space.

The assessment of users' environmental appraisals of lighting modes H, HV and HVA is presented in Section 8.4, and in Appendix IV, Table 8 and Figure 9.

7.2.1 Lighting installations H, HV, HVA

Tables 9 and 10 provide a technical description of the lighting installations, with specifications of luminaire types and lamp types utilized for the respective lighting modes H, HV and HVA. Figure 15 illustrates the layout of luminaires for the intervention lighting modes H, HV and HVA.

The illuminance distribution for the horizontal plane (ground level in Zone A) and for the vertical plane of the adjacent façade (the background in the experimental setting) are presented in Table 11 and illustrated with illuminance plots retrieved from simulations in the software DIALUX evo 12.1., in Figure 16.

7.2.2 Photometric assessment of H, HV, HVA

Photometric assessments of the intervention lighting modes H, HV and HVA were conducted with HDR images converted into luminance maps of the visual scenes. The technical equipment, camera and calibration method, lenses, and the software utilized to retrieve luminance values are described in Appendix IV.

The HDR images were captured at the viewpoint of the location for assessments of the environmental appraisals. To describe the luminance patterns in the field of view for lighting mode H, HV and HV respectively, measurements of mean and median values in the horizontal and vertical planes and their ratio of vertical over horizontal luminance were conducted. Figure 17 shows the luminance maps of the respective lighting modes H, HV and HVA. Measured luminance values retrieved from the assessment of luminance maps are presented in Table 12.

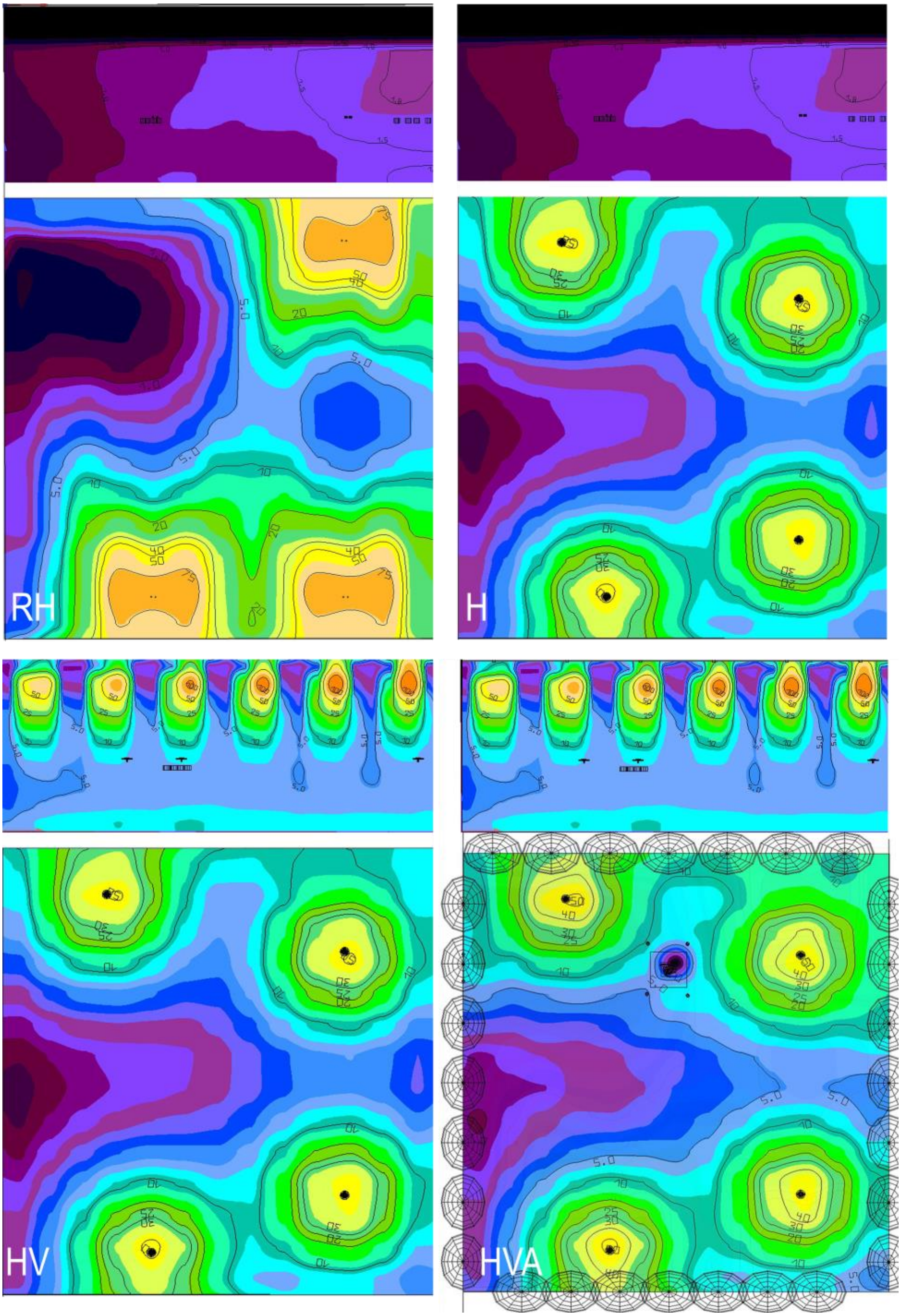

Figure 16. Horizontal and vertical illuminance plots of lighting modes RH, H, HV, HVA
Illustration of horizontal and vertical illuminances. Isobars indicate ranges from 0.25 lx to 100 lx.

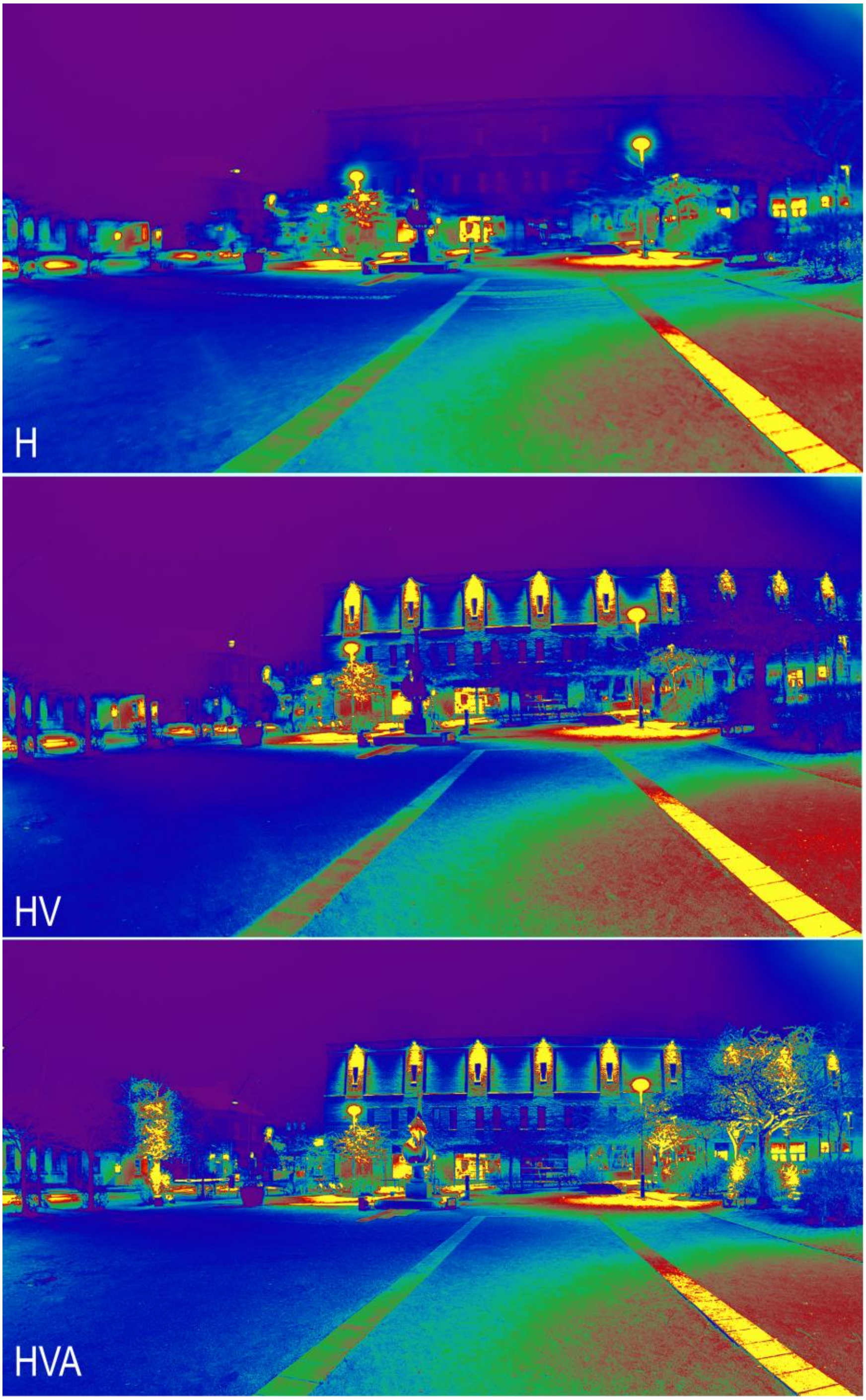

Figure 17. Luminance maps of lighting modes H, HV, HVA

Table 12. Horizontal and vertical luminances

Measurements of the horizontal and vertical luminances in the field of view of lighting modes H, HV and HVA.

Lighting mode	Luminance measurements					
	Horizontal luminance mean (cd/m^2)	Vertical luminance mean (cd/m^2)	Ratio V/H	Horizontal luminance median (cd/m^2)	Vertical luminance median (cd/m^2)	Ratio V/H
H	0.27	0.23	0.85	0.23	0.08	0.35
HV	0.28	0.31	1.12	0.21	0.11	0.52
HVA	0.27	0.50	1.87	0.21	0.20	0.95

8 Summary of the Empirical Studies

This chapter summarizes the empirical studies S1, S2, S3, and S4.

8.1 Summary of Study 1

8.1.1 Aim

The aim of S1 was to investigate user behaviour – i.e., movements and stationary activities – in daylight (DL) and electric lighting (EL) after dark in Kirseberg Square and Lindeborg Square in Malmö, Sweden. More specifically, the investigation should reveal whether user behaviour observed in DL was sustained during the corresponding time period in EL after dark in the two squares.

The main objectives were to assess the occurrences of movements and stationary activities in DL as compared to in EL after dark, and to test if any changes in these behaviours could be attributed to the effect of change in ambient light level.

8.1.2 Method

Direct, structured observations (Robson and McCartan 2016) of users were carried out at the two public squares. Observations were reported in a coding scheme with predefined types of behaviours in two categories: movements and stationary activities. Movements comprised walking, cycling, riding on scooter and other movements, and stationary activities comprised standing, sitting, hanging-out and other stationary, Figure 5.

Procedure and analysis

Data were collected two weeks before and two weeks after the autumn 2020 daylight savings clock change, in order to enable a comparison of user behaviour in DL and after dark in EL for the same times of the day. Time-of-day factor and seasonal factors were thus kept sufficiently constant, to isolate the effect of change in ambient light level (Uttley and Fotios 2017). The data collection days included two observation sessions, each of which consisted of two time slots with a duration of 45 min. Two time slots were in the afternoon (15.30-16.15 and 16.15-17.00), and two time slots were in the early evening (17.30-18.15 and 18.15-19.00). Sampling was conducted in three spatial units (Zones A, B, C; see Figures 7 and 11), with rotations between zones every 15 min. Observations were conducted for 18 hours within each square. 5296 observations were recorded.

Frequency analyses were used to establish the occurrence of different types of behaviour within the two behavioural categories movements and stationary activities.

Pearson's Chi-square test was used to test for differences between DL and EL within category of behaviour during all time slots. The general level of significance was set to $p \leq= 0.05$. The Bonferroni-corrected level of significance was used in analyses including multiple comparisons.

Odds ratio (OR) analyses were performed for each square to investigate if changes in the frequency of behaviours were associated with the effect of change in ambient light before and after the clock change. A control period (with daylight both before and after the clock change), and a case period (with daylight before the clock change but dark after the clock change) was included in the analysis. The employed OR equations are provided in Appendix I, Section 2.5).

ORs were conducted for the aggregated data across all zones and separately for Zone A (the programmed zone for stationary activities). An OR of 1.0 indicates that there was no difference in frequency of behaviour between daylight and electric light.

8.1.3 Results and conclusion

The frequency analysis (see Appendix I, Tables 5 and 6) showed that movements were generally unaffected by the change in ambient light level from DL to EL. This was confirmed with the OR analysis across all zones (Appendix I, Figure 9).

The results of the Pearson's Chi-square test (see Appendix I, Tables 5 and 6) for Kirseberg Square displayed significant decreases in the stationary activities; sitting (χ^2 (1, N =79) = 16.01, $p < 0.001$) and hanging-out (χ^2 (1, N =109)) = 29.04, $p < 0.001$) in EL compared to DL. The results for Lindeborg Square displayed an increase in the stationary activity hanging-out (χ^2 (1, N =182) = 4.58, $p = 0.032$) in EL compared to DL.

The OR analyses for Zones A (see Appendix I, Figure 10) showed a significant decrease in stationary activities after dark in EL (OR=15.6, 95% CI= 7.69-31.82, $p < 0.0001$) for Kirseberg. For Lindeborg however, the OR analysis showed a significant increase in this behavioural category (OR=0.34, 95% CI=0.14-0.83, p =0.016).

In conclusion, this study shows that spatio-temporal patterns of movements were sustained in both squares after dark. Stationary activities were not sustained in Zone A in Kirseberg, with asymmetric luminaires and MH lamps and large luminance contrasts between dark and bright areas. In Lindeborg's Zone A however, where luminance levels were substantially lower and more uniform, stationary activities in fact increased.

The findings suggest that spatial light distribution is an important light characteristic for sustaining stationary activities after dark. This interpretation aligns with experience from lighting design practice, where spatial distribution of light is intentionally used to programme stationary activities in public squares.

A plausible interpretation of the results is that user behaviour after dark might also be related to the appreciation of colour temperature of light, hence consideration of spectral characteristics might also be of importance.

8.2 Summary of Study 2

8.2.1 Aim

The aim of S2 was to investigate users' active social interaction in DL and in EL after dark in Kirseberg Square and Lindeborg Square in Malmö. The main objectives of the study were to compare the occurrences of people visiting the squares being alone, in pairs or in groups of three or larger, and to test for any differences between age groups in visitor presence in the squares after dark.

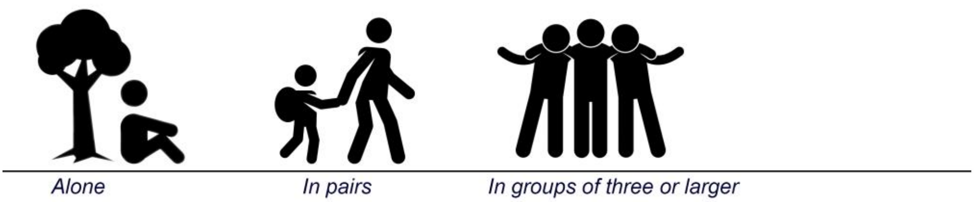

Figure 18. Categories of social interaction
Passive social interaction was operationalized as being alone. Active social interaction was operationalized as being in pairs or in groups of three or larger

8.2.2 Method

Direct, structured observations of users' social interaction were conducted at the two squares (Sussman 2016). A scan sampling technique was used for recording events of social interaction (Altmann 1974).

Active social interaction was operationalized as being in pairs or in groups of three or larger, Figure 18. The occurrences of which visitors were being alone, in pairs, or in groups or three or more (N=2522) were recorded.

Individuals present at each square were classified visually by their gender and by their age group into one of four age groups: children (approximately 0-12 years old), teens (approximately 13-19 years old), adults (approximately 20-64 years old) and elderly (over 65 years old).

Procedure and analysis

Data were collected two weeks before and two weeks after the autumn 2020 daylight savings clock change, in order to enable a comparison of users' active social interaction in daylight and in electric lighting after dark at the same times of the day. Time of day factor and seasonal factors are thus kept sufficiently constant, to isolate the effect of change in ambient light level and to offset other confounding factors (Uttley and Fotios 2017). Sampling took place in the afternoon between 16.15 to 17.00 and in the early evening between 17.30 to 18.15. Sampling was conducted in the three sampling units (Zones A, B and C; Figures 7 and 11), with rotations between zones every 15 min.

Frequency analyses for social interaction for the three categories (being alone, in pairs, or in groups of three or larger) were conducted to establish the occurrences of active social interaction in DL compared to EL after dark for each square, respectively.

Pearson's Chi-square test was used to test for differences in social interaction in DL compared to in EL after dark and to test for differences in age groups in DL and in EL after dark. The level of significance was set to $p \leq 0.05$, with Bonferroni correction for multiple comparisons.

8.2.3 Results and conclusion

The results of the frequency analysis and the Pearson's Chi-square tests for social interaction in DL as compared to in EL after dark are provided in Appendix II, Table 5, and showing dissimilar patterns for the two squares.

The results for Kirseberg Square in the afternoon reveal a significant difference between the level of social interaction in DL compared to after dark in EL (χ^2 (2, N=603) = 6.58, p=0.038), with a decrease in the occurrences of people being in pairs in EL after dark.

The results for Lindeborg Square display a significant difference in the level of social interaction in DL and in EL after dark, both for the afternoon (χ^2 (2, N=540) = 11.64, p=0.003) and the evening (χ^2 (2, N=605) = 12.45, p=0.002). After dark, fewer people are present alone; instead, more people are in pairs or in groups of three or larger.

The results of the frequency analysis and the Pearson's Chi-square tests for visiting people per age group in DL as compared to in EL after dark is provided in Appendix II, Table 7. Children and elderly have a significantly lower presence in EL in both squares, with (χ^2 (3, N=1376) = 25.28, p<0.001) for Kirseberg and (χ^2(3, N=1146) = 16.49, p<0.001) for Lindborg. This test also suggests that teens are the age group with higher presence in EL than in DL after dark compared to in DL. These findings suggest that teens seemingly have a spatiotemporal pattern of being present in Lindeborg after dark; this is however not the case for Kirseberg.

In conclusion, observations of social interaction at both squares reveal different patterns. Lindeborg Square displays the same pattern after dark, both in the afternoon and in the evening, with fewer people being alone and more people being in pairs or in groups of three or more in EL. Kirseberg Square displayed different patterns after dark in the afternoon than in the evening.

8.3 Summary of Study 3

8.3.1 Aim and hypothesis

The principal aim of S3 was to investigate the extent to which environmental appraisals explain self-reported social interaction in public squares after dark. It was hypothesized that an appraisal of a pleasant atmosphere is a prerequisite for social interaction after dark. The 'perceived atmosphere' is considered an overarching construct (Böhme 2017), presumed to be associated with perceived lighting quality, visual accessibility and reassurance.

S3 specifically aimed to investigate users' environmental appraisals in DL and in EL after dark of Kirseberg square and Lindeborg square, Malmö, Sweden, and to identify any environmental appraisal associated to users' self-reported social interaction in EL after dark. Subsequently, four specific objectives were pursued: (O1) to compare users' self-reported pattern of social interaction between lighting conditions and squares; (O2) to compare users' appraisals of perceived lighting qualities, visual accessibility, reassurance and atmosphere between lighting conditions and squares; (O3) to identify any association between users' self-reported patterns of social interaction and appraisal of atmosphere in EL after dark; (O4) to identify any association between atmosphere and perceived lighting qualities, visual accessibility and reassurance in EL after dark.

8.3.2 Method

A questionnaire survey on users' self-reported patterns of social interaction and users' environmental appraisals in DL and in EL after dark was conducted in Kirseberg Square and Lindeborg Square.
The study employed a cross-sectional research design, utilizing a between-subjects approach.

Participants and settings

Participants were invited to assess the two squares on-site. The sample comprised 158 participants in total, 68% of whom were female and 32% male, aged between 18 years and 85 years, with a mean age of 54 years. The participants were divided into four groups: Kirseberg DL, Kirseberg EL, Lindeborg DL and Lindeborg EL; these are described further in Table 4.

The two squares and the respective electric lighting conditions are described in Sections 6.2 and 6.3.

Measurements

Participants' self-reported patterns of social interaction and environmental appraisals were assessed using established response scales. A summary of scales and individual items used in the study can be found in Appendix III, Table A1. The internal reliability of scales, the Cronbach's alpha, was calculated for each lighting condition, also provided in this table. A Cronbach's alpha of α >0.7 for the averaged index was considered acceptable.

Participants' self-reported patterns of social interaction in the squares, ranging from passive social interaction to active social interaction (Figure 6), were assessed with four items, and responses were rated on a five-point Likert scale (1=no, definitely not; 5=yes, definitely).

Users' environmental appraisals in the respective lighting conditions (DL or EL at each square) were assessed with four scales. To capture how participants appraised the respective lighting conditions (DL or EL at each square), a seven-point bipolar semantic differential (SD) scale consisting of eight items was used (the Perceived Outdoor Quality scale (POLQ) (Johansson, Pedersen, et al. 2014). The participants' subjective experience of seeing – perceived visual accessibility – was captured with five items, and responses were rated on a five-point Likert scale (1=no, definitely not; 5=yes, definitely) (Johansson, Küller, and Rosén 2011). Participants' perceived reassurance was captured with seven items, and responses were rated on a five-point Likert scale (1=no, definitely not; 5=yes, definitely) (Johansson, Küller, and Rosén

2011; Blobaum and Hunecke 2005). Participants' perceived atmosphere was captured with 18 items on a single item five-point Likert scale (1=not at all; 5=very much), adapted from Stokkermans et al. and Vogels (Stokkermans et al. 2018; Vogels 2008), and expanded with items developed by Flynn et al. (Flynn et al. 1973).

Procedure and analysis

Data were collected in the last two weeks of March 2022, on weekdays from Monday to Thursday, in the afternoon in DL between 15.00-17.00, and in the evening between 18.30-20.30 in EL. Each sampling session started with a brief on the project's aim, procedure, and research ethics. Participants were asked to walk around a few minutes and reflect on how they perceived the setting before completing the questionnaire at the location marked with a triangle in Zone A (see Appendix III, Figures 2 and 3. To ascertain equivalent assessments, the viewing direction was marked with an arrow.

Two-way analyses of variance (ANOVA) were conducted to address the objective (O1), to test for differences (between subjects' effects) in users' self-reports of social interaction between squares and lighting conditions, and to address the objective (O2), to test for differences in users' environmental appraisals of perceived lighting quality, visual accessibility, reassurance and atmosphere between squares and lighting conditions. A value of $p < 0.05$ was interpreted as significant, and the partial eta-squared ηp^2 was used to assess effect size.

Two hierarchical multiple regression analyses were carried out. The first analysis addressed the objective (O3) and aimed to establish whether self-reported social interaction in EL after dark could be associated to appraisals of atmosphere. The second analysis addressed the objective (O4) to identify associations between atmosphere in EL after dark and appraisals of perceived lighting quality, visual accessibility, and reassurance.

8.3.3 Results and conclusion

ANOVA addressed the objective (O1) to investigate whether the type of lighting conditions (DL or EL) or the specific square had a statistically significant effect on participants' self-reported pattern of social interaction. The results (see Appendix III, Table 4) showed no significant effect of square, but a tendency for an effect of lighting conditions could be identified (F (1,158) = 3.82, p = 0.052, η_p^2 = .024). This comparison of self-reported social interaction between DL and EL thus reveals a tendency leaning towards self-reported decline in social interaction after dark. There was no significant interaction between square and lighting conditions on self-reported social interaction.

ANOVA addressed the objective (O2) to compare users' environmental appraisals of POLQ, perceived visual accessibility, reassurance and atmosphere between squares and between lighting conditions (DL or EL). The results of between-subjects' effects are provided in Appendix III, Table A2. Significant effects of lighting conditions were identified for each of the assessed environmental appraisals: visual accessibility (*F* (1,158) = 52.29, $p< 0.001$, $\eta_p^2 = .253$); reassurance (*F* (1,158) = 23.00, $p < 0.001$, $\eta_p^2 = .013$); pleasant atmosphere (*F* (1,158) = 14.18, $p < 0.001$, $\eta_p^2 = .084$), with DL consistently assessed as higher than EL.

The objectives (O3) and (O4) were addressed with hierarchical regression analyses.

The results of the first hierarchical multiple regression analysis with self-reported social interaction in EL after dark as a dependent variable is provided in Appendix III, Table 7. The results of the second hierarchical multiple regression analysis with a pleasant atmosphere in EL after dark as a dependent variable are provided in Appendix III, Table 8. In both analyses, the setting (square) and demographic variables (age and gender) are introduced in Models 1 and 2, followed by the environmental appraisals (i.e., the theoretically presumed predictor variables) in Models 3 and 4.

The first analysis with perceived social interaction as an outcome variable suggests that age is a predictor at a significant level of $p < 0.001$, with an explanatory power of 24% of the variance explained in Model 2, and that the appraisal of pleasant atmosphere is a predictor at a significant level of $p = 0.002$, increasing the explained variance to 31% in Model 3.

The second analysis with pleasant atmosphere as an outcome variable, suggests that the perceived lighting quality is a predictor; with significant effects for the perceived strength ($p < 0.05$) and the perceived comfort ($p < 0.001$), with 32% of the variance explained in Model 3. Furthermore, adding visual accessibility ($p < 0.01$) and reassurance ($p < 0.001$), increased the explained variance in Model 4 to 48%.

The findings of S3 suggest that self-reported social interaction after dark is associated with appraisals of perceived atmosphere. Furthermore, they indicate that perceived atmosphere is associated to perceived lighting quality, visual accessibility and reassurance.

8.4 Summary of Study 4

8.4.1 Aim and hypothesis

The principal aim of the lighting design intervention S4 was to explore the influence of spatial characteristics of light on users' environmental appraisals (previously identified in S3 as crucial for sustaining social interaction) of a public square after dark.

The objectives of S4 were as follows:

To compare users' environmental appraisals (perceived lighting quality, visual accessibility, reassurance, restorativeness and perceived atmosphere) after dark in Kirseberg Square, Malmö, Sweden, between the following lighting modes:

(O1) Horizontal Reference (RH), utilizing the original permanent lighting installation, which has a non-uniform horizontal distribution, and an updated permanent lighting installation, which has an increased horizontal uniformity, Horizontal (H).

(O2) Horizontal (H), Horizontal + Vertical (HV), and Horizontal + Vertical + Accent lighting (HVA), and to test for linear trends in the appraisals of the three lighting modes. The horizontal distribution (H) was held more or less constant.

An additional objective (O3) was to make a qualitative assessment of user-experience across the three different lighting modes H, HV, HVA.

Two a priori hypotheses were posed based on previous literature, which suggests that brightness and perceived uniformity are salient features impacting the impression of public squares after dark (Casciani 2020c; Nasar and Bokharaei 2017). A study assessing lighting modes H, HV and HVA found that lighting mode HVA increased the behavioural intent to use the space socially (Casciani 2020c).

Hypothesis 1: Increasing the horizontal uniformity from lighting mode RH to lighting mode H will result in higher ratings of the appraisals of perceived lighting comfort, visual accessibility, and thus perceived reassurance. No improvements are expected with regard to assessments of perceived restorativeness or atmosphere.

Hypothesis 2: Compared to lighting mode H, a combination of horizontal and vertical light (HV) will result in higher ratings in all investigated appraisals, i.e., in perceived lighting quality, visual accessibility, reassurance, restorativeness and atmosphere. A combination of horizontal, vertical and accent lighting (HVA) will result in even higher ratings of the appraisals. In other words, a linear increase from H, HV to HVA is expected for all investigated appraisals, with the exception of perceived atmosphere (hostile dimension), where instead a linear decrease is expected.

8.4.2 Method

A survey on users' environmental appraisals after dark of perceived lighting quality visual accessibility, reassurance, restorativeness and perceived atmosphere of the respective lighting modes was carried out.

The intervention utilized a between-subjects design and was carried out in two phases. A first phase evaluated the 'municipality intervention' (see Section 7.1), comparing the environmental appraisals between the two lighting modes with horizontal distribution-only RH and H; and in a second phase the 'spatial interventions' (see Section 7.2) were introduced; i.e., the investigation of environmental appraisals of lighting modes H, HV and HVA. The horizontal distribution was kept more or less constant, and vertical and accent lighting was added in increments. This set-up (a step-by-step model) draws on (Casciani 2020c).

Participants and settings

Participants were invited to assess the squares on-site. The sample comprises 177 participants, of which 49 assessed the reference mode (RH), and 128 assessed either of the intervention modes (H, HV and HVA). The sample is further described in Table 5.

A description of the lighting installation and photometric assessments of the respective lighting modes are provided in Chapter 7.

Measurements

Users' environmental appraisals after dark (of perceived lighting quality visual accessibility, reassurance, restorativeness and perceived atmosphere) of the respective lighting mode RH, H, HV and HVA were assessed using a questionnaire with established rating scales, and with an open-ended question for which participants could writhe descriptive narratives of their experience of the respective lighting modes.

An overview of individual items, response scales and the internal reliability of indices is provided in Appendix IV, Table A1.

To capture how participants appraised the respective lighting condition (DL or EL at each square), a seven-point bipolar semantic differential (SD) scale consisting of eight items was used (the Perceived Outdoor Quality scale (POLQ) (Johansson, Pedersen, et al. 2014). The participants' subjective experience of seeing – perceived visual accessibility – was captured with five items, and responses were rated on a five-point Likert scale (1=no, definitely not; 5=yes, definitely) (Johansson, Küller, and Rosén 2011). Participants' perceived reassurance was captured with seven items, and responses were rated on a five-point Likert scale (1=no, definitely not; 5=yes, definitely) (Blobaum and Hunecke 2005; Johansson, Küller, and Rosén 2011). Perceived restorativeness was assessed with seven items and responses were rated on a five-point Likert scale (1 = no, definitely not; 5 = yes, definitely), (a shortened version of the Perceived Restorativeness Scale (PRS) (Hartig et al. 1997). Finally, perceived atmosphere, with the sub-dimensions pleasant and hostile, was captured with 15 items, and responses were rated on a single item five-point Likert scale (1 = not at all; 5 = very much).

Procedure and analysis

Data on lighting mode RH were obtained from a data collection conducted during S3 in March 2022. Data of lighting modes H, HV and HVA were collected in S4 from 27 February to 23 March, 2023. Lighting modes H, HV and HVA were altered daily. Sampling sessions took place on weekdays from 18.30-20.00. Each session began with a brief on the background, procedures, and research ethics of the study.

Participants were instructed to walk around the setting (in Zone A) and reflect on how they perceived it before completing the questionnaire. To ascertain equivalent assessments, the viewing direction was marked with a triangle. The experimental setup with the assessment position is illustrated in Appendix IV, Figure 7.

Univariate ANOVAs were conducted to address the objective (O1) to test for differences (between subjects' effects) in users' environmental appraisals of POLQ, perceived visual accessibility, reassurance, restorativeness and atmosphere between lighting modes RH and H.

Univariate ANOVA tests for polynomial contrasts were conducted to address the objective (O2) to test for linear increase in the environmental appraisals of POLQ, perceived visual accessibility, reassurance, restorativeness and atmosphere, from lighting modes H, HV to HVA.

A qualitative assessment of users' descriptive narratives on how they experienced the square in the lighting modes H, HV and HVA, respectively, was conducted to address the objective (O3).

8.4.3 Results and conclusion

The results of the between-subject ANOVA, with lighting modes RH and H as independent variables and environmental appraisals as dependent variables, are provided in Appendix IV, Table 7. No significant effect of lighting modes was identified. Hence, a priori Hypothesis 1 was not confirmed, except the expectation of no improvements with regard to perceived restorativeness and atmosphere.

The results of the ANOVA testing for polynomial contrasts are provided in Appendix IV, Table 9. Significant linear increases were identified in the ratings of visual accessibility (F (1, 125) = 4.87, p = 0.03, $\eta_p^2 = 0.04$), restorativeness (F (1, 125) = 4.38, p = 0.04, $\eta_p^2 = 0.03$), and pleasant atmosphere (F (1, 125) = 6.54, p = 0.012, $\eta_p^2 = 0.05$) from H, HV to HVA. This aligns with the a priori Hypothesis 2, suggesting that a combination of horizontal and vertical light distribution (HV) and a combination of horizontal, vertical and accent lighting (HVA) compared to H shows a linear increase in the participants' ratings for these appraisals. With regard to reassurance, a tendency (F (1, 125) = 3.59, p = 0.06, $\eta_p^2 = 0.03$) in linear contrast was identified.

A qualitative assessment was conducted on users’ descriptive narratives of lighting modes H, HV and HVA. The response rates for the respective lighting modes were as follows (H: 69%; HV: 81%, and HVA: 94%). The following descriptors emerged for each lighting mode:

H: dark, boring, uneven, uninviting, uninteresting, and unsafe; HV: good visibility, bright, comfortable, safe, cosy, appreciative comments regarding the façade lighting, boring; HVA: Inviting, nice, pleasant, theatrical, positive comments regarding the façade, trees and sculpture, glary lampposts, negative comments regarding crime, noise from traffic etc.

S4 suggests that the change from lighting mode RH to H does not significantly contribute to environmental appraisals or pleasant atmosphere. However, with a purposeful lighting design, significant differences can be obtained, as shown by lighting mode HVA, which is perceived as more restorative, creating a more pleasant atmosphere, and providing better visual accessibility than HV and H.

9 Discussion

9.1 General Discussion

The overarching aim of thesis is to provide knowledge on the role of lighting in sustaining social interaction in public squares after dark.

A theoretical framework (deriving from the field of environmental psychology) on the modes of human-environment transactions (interpretative, evaluative, operative and responsive modes) (Stokols 1978) was employed to interpret the lighting-behaviour relationship in an environmental setting, here, two public squares in Malmö. Subsequently, the thesis proposes a socio-physical conceptual-model (see Figure 4) aimed at advancing the understanding of human-environment transactions in public squares after dark; that is transactions between the individual (user), the environmental setting (with social opportunities and physical properties, including lighting conditions) and behavioural outcomes.

Specifically, the thesis sought to investigate any association between spatial light characteristics, perceived atmosphere, and social interaction in public squares after dark.

9.1.1 The Socio-Physical Conceptual Model

The proposed conceptual model provided a 'roadmap' of aspects to consider when interpreting human-environment transactions in public squares after dark. It is argued that the model is reliable as an instrument due to its configuration (Stokols 1978), which is deeply rooted in the field of environmental psychology and builds on previous empirical research (Giuliani and Scopelliti 2009). Furthermore, the model was systematically applied across four field studies, helping to portray a holistic picture of human-environment transactions in public squares after dark by combining and inquiring into the key elements: the environmental setting, the environmental appraisals, and the behavioural outcomes. Theories (see Table 1) were employed instrumentally, adding to the understanding of each investigated element of the model.

The focus of the initial studies S1 and S2 was primarily on the behavioural outcome (operative mode), i.e., observable behaviour: movements, stationary activities and social interaction, and self-reported social interaction. While the survey S3 and the intervention S4 applied the environmental appraisal element of the model in relation to the lighting conditions of the environmental settings.

The field studies were conducted in two public neighbourhood squares, Kirseberg Square and Lindeborg Square, in Malmö, Sweden. The two squares were comparable cases due to their similarities in terms of functions, physical layouts, and programming (Dovey 2016), and as they accommodate similar user behaviour. However, their electric lighting conditions differ in terms of the light's spatial, spectral and intensity characteristics, resulting in dissimilar after dark impressions.

9.1.2 Behavioural Outcome in DL and in EL

The two observational studies, S1 and S2, investigated user behaviours (movements, stationary activities and social interaction) in DL and in EL in the two public squares, addressing objectives O1: To investigate *user behaviour*, in terms of *movements and stationary activities*, in daylight (DL) compared to in electric lighting (EL) after dark in two public squares with different lighting conditions, and to test whether any change in user behaviour could be attributed to the effect of change in ambient light level, and O2: To investigate *user behaviour* in terms of *social interaction* in DL compared to in EL after dark in two public squares with different lighting conditions.

It was found that spatiotemporal patterns of movements were sustained after dark in both squares. However, stationary activities and social interaction were not sustained in one square – Kirseberg – in the zone programmed for these activities. The luminous condition in this zone has low uniformity (U_o ~0.03) and high contrasts in luminance levels between dark and bright areas (two orders of magnitude in the ranges from 0.1-0.3 cd/m^2 to 1-20 cd/m^2). Stationary and social interaction were sustained in Lindeborg Square. This square has higher uniformity (U_o ~0.07) and the contrasts between dark and bright areas are less evident.

The findings of S1 suggest that the decrease in stationary activity in Kirseberg can be attributed to the effect of change in ambient light level. The after-dark lighting condition did not sustain the intended function of the zone. The 'dark spots' and imbalanced contrasts between bright and dark areas, supposedly affects users' sense of reassurance (Nasar and Fisher 1993) and cause people to refrain from visiting this zone of the square after dark (Rahm, Sternudd, and Johansson 2021).

Together, the findings from S1 and S2 indicated that spatial light distribution, which affects perceived uniformity and brightness, is an important characteristic for the impression of a square after dark. This supports previous findings (Nasar and Bokharaei 2016, 2017; Stokkermans et al. 2018; Veitch 2001). Spatial light distribution has previously been shown to affect perceived uniformity and brightness. These aspects in turn seemed to be associated with environmental preference.

The level of uniformity is associated to the degree of legibility and coherence (Casciani 2020a; Dovey 2016) and is therefore possibly associated with the preference for a setting (cf. the need to make sense) (Kaplan 1987). The level of uniformity determines whether the space is experienced as monotonous (uniform) or if it provides variability/interest (non-uniform) (Veitch 2001). According to Kaplan's environmental preference model (Kaplan 1987), the need to be involved in a setting is dependent on its degree of complexity and mystery. Supposedly, there is a fine differentiating line between what attributes of the environment are experienced as complex and mysterious, or frightening after dark.

Access and linkages to and from a square are crucial aspects in sustaining movements and therefore important for sustaining social interaction (Whyte 2001). Movements are often 'necessary' activities associated with basic needs such as shopping for groceries or picking up a child from day care. Facilitation of necessary activities and optional activities is crucial in supporting social life in public squares (Gehl 2006, 2010). In the cases of Kirseberg and Lindeborg it was shown that both squares accommodated movements after dark, but the patterns of stationary activities and social interaction were dissimilar after dark.

In S2 social interaction was operationalized in an objective and quantitative manner in order to establish whether spatiotemporal patterns of social interaction were sustained after dark. The study investigated the occurrences of visitors visiting the squares being alone, in pairs, or in groups of three or more. However, this operationalization of social interaction does not provide knowledge on the 'nature of social interaction' *per se*. The need to be accompanied by another after dark could also be an example of 'coping behaviour' in after-dark conditions (cf. responsive mode) (Stokols 1978), to be safe and feeling reassured (Fotios, Unwin, and Farrall 2015) when visiting the square.

S2 also investigated visitors' presence after dark between age groups. The findings suggested that teens in the Lindeborg neighbourhood were present in the square after dark; the square is their 'home turf'. Their spatiotemporal pattern of stationary activities and social interaction is sustained after dark. On the contrary, children and elderly individuals were more likely to be present in DL than in EL after dark in both squares.

9.1.3 Lighting conditions and environmental appraisals

The onsite-survey S3 addressed the objective, O3: to investigate the extent to which *environmental appraisals* are associated with self-reported social interaction in public squares after dark. The findings suggest that appraisals of perceived atmosphere may predict self-reported social interaction, and that perceived atmosphere is associated to perceived lighting quality, visual accessibility, and reassurance. While these findings might seem obvious from a design perspective, they are highly relevant to lighting practice since they offer strong arguments for implementation, and thus for stakeholders' investment in lighting design services and lighting solutions.

Specifically, the findings highlight the design criteria that should be met to support social interaction in public squares. Lighting in public squares should provide more than functional requirements for pedestrian movements (visual accessibility and reassurance) ensuring not only the access to and from the square, but indeed also enhance a pleasant atmosphere which can sustain stationary activities and social interaction. The findings from S3 are thus considered a key in interpreting the lighting-behaviour relationship in public squares.

The intervention study S4 addressed the objective O4: To investigate the influence of *spatial light distribution* on users' environmental appraisals in public squares after dark. Users' environmental appraisals (perceived outdoor lighting quality, perceived visual accessibility, reassurance, restorativeness and atmosphere) of three lighting conditions (lighting modes H, HV and HVA) in Kirseberg Square after dark were assessed and compared. The findings suggest that vertical illumination and accent lighting on structural elements (focal points and trees) are important for users' appraisals of perceived atmosphere, visual accessibility and restorativeness. This agrees with the theory of visual spatial boundaries (Wänström Lindh 2013) and also with theories on restorativeness (Kaplan 1995) and lighting (Nikunen and Korpela 2012).

On the whole, S3 thus suggests *which* lighting design criteria to address to support social interaction in public squares, and S4 indicates *how* to meet those criteria. The enhancement of atmosphere is an important design criteria possibly crucial for sustaining social interaction in public squares after dark. Qualitative methods could potentially be more suitable for investigating perceived atmosphere and capturing its essence. However, rigorous methods including technical assessments are needed to advance practice. The findings on atmosphere align with previous research, suggesting that spatial light distribution is an essential characteristic for perceived atmosphere (Stokkermans et al. 2017, 2018).

9.2 Strengths and limitations

A key strength of this research project is that all four studies were conducted as field studies in real-life settings, ensuring ecological validity and enabling generalization to other similar settings and contexts. Another strength is that the findings from the four studies may be interpreted individually as well as sequentially. The research project thus provides a holistic overview of the lighting-behaviour relationship in public squares after dark.

A strength of the project is that it adheres to the main domains of EP and lighting research, employing intrinsic and reliable methods, whilst also incorporating supporting domains (see Table 1) to provide a comprehensive socio-physical perspective.

One could shift perspective, however, and argue that the strength of this project lies in its limitations. S3 and S4, for instance, offer an overview of environmental appraisals that were demonstrated as important for sustaining social interaction in public squares after dark. However, in-depth knowledge and further investigations are needed for each of these environmental appraisals as they are applied and studied in the context of public squares. Further inquiries into the influence of light characteristics (spatial but most certainly also spectral) on users' environmental appraisals are also needed.

The quantitative methods used in S1 and S2 helped establish which user behaviour was – and was not – sustained. This also helped discern spatiotemporal patterns associated to both of the squares investigated.

One limitation of S2 was the quantitative operationalization of social interaction (see Appendix II), measuring the occurrences of people visiting the squares being alone, in pairs or in groups of three or larger. A qualitative observation (unconstrained) would potentially have resulted in a more accurate description of social interaction; that is, qualitative ethnographic studies should arguably be utilized to study the nature of social interaction.

One clear limitation of S4 was the duration of the temporary lighting installation (one month). A longer installation period would have allowed for observations to be carried out and to establish whether any changes in actual user behaviour had been effectuated due to the changes in spatial light distribution. Due to time- and cost restraints, however, this was not feasible for this project. A larger sample of participants would also have been preferable. In S4, a qualitative assessment of users' environmental appraisals was conducted based on participants' narratives of the respective lighting modes. Semi-structured interviews would have been preferable to this method, even superior, but this was not feasible for this project.

9.3 Environmental considerations

A sustainable approach to lighting, in accordance with the sustainable development goals (SDGs) of the United Nations (UN 2015), requires a holistic perspective with an informed understanding of the economic, the environmental and the social dimensions of sustainability. This thesis addressed SDG 11: to make cities and human settlements inclusive, safe, resilient and sustainable. The research project focused on the community level, targeting 11:7 – to provide universal access to safe, inclusive and accessible green and public spaces (UN 2015). This thesis also addressed SDG 3: to ensure healthy lives and promote well-being for everyone at all ages.

Sustainable lighting will fulfil users' needs, be cost- and energy efficient, and have minimal environmental impact (Jägerbrand 2020). The benefits of electric lighting (appropriately designed to sustain social life in urban environments after dark) are not without negative trade-offs for a sustainable development; these are associated with energy use (SDG 7), light pollution and negative impact on ecological systems (SDG 14 & 15). The balance between light and darkness must be carefully addressed (Hvass and Hansen 2022; Jägerbrand 2020; Tavares et al. 2021). In an urban environment such as a public square, considerations must be made in relation to e.g. energy performance, life-cycle assessment of products, programming of light levels, lighting control, avoiding obtrusive light into residential buildings, etc. Hence, spatial, spectral and intensity characteristics must be assessed to avoid glare and obtrusive light. Lighting design, especially with regards to spatial distribution, is one way of lowering energy consumption and costs. Balancing the luminance levels in a square, vertically and horizontally, may be a way to reduce energy and costs whilst enhancing visual accessibility and reassurance.

9.4 Implications for research

The proposed socio-physical conceptual model may be applicable to various environmental settings in the outdoor built environment. It forms a baseline for design of empirical studies and may be used for the stipulation of hypotheses and as an analytical tool to investigate the lighting-behaviour relationship. Operationalization of the model requires moving from a general to a specific level. Each element of the conceptual model may be studied separately, and the model can be combined with relevant validated instrumental theories specific to the setting in question.

A methodological approach that spans over multiple disciplines is required to understand the multifaceted aspects of life in public spaces, such as a public square.

Ethnographic methods would be useful for furthering knowledge on the role of lighting in sustaining social life in public spaces. To capture the nature of social interaction in public squares casual observations (un-systematic and un-constrained) are recommended (Sussman 2016). In-depth, semi-structured interviews (Robson and McCartan 2016) would provide a deeper foundation both for the study of environmental appraisals and for studying user behaviour (operative mode as well as responsive mode).

Lighting research should be incorporated into real-life projects to a greater extent and assess lighting interventions implemented by professional lighting designers.

9.5 Implications for practice

According to Böhme, 'illumination is an agent which produces atmospheres' (Böhme 2017). Essentially, lighting designers such as myself use their experience and technical and aesthetic expertise in the elaboration of spatial, spectral, intensity and temporal characteristics of light, aiming to affect perceptual attributes of light. This is how designers aim to achieve desirable impacts on the individual's task performance, health, well-being and behaviour in any chosen life-space (Veitch and Newsham 1998).

A key aspect in sustaining and supporting social life in public spaces after dark is indeed providing a desirable atmosphere. This thesis suggests that users' social interaction is dependent on their appraisal of a pleasant atmosphere, and in turn that this is intrinsically connected to visual accessibility and the feeling of reassurance after dark. Furthermore, the thesis establishes that spatial distribution of light, indeed working with vertical light to enhance appreciation of space, and the practice of accentuating organic structures and relevant structural elements, are important considerations when seeking to attune atmospheres. This thesis thus provides relevant arguments for lighting practice and for stakeholders such as municipalities to invest in lighting to accommodate social life in public space.

This thesis highlights design criteria that should be met in order to sustain social interaction after dark in public squares: the quality and visual comfort of light, the support of visual accessibility, the balancing of lighting levels in the visual field in order to ensure a feeling of reassurance (Hvass and Hansen 2022) (avoiding strong luminance contrasts in both horizontal and vertical planes; compare lighting mode RH in Kirseberg). This thesis advocates and supports the practice of illumination on the vertical plane, which is in line with earlier findings in both lighting design research (Wänström Lindh 2013) and lighting practice (Olaisen and Bredal 2022). As stated earlier, the balance between light and darkness should be carefully addressed in order to avoid light trespass and light pollution (Tavares et al. 2021). In the quest to meet users' needs and to socially enhance public space, the optimization of light levels should also be studied carefully to save energy.

9.6 Future research

In general, lighting research on exterior lighting in urban environments needs to focus on the human and social dimensions of lighting, i.e., address how lighting may support users' needs and social life after dark. Future research should inquire into how social interaction in public space is related to the facilitation of movements and to the support of stationary activities.

Lighting interventions in future research requires longer installation period to allow for any change in behaviours, i.e. in social interaction, to be assessed.

Future studies are needed on the influence of spatial light distribution on users' environmental appraisals, for instance, studies on how balanced lighting levels in the visual field may aid visual accessibility and reassurance. Methods to assess perceived brightness in relation to luminance levels in the visual field in public space should be developed further. Future research should seek to also advance knowledge about the influence of spectral light characteristics on social interaction in public space.

There is also a need to investigate users' responsive mode, such as coping behaviours, mood and well-being (Stokols 1978) in relation to lighting in public space.

9.7 Conclusion

This thesis reported on the role of lighting in sustaining social interaction in public squares after dark. It employed a transactional-contextual framework from environmental psychology that focuses on the dynamic interplay (transactions) between people and their environmental settings (context).

To further the understanding of human-environment transactions in public squares after dark, the thesis proposed a socio-physical conceptual model aimed at interpreting the lighting-behaviour relationship. The model stipulates that: individuals' environmental appraisal and therefore their behaviour is influenced by the lighting condition (in terms of spatial, spectral, intensity and temporal characteristics).

Specifically, the aim of this thesis was to provide knowledge on the association between spatial lighting characteristics, individuals' environmental appraisal of atmosphere in public squares after dark, and their behaviour in terms of social interaction.

The findings suggest that the design of electric lighting plays an essential role in sustaining spatiotemporal patterns of user behaviour, including movements, stationary activities and social interaction in public squares after dark. Moreover, the findings also propose that changes in stationary activities and social interaction are attributed to the effect of change in ambient light level between daylight and electric lighting conditions.

Survey data reveal that users' environmental appraisals of perceived lighting quality, visual accessibility, reassurance, and atmosphere were consistently rated higher in daylight than in electric lighting in both squares investigated. A key insight from the survey is the link between the perceived atmosphere after dark and users' self-reported social interaction. These findings underline the importance of attuning atmosphere after dark to sustain social interaction.

Results from the lighting intervention, S4, suggest that spatial light characteristics are crucial for individuals' appreciation of space and for their perceived atmosphere. The results propose that a carefully managed balance of luminance across the visual field enhances both the aesthetic and functional qualities of a square, contributing positively to the perception of atmosphere.

The thesis concludes that while social interaction in public squares after dark can indeed be sustained with electric lighting, the scope of lighting design should extend beyond basic needs for visual accessibility and reassurance and also consider attuning atmospheres. It appears that the balance between horizontal and vertical luminance levels is an important aspect of a lighting scheme.

Given the potential negative consequences of lighting – related to energy consumption, light pollution, and ecological impacts – future studies on lighting in public squares should also focus on optimizing spatial distribution of light in ways that balance social benefits with environmental responsibility. Integrating strategies to reduce energy use, minimize costs, and prevent intrusive light pollution will ensure that lighting contributes positively to sustainable urban environments.

10 Sammanfattning

Offentliga torg i områdescentra utgör viktiga platser för social interaktion och kan därmed bidra till människors känsla av samhörighet, livskvalitet, välmående och hälsa. En hållbar urban utveckling av städer och samhällen förutsätter att boende i bostadsområden har tillgång till trygga, tillgängliga och inkluderande offentliga torg, där människor möts och sociala band stärks.

Artificiell belysning utgör en förutsättning för att bibehålla mänsklig aktivitet i offentlig urban miljö under dygnets mörka timmar. Belysningen stödjer mänskliga behov såsom tillgänglighet, trygghet, komfort och kan även skapa en attraktiv atmosfär i människors vardag och för psykologisk återhämtning. Att supportera dessa behov är avgörande för fotgängares och cyklisters mobilitet, för bibehållen stationär aktivitet och för att främja social interaktion på offentliga torg.

I länder på nordliga breddgrader, där dagsljuset är begränsat under vintersäsongen, är utformningen av det artificiella ljuset avgörande för att främja socialt liv på offentliga torg efter mörkrets inbrott.

Idag är förståelsen för hur ljussättning inverkar på människors upplevelser av offentlig miljö (så som offentliga torg i områdescentra) i mörker begränsad, samt vilken inverkan deras upplevelser har för olika beteenden efter mörkrets inbrott. Det finns ett starkt incitament för att öka kunskapen om hur specifika ljusförhållanden inverkar på mobila och stationära beteenden, samt hur de bidrar till att stärka social interaktion på offentliga torg efter mörkrets inbrott.

Den här avhandlingen syftar till att öka kunskapen om sambandet mellan ljusförhållanden, människors miljöupplevelse och beteenden på offentliga torg efter mörkrets inbrott. Specifikt syftar avhandlingen till att undersöka sambandet mellan spatiala ljusförhållanden, upplevd atmosfär och social interaktion på offentliga torg i områdescentra efter mörkrets inbrott.

Ett socio-fysiskt teoretiskt perspektiv tillämpades för att för att tolka sambandet mellan ljusförhållanden, miljöupplevelse och beteende. En socio-fysisk konceptuell modell utvecklades i syfte att fördjupa vår förståelse för hur specifika spatiala ljusförhållanden inverkar på människa-miljötransaktioner på torg efter mörkrets inbrott. Modellen baseras på miljö-psykologisk teori (ett så kallat transaktionellt-kontextuellt perspektiv) om människa-miljötransaktioner samt en litteratur studie om offentliga platser och offentligt liv i urban miljö, belysningsforskning samt urban sociologi. Modellen föreslår att individens miljöupplevelse och därmed hens beteende är beroende av ljusförhållandet på ett torg efter mörkrets inbrott.

Den konceptuella modellen applicerades i fyra empiriska fält-studier, på två offentliga torg med distinkt olika ljusförhållanden (spektrala, spatiala egenskaper samt avseende ljusets intensitet) i två bostadsområden, Kirseberg och Lindeborg, i Malmö, Sverige.

Två observationsstudier (S1 och S2) - vilka jämförde förhållandena i dagsljus och i artificiellt ljus vid samma tid på dygnet - påvisade att mobila beteenden (t.ex. gå och cykla) var bibehållna på båda torgen medan stationära beteenden (t.ex. stå och sitta) och social interaktion minskade på ett av torgen (Kirsebergs torg) på den del av torget som designats för denna funktion. De befintliga ljusförhållandena på Kirsebergs torg, med asymmetriska armaturer bestyckade med metallhalogen, ger starka kontraster mellan ljus och mörker i jämförelse med Lindeborgs torg, där rotationssymmetriska parkarmaturer bestyckade med högtrycksnatrium ger ett betydligt diffusare och jämnare ljus. Se kapitel 6, avsnitt 6.2 samt 6.3.

S1 påvisade att förändringen i fråga om stationära beteenden vid en jämförelse mellan dagsljus och artificiellt ljus, kunde tillskrivas effekten i ljusförändring.

En enkätstudie (S3) - vilken jämförde torgbesökares miljöupplevelser i form av upplevd ljuskvalitet, ljus-komfort, visuell tillgänglighet, trygghet och atmosfär i dagsljus och i artificiellt ljus - visade en signifikant förändring avseende alla upplevda aspekter. I denna studie påvisades ett viktigt samband mellan självrapporterad social interaktion och upplevelsen av en trivsam atmosfär i artificiellt ljus efter mörkrets inbrott.

En interventionsstudie (S4) - vilken undersökte sambandet mellan spatiala belysningsförhållanden och torgbesökarnas miljöupplevelser - visade en linjär förbättring av upplevd visuell tillgänglighet, trygghet, psykologisk återhämtning samt en trivsam atmosfär, när tre olika spatiala förhållanden jämfördes. Metoden byggde på en tidigare studie inom ljusdesign-forskning (Casciani 2020c), där tre spatiala ljusförhållanden jämförs: enbart horisontellt riktat ljus (H), horisontellt ljus i kombination med vertikalt riktat ljus (HV) samt en kombination med horisontellt, vertikalt och accentljus (HVA). Det belysningsförhållande på torget där horisontell belysning kombinerades med vertikal belysning på fasad och accentbelysning på träd och skulptur (HVA) var det scenario där miljöupplevelser skattades högst av torgbesökarna. En möjlig tolkning av dessa resultat är ljusets kontraster balanseras genom kombinationen av horisontellt och vertikalt ljus, vilket därmed ökar visuell tillgänglighet, trygghet, och upplevelsen av atmosfär. Ljus på fasader skapar en rumslighet, vilken tycks vara essentiell för stadens olika offentliga rum. Resultaten stöttar tidigare forskning, som påvisar att ljusets spatiala distribution är avgörande för upplevelsen av rumslighet samt upplevd atmosfär (Wänström Lindh 2013).

Avhandlingen påvisar att det finns ett samband mellan rumsliga ljusförhållanden på offentliga torg och torgbesökares sociala interaktion efter mörkrets inbrott.

I praktisk tillämplig av professionella ljusplanerare kan detta ses som uppenbart - en självklarhet. Denna avhandling bidrar med argument som påvisar att ljusförhållandena vid ett torg efter mörkrets inbrott är avgörande för att stötta socialt liv. Där av, stärks även de ekonomiska incitamenten till att satsa på välplanerad belysning.

Artificiell belysning som tillvaratar mänskliga behov som visuell tillgänglighet, trygghet, som ger förutsättningar för återhämtning och som skapar atmosfär åt offentliga torg ger goda försättningar för social hållbarhet.

De positiva sociala aspekter som en god ljusplanering av offentliga torg kan medföra måste ses i förhållande till eventuella negativa miljökonsekvenser ifråga om ljusförorening, energiförbrukning, hälsoaspekter, biodiversitet etc.

Praktisk tillämpning inom ljusdesign förespråkar att det finns stor en potential i att arbeta med ljusets spatiala fördelning (balans mellan vertikalt och horisontellt ljus) för att spara energi (Olaisen and Bredal 2022). Framtida forskning avseende ljusets spatiala fördelning i urban miljö bör fokusera på denna potential. Forskningsmetodik som i större grad integrerar praktik bör eftersträvas.

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Appendices I-IV

Appendix I

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The Society of Light and Lighting

User behaviour in public squares after dark

VKR Hennig MSc[a], **N Gentile** PhD[b], **S Fotios** PhD[c], **C Sternudd** PhD[a] and **M Johansson** PhD[a]

[a]Department of Architecture and Built Environment, Lund University, Lund, Sweden
[b]Department of Building and Environmental Technology, Lund University, Lund, Sweden
[c]School of Architecture, The University of Sheffield, Sheffield, UK

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This research concerns the influence of electric lighting on user behaviour in public squares and whether differences in people's use of the square can be observed between daylight and darkness. Previous research on pedestrians suggests that lighting can support human needs for reassurance, accessibility, comfort and pleasure. While these findings are also likely to be applicable to the use of public squares, there is little empirical evidence to verify that. A field study was conducted to explore user behaviour in two differently illuminated public squares. Observations of the movements and stationary activities of people in the squares were recorded at both squares for the same times of day in the weeks before and after the daylight savings clock change, enabling a comparison of activity in daylight and after dark. 5296 observations were recorded and lighting conditions were captured with HDR-photography and aerial photos. Kirseberg square, with asymmetric luminaires and metal halide lamps, revealed a decrease in stationary activity after dark. Lindeborg square, with omnidirectional luminaires and high-pressure sodium lamps, revealed an increase in stationary activity. In conclusion, the patterns of user behaviour in the two public squares after dark seem to be differently influenced by electric lighting, pointing to a need for further understanding of users' experience of the squares after dark.

1. Introduction

The United Nations *New Urban Agenda*[1] and the Habitat III policy paper I *The Right To The City And Cities For All*[2] envisage the right of people to safe and healthy habitats, including the right to fully enjoy the city with its sufficient, accessible and quality public spaces. Public spaces are here defined as publicly accessible spaces, such as parks, streets and squares.[3] At their best, public spaces are 'sites of civic promise',[4] supporting the quality of life[3,5] and wellbeing of individuals.[6,7] Good public spaces are accessible and open, meaningful in their design and the activities and behaviour they support, and provide a sense of safety, comfort and pleasure.[3,8] Electric lighting may support function and amenity[9] and encourage use after dark.[8,10]

This paper specifically concerns local public squares i.e. squares that constitute users' everyday life spaces in their respective neighbourhood (hereafter referred to as 'squares').[3,11] The square typically includes different functional zones such as paths to reach destinations and seating spaces for contemplation or socialisation.[12] The focus of the

Address for correspondence: VKR Hennig, Department of Architecture and Built Environment, Lund University, Box 18, Lund, SE-221 00, Sweden.
E-mail:katarina.hennig@abm.lth.se

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research presented here is on the movements and stationary activities[13] that occur in this specific physical setting in a given time frame i.e. behaviours with spatio-temporal patterns.[14,15]

Research on squares is multidisciplinary.[16,17] Architects and urban designers have investigated the association between square attributes and their use.[3,13,18–20] It has been shown that well-frequented squares are distinguished by having recognizable and comprehensive physical features,[19] which resonates with users' needs not only for movement but also stationary activities,[3] by providing adequate seating, trees and favourable wind and light conditions.[12,18]

Scholars within the fields of public life studies and urban sociology have stressed the importance of defining how people use squares, and therefore employed methods for observing how users move and stay to participate in social activities.[11,20–25] In squares with appropriate physical characteristics, user activities tend to grow in number, duration and scope.[13]

Research on exterior electric lighting has largely focused on performance and requirements for urban infrastructure designed for transportation (roads, cycle and pedestrian paths).[10] The square is, however, intentionally designed to support social interaction in the local community.[20,26] It needs to be experienced as a comfortable and safe place where one likes to stay and spend time, which requires an atmosphere for social interaction and associated stationary activities. Consequently, it is important to further the understanding of the role of electric lighting in squares that include functional zones designed with the intention to sustain user behaviour of movements and stationary activities after dark.

1.1 Framework for user behaviour in public squares

By adopting a transactional-contextual perspective on the human–environment behaviour relationship, we suggest that there is a dynamic interplay between people and their environmental setting.[15] This study focuses on the users' operative mode i.e. observable behaviour,[27] operationalised as movements and stationary activities as depicted in Figure 1[25] and spatial use i.e. how behaviours relate to functional units of the square in daylight compared to after dark in electric lighting. User behaviour is viewed in its socio-physical and temporal context,[15] that in our case is a local public square set within the social realm of a neighbourhood and its associated behavioural patterns. Moreover, user behaviour is considered to be partly derived from the person's environmental perception as guided by individual characteristics, past experiences and expectation.[28]

Squares tend to have physical limits and characteristics that can impede or facilitate users' behaviour. A behaviour such as taking a seat and chatting with a neighbour is affected by the physical opportunities that exist in the square,[15] as mediated by environmental perception, affective and cognitive processes;[29] for example, seats perceived to enable socially comfortable sitting on a sunny afternoon might affect tranquillity, excitement or pleasure and may therefore invite the user for participation.[18]

We employ the typology of 'necessary' versus 'optional' activities, where stationary activities to a greater extent are optional in nature.[25,30] Necessary activities are more-or-less compulsory (such as shopping for groceries), whereas optional activities are voluntary (such as taking a stroll or sitting sunbathing) and more likely influenced by physical conditions.[13] Whenever necessary and optional activities are given better conditions in a public space, social life is also indirectly supported.[13] Previous studies (which were performed in daytime) suggest that optional behaviours are largely dependent on the physical conditions, mediated by an appropriate design[21]

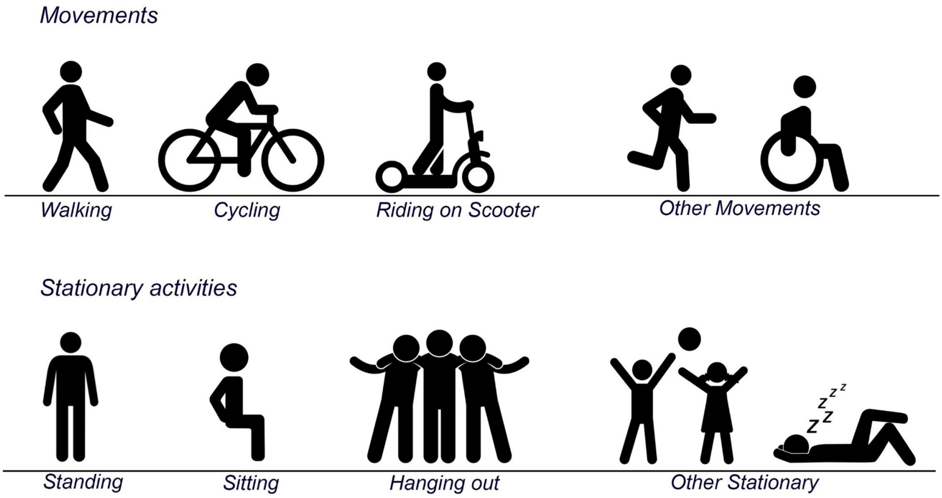

Figure 1 Pictograms, movements with the subcategories of behaviour (walking, cycling, riding on scooter and other movements), stationary activities with the subcategories of behaviour (standing, sitting, hanging out and other stationary)

and perceived affordances.[31] Where the user-experience is a 'good' one, people are more likely to stay.[8] User behaviour in terms of sustained movements and stationary activities, might however differ between daylight conditions and electric lighting.

1.2 Performance of a square after dark

The facilitation of user behaviour in squares is mediated by experiential factors such as the perceived access and linkage, activities and uses, comfort and sociability, amongst other factors.[12] Arguably, these factors are as important in daylight as after dark, but for several reasons such experiential factors may differ between daylight and electric light. The perception and appreciation of a space in daylight, which typically implies photopic conditions of vision, allows for both colour vision and fine resolution. Critical characteristics of daylight include variability in illuminance (ranging from about 1000 lx to 100 000 lx), variability in cloud cover (from completely overcast to clear skies, changing with latitude, season and time of day) and solar geometry, and hence variability in the directionality, varying correlated colour temperature (CCT), and spatial distribution.[32] After the sun sets, the portrayal of spatial properties alters. In electric light, illuminances are much lower, meaning that the visual system operates in mesopic conditions with reduced colour vision and resolution.[32] Temporal variation in directionality and spatial distribution are largely absent. Therefore, features in a space such as trees, sculptures as well as features of people, will be differently modelled between daylight and electric light, and between electric lighting designs of different after-dark uniformity. Thus, the way users perceive, interpret and behave in a square after dark may be influenced by the design choices for electric lighting.[33]

A discrepancy in users' perception, and thus experiential factors, between daylight and electric light may have different consequences to the performance of spaces designed for movements as compared to spaces designed for stationary activities. Footpaths have been systematically examined with regard to pedestrians' movement,[10,34] and their ability to move safely is essentially a matter of visual performance involving the visual tasks of orientation, obstacle detection and facial recognition.[35–37] Walkability[36,38] and reassurance i.e. the confidence a pedestrian might gain from lighting when walking along a footpath after dark,[39–45] is a prerequisite for access and linkages and thus for the potential use of a square.[12] A hierarchical order has been proposed with appraisals of feasibility, accessibility and safety (or reassurance) as fundamental to walking, and comfort and pleasure as facilitating walking.[38,46]

Stationary activities are likely to be more dependent on the portrayal of space and perceived affordances.[31,47] Light has emotional connotations,[48] and therefore the role of lighting in spaces programmed for stationary activities in a square is also to enhance a comfortable and pleasurable atmosphere.[9,49] Changes in light distribution, light level, contrast, uniformity and spectral power distribution will affect spatial brightness[50–54] and appreciation of the scene.[9,53,55–57] In directing the eye and providing brightness transitions through the space,[58] by revealing shape, texture and colour, the atmosphere of a space is generated.[59,60] So far, preference assessments of 3D-visualisations have demonstrated that the appeal of squares after dark is associated with different lighting modes.[61,62] Thus, lighting may present a powerful tool to enhance also areas programmed for stationary activities and thereby vitalize squares.[8,10]

1.3 Aim

The aim of this study is to investigate user behaviour and spatial use in two local public squares, each having a different lighting installation, and to assess if these behaviours change when the squares are lit by daylight as compared to electric lighting. To offset other factors, this comparison is made for the same times of day using the biannual daylight savings clock change.

The objectives are:

1. To describe the types and the occurrences of movements and stationary activities in local public squares in daylight compared to after dark with electric lighting.
2. To compare the spatial use across different functional zones in local public squares.
3. To test if any change in movements and stationary activities can be attributed to the effect of change in ambient light.

2. Method

2.1 Observations

Structured observations[63] of users were carried out at two local public squares in different neighbourhood centres in Malmö, Sweden. Observations were performed with a scan-sampling technique[64] recording cases consisting of both events (e.g. a sequence of a movement and a stationary activity such as a male adult is walking and takes a seat) and states (e.g. a stationary activity such as an elderly female is sitting), as shown in Figure 2. During sampling, users were visually classified by apparent gender and by apparent age into four different approximate age groups: children (0–12 years), teens (13–19 years), adults (20–60 years) and elderly (above 60 years). Observations were reported in a coding scheme, which employed predefined types of behaviour in two main categories: movements and stationary activities, which were inspired by behaviour previously identified in the area of public life studies.[25] A pilot study was carried out over a 2-week period in late

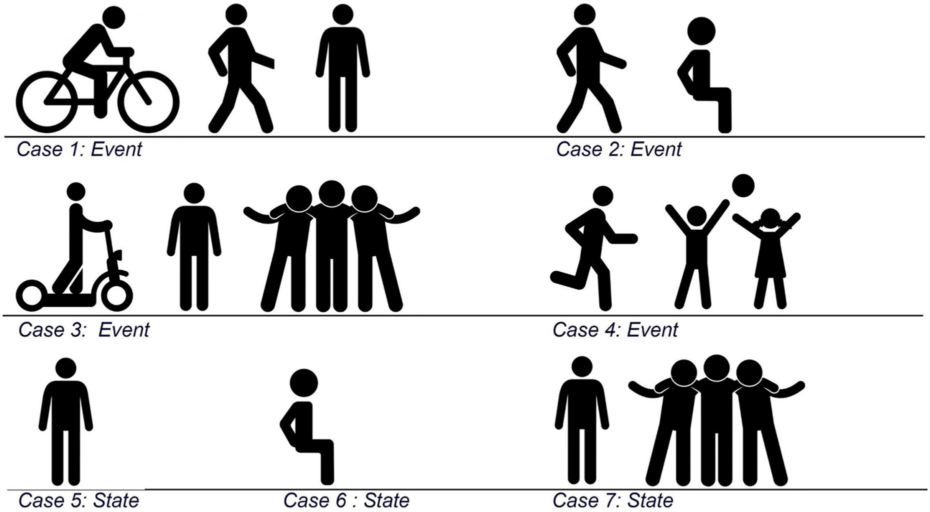

Figure 2 Pictograms of examples of cases illustrating the scan-sampling technique with different type of events (instantaneous sequence of behaviours) and states (a behaviour of appreciable duration). Case 1 – a person is cycling then walking and then standing; Case 2 – a person is walking and takes a seat; Case 3 – a person arrives with a scooter then stands and hansgout; Case 4 – a person is running and thereafter playing; Case 5 – a person is standing; Case 6 – a person is sitting; Case 7 – a person is standing and hanging out

summer 2020, to confirm which type of behaviours take place at the specific squares. This pilot study suggested that the coding scheme was sufficient to characterise all movements and stationary activities observed in the squares.

The coding scheme, as shown in Figure 1, consists of binary categorical data on types of movements including walking, cycling, riding on scooter and other movements and types of stationary activities comprising standing, sitting, hanging out and other stationary. To hang out was defined as 'to spend time idly, relaxing or socializing' with another.[65] To test inter-observer reliability the coding scheme was tested in field, revised and verified again by three observers.

2.2 Data collection

Data were collected during two weeks before and two weeks after the autumn 2020 daylight savings clock change, to enable a comparison of activity in daylight and after dark for the same times of the day. Time-of-day factor and seasonal factors where thus held sufficiently constant to isolate the effect of change in ambient light level.[66] In each of the data collection periods, observations were carried out on six days; distributed over two weekdays and one weekend-day per square. Each day included two observation sessions, each of these consisted of two timeslots with a duration of 45 min (Figure 3). Timeslots 1 and 2 took place in the afternoon at 15:30–16:15

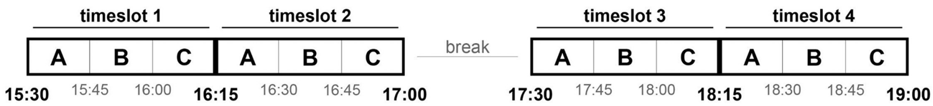

Figure 3 Data collection procedure during a day. Each timeslot includes 15 min in each sampling unit

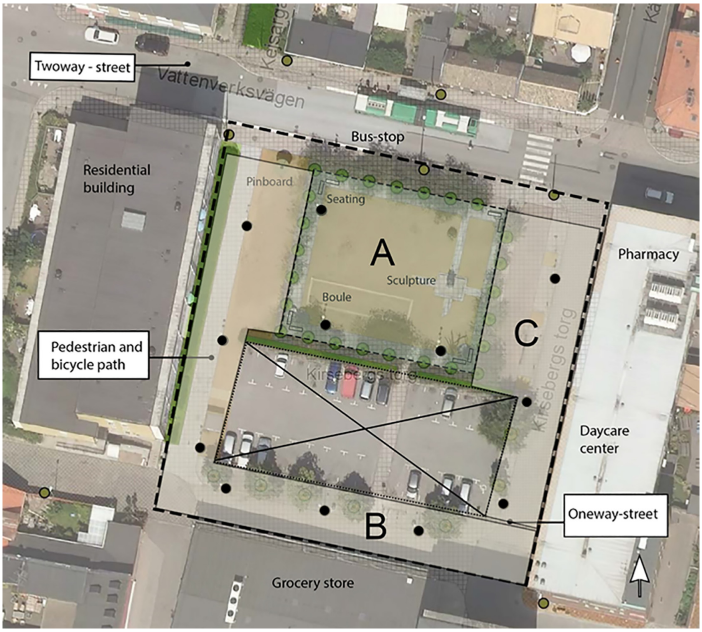

Figure 4 Plan of Kirseberg square. Sampling units (zones) are indicated with A, B and C. Black dots symbolize lamp posts

and 16:15–17:00 and timeslots 3 and 4 took place in the early evening at 17:30–18:15 and 18:15–19:00. Observations were conducted for 18 h within each square.

The squares were divided by the observer (author VKRH) into three sampling units (zones A, B and C) on the basis of its intended function (its programmed design[3,67]) and spatial setting. In each square, zone A is a designated social area for stationary activities, B is a combined commercial area and path and C is a designated path (Figures 4 and 5). The sampling units covered the whole of each square. Each observation session started in zone A, with a rotation between zones taking place every 15 min, allowing for six rotations in 90 min. The recording also noted the conditions in

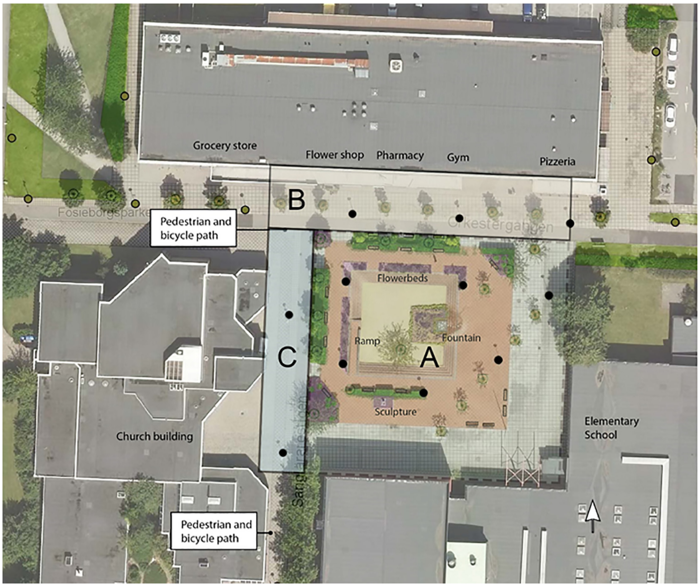

Figure 5 Plan of Lindeborg square. Sampling units (zones) are indicated with A, B and C. Black dots symbolize lamp posts

which observations were made; air-temperature, precipitation, vegetation, sky-condition and whether lights were switched on or off.

2.3 Settings

The two squares in which observations were conducted both serve as a central area of their respective neighbourhoods of Kirseberg and Lindeborg and are of similar size (surface area) and include similar spatial zones with programmed design for movements and stationary activities. However, the lighting installations are not similar, having differences in the spatial light distribution, illuminance uniformity, contrasts and spectral characteristics as defined using CCT, the CIE general colour rendering index (CRI) and the Scotopic/Photopic (S/P) luminance ratio. The two squares and the lighting installations are further described below.

2.3.1 Kirseberg square

Kirseberg in northern Malmö, Sweden, has approximately 6000 inhabitants. The square, described in Figure 4 and Table 1, has an area of approximately 3100 m^2. It has a parking area to the south, an area for stationary occupancy of approximately 700 m^2 to the north (zone A), with a boule court, a sculpture, two benches in each corner and soft-scape of trees and bushes. A pedestrian route runs along the commercial area and along the west side (zone B). Motorised vehicles, limited to a one-way direction, are mixed with pedestrians and cyclists in the east (zone C). The enclosing buildings were constructed in the 1960s.[68] A residential building flanks the west side. Services available within the square are a children's day care, a pharmacy and a food chain store.

Table 1 Description of squares and sampling units (zone A, B and C) in terms of function, hardscape and soft scape

Location	Function	Hardscape/Features	Facades	Seats	Soft scape
Kirseberg square					
Zone A	Stationary area	Gravel/Sculpture	–	8	Trees: Cherry trees –*Prunus ssp*. Trees: Lime – *Tilia cordata* Bushes: Rose bushes – *Rosa ssp*. Additional pots with flowers
Zone B	Commercial/path	Light concrete slabs	Shop windows	None	Trees: Lime – *Tilia cordata*
Zone C	Path/service	Light concrete stones	Dark brick wall	None	
Lindeborg square					
Zone A	Stationary area	Red bricks/gravel/water feature	Red brick wall	13	Trees: Lime – *Tilia cordata* Trees: Cherry trees – *Prunus ssp*. Composed perennial flowerbeds
Zone B	Commercial/path	Asphalt/light concrete slabs	Shop windows	3	Hedges: Beech – *Fagus sylvatica* Trees: Lime – *Tilia cordata*
Zone C	Path/service	Asphalt	Red brick wall	None	Composed perennial flowerbeds

Kirseberg square has 12 lamp posts, 3.7 m high: the locations are shown in Figure 4. Double reflector-luminaires with asymmetric light distribution are fitted with 2 × 70 W metal halide lamps (MH). The sculpture in zone A is lit with a spotlight with a 150 W, high-pressure sodium lamp (HPS). Shop-windows in zones B and C contribute to illumination in these areas. Windows in the residential building give a lit impression to the vertical surface. Lamp and luminaire types are shown in Tables 2 and 3. The lighting installation layout is shown in Supplemental Figure S1.

2.3.2 Lindeborg square

Lindeborg in southern Malmö has approximately 5000 inhabitants.[69] The square, described in Figure 5 and Table 1, has an area of approximately 3100 m^2. The designated area for stationary occupancy is approximately 1300 m^2 (zone A). The soft-scape includes trees, hedges and flowerbeds, seating and a water-feature. A pedestrian and bicycle path runs along the north with access to the commercial building (zone B). There is also a pedestrian and bicycle path along the west side (zone C). The neighbourhood centre was constructed in the 1970s and hosts different commercial services, an elementary school and a church.[70]

Lindeborg square has 11 lamp posts, 4.2 m high, located as shown in Figure 5, spaced at a distance of 20 m along the paths in B and C and in an arrangement to accompany the flowerbeds and seating in zone A. The lanterns are omnidirectional with opal diffusers and fitted with 70 W, HPS. The light setting in Lindeborg results in a visual scene with warm ambiance, poor colour rendering and a diffuse light distribution in zones A and B. The path in zone C is lit with MH lamps, which gives higher light levels and cooler appearance locally. The shop windows in zone B and linear fluorescent tubes cause substantial contrasts in the visual scene. Lamp and luminaire types are shown in Tables 2 and 3. The lighting installation layout is shown in Supplemental Figure S2.

2.4 Photometric assessment

A photometric assessment of the electric lighting scenario at each square was carried out as follows:

Table 2 Lighting installations: Description of lamp types for the two squares as reported by the manufacturer

Lamp type		Qty.	Luminous flux (lm)	CCT (K)	CRI (R_a)	S/P ratio
Kirseberg square						
MH	CDO-ET 70W/828	2 × 12	7030	2800	84	1.3
HPS	HST-DE 150 W	1	15000	2000	25	0.5
Lindeborg square						
MH	CDO-ET 70W/828	2	7030	2800	84	1.3
HPS	SON Pia Plus 70W	9	6000	2000	25	0.5

MH: metal halide lamps; HPS: high-pressure sodium lamp.

Table 3 Lighting installations: Description of luminaire types for the two squares as reported by the manufacturer

Luminaire type		Height	Qty.	Light distribution	Optic	Shielded
Kirseberg square						
Road luminaire	Philips, Copenhagen	3.7 m	2 × 12	Asymmetric	Reflector	Upwards
Spotlight	SILL, Plane-projector	–	1	Rot. symmetric	Reflector	Lamellas
Lindeborg square						
Park lantern	DEFA, Helena	4.2 m	11	Omni directional	Opal diffuser	Glare rings

1. Horizontal illuminances were measured at ground level across the squares, with a grid size of 3 m × 3 m in compliance with SS-EN 12464-2:2014.
2. Horizontal illuminances were measured at ground level on designated footpaths in compliance with SS-EN 13201-3:2016.
3. High-dynamic range (HDR) images of visual scenes were captured for viewpoints assumed to be vital and converted into luminance maps calibrated against a luminance spot measurement using a diffusive cardboard placed in each of the viewpoints.

The instruments used for these three sets of measurements were a Hagner E4-X (Solna, Sweden) illuminance meter with SD2 external detector, a Hagner S4 (Solna, Sweden) luminance meter and a calibrated Techno Team LMK Canon EOS 550D HDR camera (Illmenau, Germany).

2.5 Data analysis

For each square, frequency analysis was used to establish the occurrence of different types of behaviour within the two behavioural categories movements and stationary activities and the distribution of behaviour across the three spatial units. These analyses are based on the total dataset i.e. all four timeslots, see Figure 3. Pearson's chi-square test was performed to test for differences between:

1. Daylight (DL) or electric lighting (EL) within category of behaviour during all timeslots i.e. aggregated data for all observations.
2. Spatial use of the different zones i.e. to reveal if movements and stationary activities are related to the different functional zones.

The general level of significance was set to $p \leqslant 0.05$. In analyses including multiple

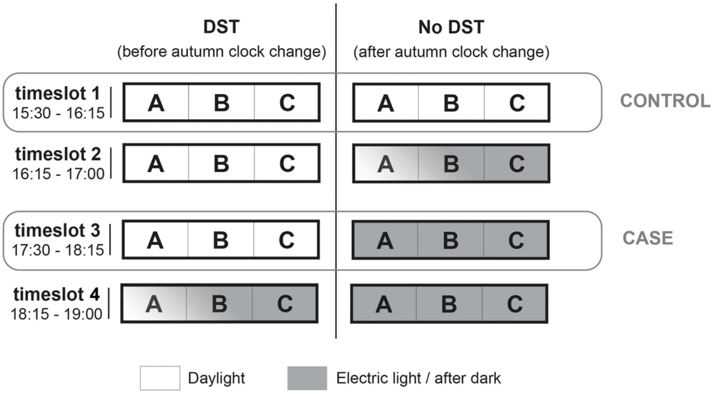

Figure 6 Selection of timeslots for the OR analyses.
DST: daylight saving time

comparisons, the Bonferroni-corrected level of significance was used.

For each square, an odds ratio (OR) analysis was performed to investigate if changes in frequency of behaviours were associated with the change in ambient light before and after clock change. During each recorded observation, the status of EL (on–off) was noted. This information was used to filter the recorded observations, assuming 'electric lighting off' for observations in daylight and 'electric lighting on' for observations after dark. To ensure consistency in the dataset, the analysis included only timeslots where the totality of observations were either during daylight or after dark. These timeslots resulted to be the first 15:30–16:15 (control period, with daylight before and after clock change) and the third 17:30–18:15 (case period, with daylight before clock change but dark after clock change) (Figure 6).

The OR defined by Equation (1) was used to examine the effect of ambient light on the frequencies of occurrence for each specific category of behaviour. ORs higher than 1 indicate higher likelihood that a certain behaviour occurs in daylight rather than in electric light. An OR of 1.0 indicates no difference in frequency of behaviour between daylight and electric light.

$$R_{\text{odds}} = \frac{\left(\dfrac{B_{3,\,\text{DL},\,\text{DST}}}{B_{3,\,\text{EL},\,\text{no DST}}}\right)}{\left(\dfrac{B_{1,\,\text{DL},\,\text{DST}}}{B_{1,\,\text{DL},\,\text{no DST}}}\right)} \tag{1}$$

where B_1 is the frequency of behaviour in timeslot 1 and B_3 is the frequency of behaviour in timeslot 3 and the other subscripts DL, EL, daylight saving time (DST) and no DST are as already defined.

The 95% confidence intervals were calculated using Equation (2).

$$95\%\,\text{CI} = \exp(\log(R_{\text{odds}})) \pm 1.96 \times \text{SE}(\log(R_{\text{odds}})) \tag{2}$$

where the standard error (SE) of the log OR is defined as being:

Table 4 Measurements of horizontal illuminance at ground level and uniformity of illuminance

Zone	$\bar{E}$(lx)	E_{min} (lx)	U_o	Class
Kirseberg square				
All	23.4	0.6	0.03	
Path B	35.9	8.9	0.25*	P1
Path C	25.5	6.5	0.26*	C2
Lindeborg square				
All	5.8	0.4	0.07	
Path B	7.1	3.9	0.55	P4
Path C	11.1	4.7	0.42	P2

*U_o lower than the recommended value in SS-EN 13201-2:2016.

$$\mathrm{SE}(\log(R_{\mathrm{odds}})) = \sqrt{\frac{1}{B_{3,\mathrm{DL,DST}}}+\frac{1}{B_{3,\mathrm{EL,noDST}}}+\frac{1}{B_{1,\mathrm{DL,DST}}}+\frac{1}{B_{1,\mathrm{DL,noDST}}}}$$

3. Results

3.1 Photometric assessment

3.1.1 Kirseberg square

Horizontal illuminances across Kirseberg square, shown in Table 4, have an average of $\bar{E}=23.4$ lx and a uniformity of $U_o=0.03$. The paths in zone B and zone C, Figure 7, have illuminance levels above required average maintained levels of class P1, in SS-EN 13201-2:2016, for pedestrians and cyclists. However, uniformity levels are lower than recommended (the average illuminance exceeds 1.5 times the minimum) for this class.

Luminance maps for zones at Kirseberg square portray large contrasts on the ground level in zone A, with luminance ranging from 0.1 cd/m^2 to 20 cd/m^2, but less contrasts in zone B and zone C, Figure 7.

3.1.2 Lindeborg square

Measurements of horizontal illuminances across Lindeborg square, shown in Table 4, have an average of $\bar{E}=5.8$ lx and a uniformity of $U_o=0.07$. In comparison, lighting levels are substantially lower than Kirseberg square. Contrasts between bright and dark areas are less evident at the horizontal ground level. The horizontal illuminance levels and uniformity on paths in zone B and zone C, comply with P2 and P4 classes in SS-EN 13201-2:2016.

Luminance maps depict a visual scene in zones A and B with diffuse light distribution from the lanterns, poor modelling of hedges, curb stones and objects, poor colour rendering due to HPS lamps resulting in distorted colours of plant materials, Figure 8. In zone C, the MH lamps give a cooler temperature and grey depiction of concrete slabs and asphalt, Figure 8.

3.2 Behaviour in DL and in EL

In total, 5296 observations were sampled at both squares. Tables 5 and 6 show the results of the frequency analysis and the results of Pearson's chi-square tests for each type of behaviour within the categories, movements and stationary activities, in daylight compared to electric light during all timeslots for the squares. Walking was the most frequent type of movement observed in both squares. Kirseberg displayed higher rates of walking and sitting than

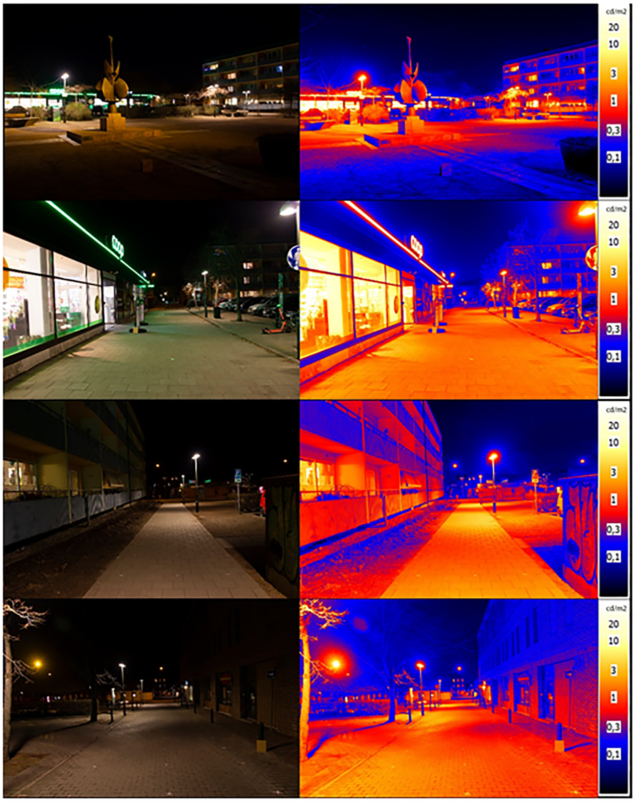

Figure 7 Kirseberg square – HDR images with corresponding luminance maps for zones A, B and C. From the top: zone A, zone B in the commercial area, zone B path and zone C path

Lindeborg. Cycling and riding on scooter were more frequent at Lindborg.

The Pearson's chi-square results for Kirseberg square suggest a significant increase in walking (χ^2 (1, N=2365)=8.44, p=0.004), and significant decreases in the stationary activities; sitting (χ^2 (1, N=79)=16.01, $p < 0.001$) and hanging-out (χ^2 (1, N=109)=29.04, $p < 0.001$) in EL compared to DL.

The Pearson's chi-square results for Lindeborg square display no significant differences in any of the movement types, however an increase in the stationary activity hanging-out (χ^2 (1, N=182)=4.58, p=0.032) in EL compared to DL.

3.3 Spatial use in functional zones

Tables 7 and 8 show the results of the frequency analysis and the results of Pearson's chi-square tests for each type of behaviour within the categories, movements and stationary activities, between the functional zones (A, B and C).

Figure 8 Lindeborg square – HDR images with corresponding luminance maps for zones A to C. From the top: zone A, zone B and zone C

Table 5 Frequencies for movements and stationary activities in DL versus EL conditions during all timeslots for Kirseberg square. Measures are given in absolute (*N*), relative (%) and expected (Exp.) counts

Lighting condition	DL			EL			Pearson's chi-square tests			Total
	N	%	Exp.	*N*	%	Exp.	χ^2	*p*	df	*N*
No. of valid cases behavioural category	1693	100		1101	100					2794
Movements										
Walking	1406	83	1433	959	87.1	932	8.440	0.004	1	2365
Cycling	161	9.5	151	88	8.0	98	1.891	0.169	1	249
On scooter	21	1.2	17	7	0.6	11	2.458	0.117	1	28
Other mov.	32	1.9	33	23	2.1	22	0.137	0.712	1	55
Stationary activity										
Standing	253	14.9	236	137	12.4	154	3.474	0.062	1	390
Sitting	65	3.8	48	14	1.3	31	16.010	<0.001	1	79
Hanging out	93	5.5	66	16	1.5	43	29.044	<0.001	1	109
Other stat.	30	1.8	22	7	0.6	15	6.591	0.010	1	37

df: degree of freedom; DL: daylight; EL: electric lighting.

Table 6 Frequencies for movements and stationary activities in DL versus EL conditions during all timeslots for Lindeborg square. Measures are given in absolute (*N*), relative (%) and expected (Exp.) counts

Lighting condition	DL			EL			Pearson's chi-square tests			Total
	N	%	Exp.	*N*	%	Exp.	χ^2	*p*	df	*N*
No. of valid cases	1480	100		1022	100					2502
Behavioural category										
Movements										
Walking	1176	79.6	1168	798	78.1	806	0.689	0.407	1	1974
Cycling	177	12	170	110	10.8	117	0.852	0.356	1	287
On scooter	64	4.3	73	59	5.8	50	2.714	0.099	1	123
Other mov.	21	1.4	27	24	2.3	18	2.957	0.086	1	45
Stationary activity										
Standing	186	12.6	185	127	12.4	128	0.011	0.917	1	313
Sitting	24	1.6	23	15	1.5	16	0.093	0.760	1	39
Hanging out	94	6.4	108	88	8.6	74	4.575	0.032	1	182
Other stat.	9	0.6	10	7	0.7	6	0.560	0.813	1	16

df: degree of freedom; DL: daylight; EL: electric lighting.

Table 7 Frequencies for movements and stationary activities per zone A, B and C based on the aggregated data of both DL and EL conditions during all timeslots for Kirseberg square. Measures are given in absolute (*N*) and expected (Exp.) counts

Zone	Zone A		Zone B		Zone C		Pearson's chi-square tests			Total
	N	Exp.	*N*	Exp.	*N*	Exp.	χ^2	*p*	df	*N*
No. of valid cases per zone	387		1663		744					2794
Behavioural category										
Movements										
Walking	302	327	1445	1408	618	630	21.58	<0.001	2	2365
Cycling	18	35	136	148	95	66	23.32	<0.001	2	249
On scooter	5	4	11	17	12	8	5.06	0.088	2	28
Other mov.	11	8	30	33	14	15	1.80	0.407	2	55
Stationary activity										
Standing	56	54	226	232	108	104	0.559	0.765	2	390
Sitting	58	11	19	47	2	21	243.39	<0.001	2	79
Hang out	65	15	27	65	17	29	201.41	<0.001	2	109
Other stat.	31	5	1	22	5	10	155.29	<0.001	2	37

df: degree of freedom; DL: daylight; EL: electric lighting.

Analyses are based on all timeslots in both lighting conditions. Results confirm significant difference in spatial use in the zones. In both squares more of the stationary activities, sitting

Table 8 Frequencies for movements and stationary activities per zone A, B and C based on the aggregated data of both DL and EL conditions during all timeslots for Lindeborg square. Measures are given in absolute (*N*) and expected (Exp.) counts

Zone	Zone A		Zone B		Zone C		Pearson's chi-square tests			
	N	Exp.	*N*	Exp.	*N*	Exp.	χ^2	*p*	df	*N*
No. of valid cases per zone	240		1707		555					2502
Behavioural category										
Movements										
Walking	173	189	1379	1347	422	438	13.08	<0.001	2	1974
Cycling	26	27	180	196	81	64	6.87	0.032	2	287
On scooter	16	12	63	84	44	27	17.83	<0.001	2	123
Other mov.	10	4	25	31	10	10	8.70	0.013	2	45
Stationary activity										
Standing	78	30	199	214	36	69	107.15	<0.001	2	313
Sitting	25	4	10	26	4	9	135.79	<0.001	2	39
Hang-out	78	18	73	124	31	40	251.51	<0.001	2	182
Other stat.	2	1	12	11	2	4	0.93	0.628	2	16

df: degree of freedom; DL: daylight; EL: electric lighting.

and hanging-out, takes place in zone A than in zones B and C; Kirseberg square: sitting (χ^2 (2, $N=79$) = 243.39, $p < 0.001$), hanging-out (χ^2 (2, $N=109$) = 201.41, $p < 0.001$). Lindeborg square: sitting (χ^2 (2, $N=39$) = 135.79, $p < 0.001$), hanging-out (χ^2 (2, $N=182$) = 251.51, $p < 0.001$). In both squares, most movements take place in zone B followed by zone C; Kirseberg square: walking (χ^2 (2, $N=2365$) = 21.58, $p < 0.001$) and cycling (χ^2 (2, $N=249$) = 23.32, $p < 0.001$). Lindeborg square: walking (χ^2 (2, $N=1974$) = 13.08, $p < 0.001$) and cycling (χ^2 (2, $N=287$) = 6.87, $p=0.032$).

3.4 OR for behaviour types in DL and in EL

In total, 2887 observations were identified within the control periods (timeslot 1) and case periods (timeslot 3), used for the OR tests for differences in frequencies of movements and stationary activities in DL and in EL. Figure 9 shows a summary of ORs and associated 95% CI for behaviour types across all zones for both squares. Figure 10 shows ORs for the main behavioural categories movements and stationary activities for zone A. All ORs and 95% CI are shown in Supplemental Tables S1 and S2.

ORs and 95% CIs for Kirseberg square do not suggest significant differences between daylight and darkness for walking or cycling. The OR for the stationary activity standing is 0.52 (95% CI = 0.29-0.91, $p=0.022$), indicating a significant increase in EL compared to in DL. The observer's notes confirm that these cases refer to withdrawals at the automated teller machine outside the grocery store and cases of people standing waiting outside the store for someone.

The ORs for Kirseberg square zone A (Figure 10 and Supplemental Table S1) show a significant decrease in stationary activities after dark in EL (OR = 15.6, 95% CI = 7.69–31.82, $p < 0.0001$). However, the difference in movements is non-significant (OR = 0.82, 95% CI = 0.46–1.47).

The ORs for Lindeborg square, shown in Figure 9 and Supplemental Table S2, indicate a

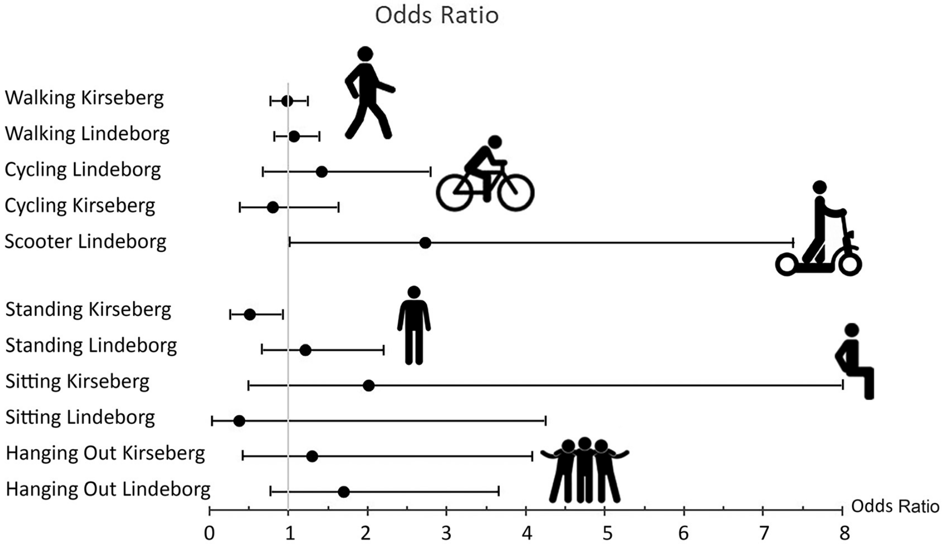

Figure 9 Summary of odds ratios for all behaviour types with 95% confidence intervals across all zones

significant decrease in the movement category on scooter in EL but do not suggest significant differences for any other movement. ORs for the stationary activities do not indicate significant differences. The ORs for Lindeborg square zone A, shown in Figure 10, indicate a tendency of increase in movements in EL in zone A. The OR for stationary activities in zone A (OR = 0.34, 95% CI = 0.14–0.83, $p = 0.016$) indicates a significant increase in this behavioural category in EL.

4. Discussion

This study analyses user behaviour at two local public squares in DL compared to EL after dark. Moreover, the spatial use related to different functional zones of the squares i.e. where different behaviour take place, is examined. To discern if the same types of user behaviour are sustained in EL or not, observations were made at the same times of day in the period before and after the daylight savings clock change. The two investigated squares are located in residential areas of similar size, and they are similar in terms of spatial arrangements, planning and function but have different lighting installations. The squares thereby provide two parallel cases to discuss the performance i.e. the facilitation of users' movements and stationary activities after dark.

The frequency analysis showed that all of the studied types of user behaviour occurred during all timeslots at both squares, regardless of ambient light.

However, results of spatial use for both squares confirm that movements and stationary

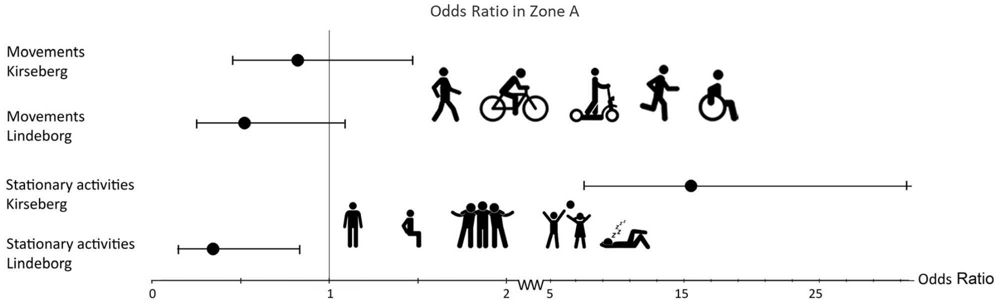

Figure 10 Summary of odds ratios for movements and stationary activities with 95% confidence intervals for zone A

activities were related to functional zones of the squares, see Tables 7 and 8. In line with the physical design or the so-called 'programming',[3,67] the zones A displayed more stationary activities than did the zones B and C, whereas the results were reversed for the other behavioural category with more movements in the zones B and C. It thereby becomes useful to explicitly consider spatial use in discussions on how lighting might support user needs in different functional zones after dark.

The frequency analysis (Tables 5 and 6) showed that movements generally were not affected by the change from DL to EL. This was confirmed by the OR analysis (Figure 9). According to the chi-square tests, Kirseberg square displayed an increase in walking after dark. One explanation for this discrepancy might be that people in Kirseberg tended to do their necessary errands in the twilight before it gets completely dark i.e. the observations excluded in the OR. Another explanation could be that behaviour displays different spatial-temporal patterns associated with each square at different time frames, due to somewhat different destination availability (Section 2.3), for example, movements to and from the children's day-care centre in Kirseberg and movements associated with evening activities in the church in Lindeborg.

The lighting installation of Kirseberg square with asymmetric distribution and MH lamps gives high horizontal illuminance levels on paths in zones B and C (above 26 lx, exceeding class P1 in SS-EN 13201-2:2016) and low uniformity (around 0.25, i.e. below recommended values for the horizontal illuminance as per the same standard). In Lindeborg square with omni-directional distribution and HPS lamps in zone B and MH lamps on the path in zone C, average horizontal illuminance levels on the ground (7.1 lx and 11.1 lx for zones B and C, respectively) and uniformity (0.55 and 0.42, respectively) comply with class P4 and P2. Hence, movements that include necessary or habitual behaviour within the zones designed for walking, such as buying food at the local grocery shop may, be less sensitive to people's experience of the after dark lighting condition such as horizontal uniformity of paths, and as previously suggested for such behaviour in daylight conditions, to be less sensitive to the perceived atmosphere.[71]

Results of the frequency analysis and the OR showed that stationary activities, sitting and hanging-out, decreased after dark in Kirseberg square, in particular within zone A, which is the designated area for stationary activities. This indicated that the stationary activities that are of optional nature were not sustained in zone A, Table 7 and Figure 10.

On the contrary, in Lindeborg square, stationary activities in zone A increased from DL to EL. This result was confirmed by the OR test for zone A. One reason may be that a greater proportion of the movements in Lindeborg square than in Kirseberg were combined with stationary activities. A typical example would be a person who walks along the path to reach the grocery shop and runs into a neighbour and stops for a chat. This implies that a necessary behaviour might also evolve into a behaviour of optional nature.[25]

A comparison of luminance maps of zone A of both squares, Figures 7 and 8, shows large differences in the light uniformity at ground level. In Kirseberg, dark and bright spots show luminance differing up to two orders of magnitudes, going from 0.1–0.3 cd/m^2 to 1–20 cd/m^2, whereas in Lindeborg square, zone A, with omnidirectional distribution, the luminance at ground level is in the range of 0.3–1 cd/m^2 across the whole zone. The two A zones differed also in term of colour appearance due to lamps with different spectral power distribution, with MH in Kirseberg delivering CCT = 2800 K and CRI = 84 and the HPS in Lindeborg showing the characteristic yellow appearance for this type of lamp technology, with a nominal CCT = 2000 K and CRI = 25. Previous research suggests that appreciation of a space is related to the appraisals of brightness and perceived uniformity, which in turn is related to light levels and spatial distribution of light.[53] The present results raise questions regarding the importance of light distribution, perceived spatial brightness and uniformity to also sustain stationary activities in public squares. Moreover, appreciation of a visual scene after dark is related to the appearance of colours and colour temperature.[54,57] Such associations should be considered in further research on EL and in particular, on stationary activities in squares.

European lighting standards provide no requirements for stationary activities in public space. However, the Australian road lighting standard AS/NZS 1158:3.1:2020[72] introduces public activity area classes for activity in public space and lists ‘amenity’ as one of the selection criteria, where low, medium or high amenity corresponds to average horizontal illuminances from 7 lx to 21 lx, implying that ‘amenity’ requires higher lighting levels. Users’ movements and stationary activities are of both necessary and optional character, where stationary activities to a greater extent are of optional nature and thus presumably more dependent on perceived affordances and amenity after dark.

Studies on pedestrian responses suggest that lighting may facilitate a range of user needs after dark such as accessibility, reassurance, comfort and pleasure and may therefore encourage use of public squares.[35,36,38,41,43,45] Although both movements and stationary activities in public squares can be of both necessary and optional nature as part of the user’s everyday life, it is implied that stationary activities in particular requires amenity and therefore fulfilment of higher order needs i.e. beyond accessibility and reassurance.[8,30,46] A key sentiment of public life studies proposes that, when a physical setting facilitates both necessary and optional activities, sociability is also supported. To what extent this applies also for dark conditions remains to be investigated.

The findings of this study are limited to the difference in behaviour recorded in two squares with different lighting installations. However, the results provide justification for further research on the lighting–behaviour relationship in local public squares. Future research should therefore strive to take users' appraisal of the visual scene into account as well as inquire into how social interaction in public space is related to facilitation of movement and stationary activities.

5. Conclusion

The present study aimed to investigate the influence of electric light on user behaviour, in terms of facilitation of movements comprising walking, cycling, riding on scooter and other movements, and stationary activities comprising standing, sitting, hanging-out and other stationary, in local public squares.

A square includes different functional zones: those designed for movement and those designed for stationary activities. Given the complexity of a visual scene in a square, it seems valuable to analyse each functional zone in relation to its use. The observations of user behaviour at two different squares in daylight and electric light suggest that movements are sustained in zones designed for walking across different lighting conditions, as well as differences in average horizontal illuminance levels and uniformity. In zones designed for stationary activities, such behaviour seems more sensitive to changes in lighting conditions, supposedly as they may require an appreciation of the visual scene and of the perceived affordances.[73]

When we understand why certain luminous conditions produce the behavioural outcomes we desire, then we will be able to re-create those conditions, and those outcomes, more reliably.[33]

There are tremendous possibilities to improve the atmosphere of a public space with electric light, and thereby the opportunity to enhance public life in squares is at hand. However, there is a need for both theoretical and methodological development on how to relate lighting to behavioural dimensions in local public squares, also including the social dimension.

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ORCID iDs

VKR Hennig https://orcid.org/0000-0001-7714-7148
S Fotios https://orcid.org/0000-0002-2410-7641

Supplemental material

Supplemental material for this article is available online.

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Appendix II

Social interaction in local public squares after dark

VKR Hennig[1,4], S Fotios[3], N Gentile[2], C Sternudd[1] and M Johansson[1]
[1] Environmental Psychology, Dept. of Architecture & Built Environment, Lund University, Sweden
[2] Division of Energy and Building Design, Dept. of Building & Environmental Technology, Lund University, Sweden.
[3] School of Architecture, The University of Sheffield, Sheffield, UK
[4] Author to whom any correspondence should be addressed. E-mail: katarina.hennig@abm.lth.se

Abstract. This paper explores social interaction in local public squares under different lighting conditions. At its best public squares are social spaces that engender a sense of belonging, increase the quality of life and wellbeing of individuals. It is proposed that outdoor lighting would be essential to the use of the public realm after dark, but empirical results regarding lighting conditions and social aspects of life in public squares are limited. Based on a socio-physical conceptual model of the transactional relationship of the user, the lit environment and the behavioural outcome, this study investigated active social interaction in daylight compared to after dark. A field study was conducted in two local public squares in Malmö, Sweden. The occurrences of which visitors were being alone, in pairs, or in groups of three or more (N=2522), and verbal or non-verbal interaction amongst those in company of another person were recorded. The lit appearance of the two squares after dark, was assessed with HDR-photography and photometric measurements; portraying dissimilar spatial, spectral and intensity characteristics. The results of social interaction show dissimilar patterns of the two squares; an increase in social interaction in EL after dark was observed in one of the squares, while a decrease in the afternoon and no significant difference was displayed in the evening after dark in the other square. It is suggested that lighting may sustain patterns of social interaction after dark, however it might be, that the company of another is especially important after dark.

1. Introduction

UN Sustainable Development Goal (SDG) 11 targets the provision by 2030 of universal access to safe, inclusive and accessible public spaces in cities and human settlements.[1] Consequently, UN Habitat III policy paper *The Right to the City and Cities for All* promotes quality public spaces that are participatory, enhance social interaction, and engender sense of belonging.[2] The implementation of SDG 11 requires focus at a community level to make tangible differences to the everyday lives of people.[3] Urban theorists argue that the social and psychological health of modern communities requires quality public spaces, here defined as 'publicly accessible spaces' which generate public life, and support active and passive social interaction.[4-7] Social life in public spaces increase the quality of life and wellbeing of individuals.[4, 8] Measures of social interaction in public space may therefore be used to assess the level of health and vitality of communities.[9] Urban public spaces include a variety of urban settings such as streets, parks and squares. Outdoor lighting is essential to promote the use of public squares after dark because it supports movements and stationary activities.[10, 11] However, most research on the qualities of urban design and its role in facilitating social life in public space concern daylit conditions. Frequented public spaces are meaningful, protective of rights of different user groups, and responsive; that is, designed to serve the needs of users.[9, 12, 13] Users are here defined as those who frequent public spaces and rely on them for active and passive engagement.[13] Perceived environmental qualities such as accessibility, safety, comfort, pleasure and sociability encourage use of public spaces by day.[5, 14] While lighting research on pedestrians suggests that electric lighting may support these needs,[15] field-studies on the association between the lit environment and social life of public squares are still limited. Ethnographic approaches have revealed affective capacities of light and darkness by 'light walks', and thus accentuated the on-going flow of shifting impressions and feelings which are embodied in the experience of moving through an urban lightscape.[16] Lighting design research with a social oriented scope have stressed the need to study people's activities, pattern of use, and appraisals of lit environmental settings, to understand how lighting might encourage sociability and support users' daily life in public space.[9]

This paper reports on lighting conditions and social interaction in local public squares, which constitute 'everyday life spaces' set within the context of a neighbourhood.[17] While a local public square is a publicly accessible space, the sense of 'publicness' may vary along a continuum from 'public' to 'private', and so may the type of interactions vary from strangers to friends.[17] It is a space which offers an opportunity to be co-present with people, who might be either unknown (unacquainted), categorically known (the woman from the flower-shop), acquainted, or even a friend.[17, 18] Social interaction in a local public square might be expressed as a brief glance of recognition (face engagement), a greeting, a small chat or even spending time socializing with friends.[17, 18] Though merely observing others, to be co-present with strangers, to see and be seen, may induce a sense of belonging. A local public square may therefore serve as a social space *where interrelatedness with other human beings is affirmed*.[19] Public solitude (passive social interaction) may be a lone pleasure derived from people-watching. Public sociability though, by definition involves, spoken interaction between people in dyads, triads or larger groups.[17]

1.1. Aim

The intent of this study was to investigate active social interaction in daylight (DL) and in electric lighting (EL) after dark, in two local public squares in Malmö, Sweden. Three objectives were targeted. (1) To compare occurrences of people visiting the squares being alone, in pairs or in larger groups. (2) To assess the share of verbal and non-verbal interaction amongst those in company of others. (3) To investigate if there is any differences in visitors presence in the squares after dark between age groups.

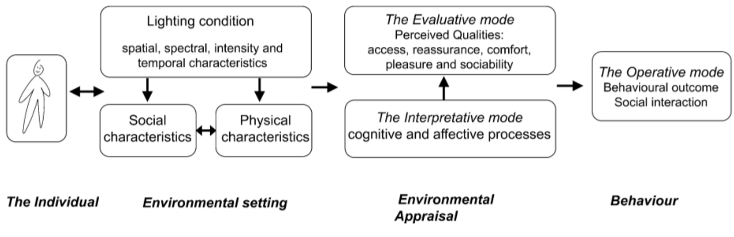

Figure 1. A socio-physical conceptual model of the transactional relationship between the Individual, the Environmental setting and the Behavioural outcome.

1.2. *A transactional-contextual framework*

To interpret the behavioural relationship between the individual (user), the lit environment of a public square and the behavioural outcome in terms of social interaction we employ a framework, that suggests a dynamic interplay between people and their every-day environmental settings.[20] With this perspective a behaviour is viewed in its socio-physical and temporal context. In any given setting physical aspects are closely linked to social ones, also giving spatiotemporal patterns to the occurrences of behaviours.[20] Furthermore physical aspects (limits, spatial arrangement and characteristics including lighting condition) may either facilitate or impede behaviours depending on the individual's appraisal of the setting.[20] We propose a socio-physical conceptual model (Figure 1) which shows the transactional relationship between the individual (with personal traits, abilities and needs), the environmental setting (with social and physical characteristics including lighting condition), the environmental appraisal (including cognitive interpretative and evaluative processes), perceived qualities (access, reassurance, comfort, pleasure and sociability), and the behavioural outcome (social interaction). The configuration of the model departs from Stokols' modes of human environment transactions; the interpretive, the evaluative, the responsive and the operative mode.[21] It is stipulated that the individual's appraisal of a setting and therefore her behaviour, is conditioned by the lighting condition in terms of spatial, spectral, intensity and temporal characteristics.[22, 23]

2. Method

2.1. Direct observation of users' active social interaction

Direct structured observations of users' active social interaction was conducted at two local neighbourhood squares in Malmö, Sweden. In this method the observer adopts, as far as feasible, a non-participant pure observer role to avoid reactivity of those being observed.[24] Direct observation here involved watching, listening and recording types and frequencies of individuals' active social interaction, in DL and after dark in EL. A scheme for coding active social interaction was developed and tested in a pilot study. Amongst those involved in active social interaction, defined as being in the company of others, the occurrences of verbal or non-verbal interaction was recorded. A scan-sampling technique was employed for the recording of events of active social interaction in each setting.[25] Each event involving a social interaction was given an ID-number, used for field notes to provide qualitative information of social interaction and to discern any spatiotemporal pattern.

2.2. Settings

The two squares, Kirseberg square and Lindeborg square (Figure 2), were selected for having several features in common; function (as a local centre with services and amenities), size (in terms of surface area), physical setting and spatial arrangement (with design features such as benches, trees and planting). However, the lighting installations and lighting conditions were dissimilar in terms of spatial light distribution, intensity, uniformity, level of contrasts in the visual field, spectral power distribution (SPD), correlated colour temperature (CCT), CIE general colour rendering index (CRI) and differences in scotopic/photopic (S/P) luminance ratios. Therefore the after dark appearances and ambience of the squares are different, which enabled a comparison. Both neighbourhoods have equivalent number of inhabitants; approximately 5300 in Kirsebergsstaden in northern Malmö and approximately 5000 in Lindeborg in southern Malmö.

2.2.1. Kirseberg square has a surface area of approximately 3100 m^2. To the north there is an area (zone A) for stationary occupancy with design features including benches in each corner, a sculpture and a boule court. Cherry trees and rose bushes flank each side. To the east there is a one-way street mixed with vehicle, cyclists and pedestrians (zone B). To the south there is a pedestrian route with access to a frequented grocery store and to the west a pedestrian route along a residential building (zone C). The surrounding buildings are low rise (between one and four stories high) and were constructed in the 1960's. A technical description of the lighting installation is shown in Table 1 and Table 2. The square has 12 lampposts (3.7 m high) with two asymmetric reflector luminaires, each containing a 70W metal halide lamp (MH). The low height of the lamppost combined with a high luminous output of the lamp results in large contrasts between bright and dark areas (see the technical assessment of the luminous appearance, section 3.1).

2.2.2. Lindeborg square has a surface area of approximately 3100 m^2. The area for stationary occupancy (zone A) subjectively suits its purpose well; with a soft-scape of lime trees and cherry trees, cut hedges of beech and well composed flowerbeds with perennials, a water feature and a little sculpture. The surrounding buildings are low rise (between one and two stories high), constructed in the 1970s and host commercial services, gym, church and an elementary school. A pedestrian and cyclist's path (zone B) to the north gives access to the commercial service building and another path (zone C) along the western side provides a linkage to the surrounding neighbourhood. A technical description of the lighting installation is provided in Tables 1 and 2. There are 11 lamp posts (4.2 m high) placed at intervals of 20 m along paths and arranged to accompany flowerbeds and seating. The lanterns, with opal diffusers, have an omnidirectional distribution and 70 W high pressure sodium (HPS) lamps (see the technical assessment of the luminous appearance, section 3.1).

Table 1. Specification of Luminaire types

	Luminaire types						
Square	Type	Name	Light distribution	Optics	Shield	Height	Qty.
Kirseberg	road-luminaire	Philips, Copenhagen	asymmetric	reflector	upwards	3.7 m	2x12
	spotlight	SILL, Plane projector	rotational symmetric	reflector	lamels		
Lindeborg	park lantern	DEFA, Helena	omnidirectional	opal diffuser	glare rings	4.2 m	11

Table 2. Specification of Lamp types

	Lamp types						
Square	Type	Name	Luminous flux (lm)	CCT(K)	CRI (Ra)	S/P ratio	Qty.
Kirseberg	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x12
	HPS2	HST-DE 150W	1500	2000	25	0.5	1
Lindeborg	HPS	SON Pia Plus 70W	6000	2000	25	0.5	9
	MH	CDO-ET 70W/828	7030	2800	84	1.3	2

2.3. Data collection

Observations were conducted for the same times of day in the two weeks before and two weeks after the autumn 2020 daylight savings clock change. This enables a comparison of users' active social interaction between the two lighting conditions and which offsets other confounding factors; i.e. the time of day factor is held constant and seasonal factors are sufficiently constant during the sampling periods. The spatiotemporal patterns of users' behaviour in a given time frame are supposedly similar, e.g. inhabitants of each neighbourhood would hypothetically perform the same activities and social interaction as part of their daily life rhythm.[20] Sampling in each square was performed on six days, two week-days and one weekend-day. Sampling sessions were scheduled in the afternoon at 16.15 to 17.00 and in the early evening at 17.30 to 18.15. In total, 18 hours of sampling was conducted and 2522 events were recorded. Prior to each sampling session, conditions such as precipitation and air-temperature, the present sky-condition (e.g. clear, semi-overcast, over-cast), the state of vegetation and the lighting condition (DL) or (EL) were recorded. Field notes regarding the ambient feeling, pace of movements and interactions were also taken prior to sampling sessions, in combination with notes on social interaction IDs these provided qualitative data used for a written narrative.

2.3.1. Sample. Individuals present at each of the square were classified visually by their apparent gender and by their apparent age into four age groups: children (0 - 12 years old approximately), teens (13 - 19 years old approximately), adults (20 - 64 years old approximately) and elderly (over 65 years old). Due to the observers non-participant role a visual classification of the individuals was employed. Table 3 shows the demographics of the visually classified sample.

Table 3. Demographics of sample based on a visual classification during observations.

	Age-group									Gender				
	0 – 12 yr.		13–19 yr.		20 – 64 yr.		> 65 years		Total	Female		Male		Unidentified
	N	%	N	%	N	%	N	%	N	N	%	N	%	%
Kirseberg	147	10.7	140	10.2	867	63.0	222	16.1	1376	743	54.0	627	45.6	0.4
Lindeborg	94	8.2	294	25.7	558	48.7	200	17.5	1146	606	52.9	538	46.9	0.2

2.3.2. Sampling units. To enable observations of individuals' social interaction from a visible and audible distance each square was divided into three sampling units (zones A, B and C), as shown in Figure 2. These zones were chosen due to their spatial arrangements and specific function; A is designed as a 'social' area with seating, B is a pedestrian and cyclist path with access to commercial shop(s) and other services(s) and C is a path linking the surrounding residential areas of the neighbourhood to its local square. A sampling session of 45 min enabled 3 rotations between the sampling units, with one rotation every 15 minutes always starting in sampling unit A, continuing to B and hereafter to C.

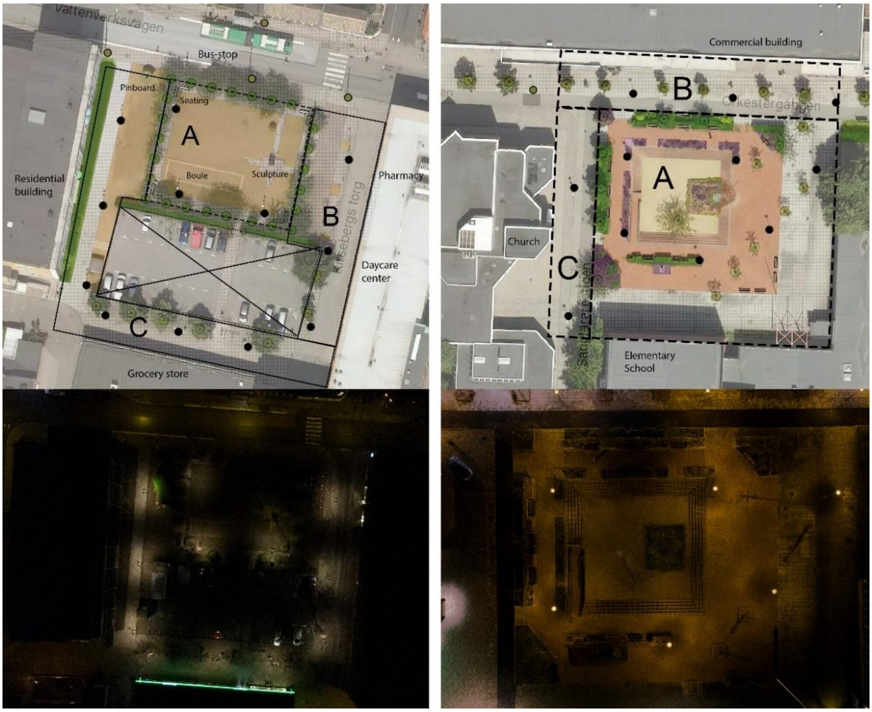

Figure 2. Plans of the two squares with sampling units (zone A, B, C) and after dark lighting layouts. From left Kirseberg Square. and to the right Lindeborg Square.

2.4. Technical environmental assessment

EL conditions were assessed in terms of spatial, spectral, intensity and temporal characteristics. The assessment was carried out as follows:

- HDR-images were captured for vital viewpoints in each sampling unit (zones A, B, C). These images were converted into luminance maps, calibrated against luminance spot measurements on a board placed in each image frame.
- HDR-images of spheres were taken in each sampling unit to convey facial recognition.
- Horizontal illuminance was measured at ground level across the whole square in a grid with a grid size of 3 m x 3 m.
- Horizontal illuminance was measured on paths (in zones B and C) in compliance with SS-EN 13201-3:2016.
- SPD, intensity and S/P-ratios of light sources were retrieved from the manufacturer.

2.5. Data analysis

Data analysis was carried out in IBM SPSS in two steps to establish the occurrences of active social behaviour in daylight compared to after dark in electric lighting in each of the squares:

Step 1: A frequency analysis for each of the selected behavioural categories:

- active social interaction operationalized as being alone, in pairs or in a group of three or larger,
- verbal versus non-verbal interaction amongst those individuals engaged in active social interaction.

Step 2: A Pearson's Chi-square test to test for any differences of behaviour between:

- lighting condition in DL and after dark in EL,
- age groups in DL and after dark in EL.

The level of significance was set to $p \leq 0.05$ with Bonferroni correction for multiple comparisons.

3. Results

3.1. Technical environmental assessment

HDR-images with corresponding luminance maps are shown in Figures 3 and 4. An overview of the illuminance measurements is shown in Table 4. The illuminances in Kirseberg square have a high average and a low uniformity, resulting in large contrasts between bright and dark areas, especially in zone A, the stationary area for occupancy. Lit windows in the residential building (zone C) and the shop windows (zone B and C) contribute to a lit impression of the square. Lindeborg square on the other hand, has a low average illuminance but higher uniformity. The lit scene has a warm ambiance, diffuse and soft, with poor modelling characteristics of objects and spatial elements and poor colour rendering due to the low CRI of the HPS lamp. Along the commercial building linear fluorescent tubes cause a high contrast in the visual scene.

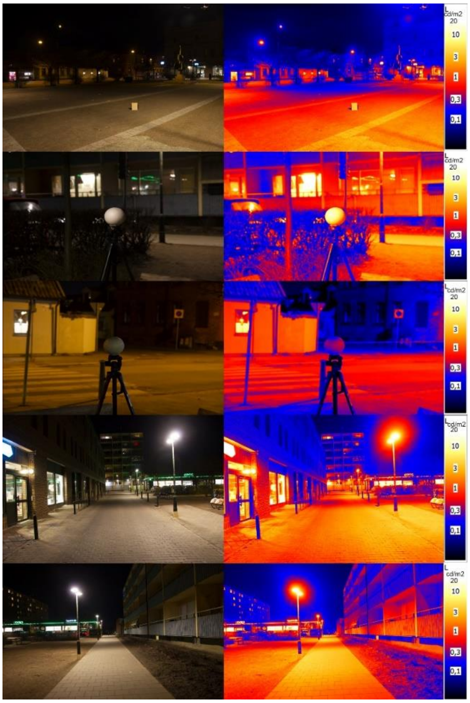

Figure 3. HDR-images with corresponding luminance measurements in Kirseberg square, from the top:

- Zone A - There are big contrasts between dark and bright areas on the horizontal level with luminance levels in the range of 0.1 – 15 cd/m^2.
- Zone A (bright corner) - The illuminated sphere with luminance levels in the range of 1 – 15 cd/m^2 depicts good facial recognition.
- Zone A (dark corner) - The dark sphere with low luminance levels in the range of 0.1 – 1 cd/m^2 depicts poor modelling and poor facial recognition.
- Zone B (path) - The façade is dark while the path is bright with luminance levels in the range of 1 – 15 cd/m^2.
- Zone C (path) - The path is bright with luminance levels in the range of 1 – 15 cd/m^2.

Table 4. Measurements of horizontal illuminances and uniformity of illuminance.

Square	Zone	Ē (lx)	E min (lx)	U_o
Kirseberg	All	23.4	0.6	0.03
	B (path)	35.9	8.9	0.25
	C (path)	25.5	6.5	0.26
Lindeborg	All	5.8	0.4	0.07
	B (path)	7.1	3.9	0.55
	C (path)	11.1	4.7	0.42

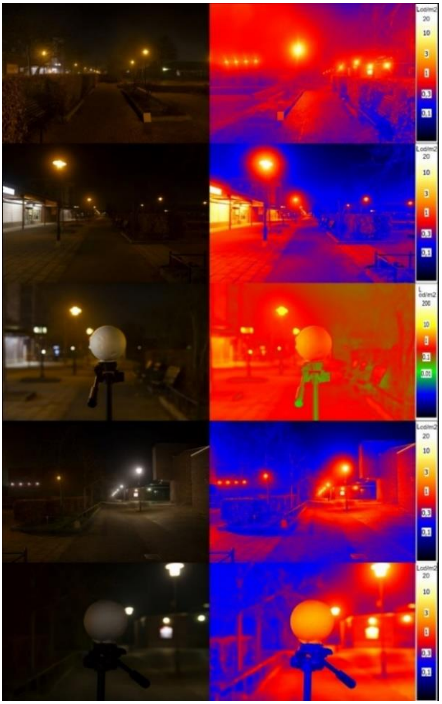

Figure 4. HDR-images with corresponding luminance measurements in Lindeborg square, from the top:

- Zone A - This area is characterized by a uniform and diffuse light distribution with low luminance levels in the range of 0.1 – 1 cd/m^2 and a poor colour rendering due to the low CRI of the HPS lamp. This also results in poor modelling of steps, benches and hedges.
- Zone B (path) - The luminance levels along the path are low in the range of 0.1 – 1 cd/m^2. There is a huge contrast to the light levels along the shops where luminance levels exceed 10 cd/m^2.
- Zone B (path) - The light distribution on the sphere depicts a fair modelling with luminance levels in the range of 1 – 10 cd/m^2 which give a fair facial recognition.
- Zone C (path) - The average illuminance levels are 11 lx with a uniformity of 0.42. Luminance levels are in the range of 1 - 10 cd/m^2.
- Zone C (path) - The light distribution on the sphere depicts poor modelling due to the diffuse distribution of light. Luminance levels are in the range of 1 – 3 cd/m^2.

3.2. Social interaction in Daylight and in Electric lighting after dark

3.2.1. Alone or accompanied? Results of the Chi-Square test, shown in Table 5, for Kirseberg square. in the afternoon session display a significant difference between the level of social interaction in DL compared to after dark in EL (χ^2 (2, N=603) = 6.58, p=0.038). Social interaction of people being in pairs or in group of three or larger decreases after dark. Results for the early evening session display no significant difference between the level of social interaction in DL and after dark in EL (χ^2(2, N=772) = 2.74, *n.s.*). The results of Chi-Square test, shown in Table 5, for Lindeborg square display a significant difference between the level of social interaction in DL and after dark in EL for both the afternoon session (χ^2(2, N=540) = 11.64, p=0.003) and for the evening session (χ^2(2, N=605) = 12.45, p=0.002). After dark in EL less people are present alone, more people instead are present in pairs both in the afternoon and in the early evening session. The presence of people in groups of three or larger also increases in EL.

3.2.2. Narrative of the spatiotemporal patterns and social interaction
Narrative 1 – Kirseberg square, Afternoon in DL on the 7th of October. The sky is clear. Long afternoon shadows stretch across zone A. A pair, a girl and a woman, is sitting on a bench enjoying the late afternoon sun, which still lingers in the north eastern corner of zone A. An elderly woman rests on her walker, she is smoking. As the bus stops a few people get off, they head in different directions, some of them cross zone A and head for the grocery store. A man and two boys halt at the sculpture and the boys start climbing. Later a man on his bike rush towards the children's day-care centre in zone B. He picks up his son and chats to the lady at the centre, while the little boy patiently waits on his side on the curb-stone. Two chatting teenage girls walk by, heading for the grocery store. An elderly woman, a beggar, sits on the pavement outside the store. There is a gentle flow of people entering and exiting the grocery

store. Occasionally people stop and exchange a few words with the begging woman. In zone C an elderly man walks his dog in a slow pace. A man in his fifties walks along the path, he stops to chat with a woman on her balcony. Kirseberg square, Early evening in EL on the 13th of October. There is an evening chill. Four men in zone A are playing boule, the game is not intense though. They are chatting and drinking rather than playing, it seems. The pace of people walking to and from the grocery store is intensified.

Narrative 2 – Lindeborg square, Afternoon in DL on the 2nd of November. The sky is partly overcast with clouds passing quickly, autumn leaves whirl in the wind. Four boys in their teens are hanging out by the benches in the north east yet sunny corner of zone A. A boy on scooter roams around. Every now and then someone enters and exits the grocery store. Two teen girls walk by, they receive attention and comments from the boys. Lindeborg square, Early evening in EL on the 2nd of November. The sky is dark, it is still warm for the season, 16 degree Celsius. A teen boy is sitting on a bench texting on his mobile. He is anxiously looking out for his friends. He makes a call. A few minutes later another boy arrives and soon they are an enclave of six. A man walks by he is heading towards the fitness centre. The flow of people to and from the grocery store is steady at this hour.

Table 5. Frequencies for visitors being alone, in pairs or in groups of three or larger in DL and in after dark in EL conditions, measured in the afternoon and in early evening in the period with (DST) and in the period after daylight savings clock change.

Square	Social interaction	DL		EL		Total	Pearson's Chi-Square Tests		
		N	exp.	N	exp.	N	χ^2	*p*	df
Afternoon at 16.15-17.00									
Kirseberg	Alone	211	226	151	136	362			
	Pairs	122	110	54	66	176			
	Group ≥3	43	40	22	25	65			
	Total	376		227		603	6.58	0.038	2
Lindeborg	Alone	188	173	120	135	308			
	Pairs	86	88	70	68	156			
	Group ≥3	30	43	46	33	76			
	Total	304		236		540	11.64	0.003	2
Early evening at 17.30-18.15									
Kirseberg	Alone	212	203	229	238	441			
	Pairs	94	105	134	123	228			
	Group ≥3	49	47	54	56	103			
	Total	355		417		772	2.74	0.255	2
Lindeborg	Alone	168	146	124	146	292			
	Pairs	88	100	112	100	200			
	Group ≥3	47	57	66	56	113			
	Total	303		302		605	12.45	0.002	2

3.2.3. Verbal or non-verbal after dark? The results of Chi-Square test, Table 6, suggests a significant difference between the level of active social interaction in terms of non-verbal or verbal amongst those people being present in pairs or in groups of three or larger, in DL compared to after dark in EL for both squares. In Kirseberg square results suggest that people being present in pairs or groups of three or larger are engaged in verbal interaction in EL (χ^2(1, N=573) = 6.010, *p*=0.016), while in Lindeborg square people are less verbal after dark with (χ^2(1, N=546) = 23.221, *p*<0.001).

3.2.4. Home turf of the teens? Which age groups visit the squares after dark? The frequencies for visiting people per age-group in DL and EL after dark are shown in Table 7. In both squares children and elderly are more likely present in DL than after dark in EL. In Lindeborg square, teens have a significantly higher presence in the square after dark, which suggests a spatiotemporal pattern of the teens in this neighbourhood.

Table 6. Frequencies for verbal and non-verbal interaction amongst those involved in social interaction in DL and after dark in EL, measured in both timeslots in the period with (DST) and in the period after daylight savings clock change.

		DL		EL		Total	Pearson's Chi-Square Tests		
Square	Active social interaction	N	exp.	N	exp.	N	$χ^2$	*p*	df
Kirseberg	Non-verbal	114	100	72	86	186			
	Verbal	195	209	192	178	387			
	Total	309		264		573	6.010	0.016	1
Lindeborg	Non-verbal	45	70	107	82	152			
	Verbal	207	182	187	212	394			
	Total	252		294		546	23.211	<0.001	1

Table 7. Frequencies for visiting people per age group in DL and after dark in EL, measured in both timeslots in the period with (DST) and in the period after daylight savings clock change.

		DL		EL		Total	Pearson's Chi-Square Tests		
Square	Age group	N	exp.	N	exp.	N	$χ^2$	*p*	df
Kirseberg	Child	95	78	52	69	147			
	Teen	87	74	53	66	140			
	Adult	417	461	450	406	867			
	Elderly	133	118	89	104	222			
	Total	732		644		1376	25.28	<0.001	3
Lindeborg	Child	58	50	35	44	94			
	Teen	132	156	162	138	294			
	Adult	295	296	263	262	558			
	Elderly	122	106	78	94	200			
	Total	608		538		1146	16.49	<0.001	3

4. Discussion

This study investigates active social interaction in DL compared to EL after dark in two local public squares in Malmö, Sweden. To interpret the relationship of the individual (user), the lit environment of a public square and the behavioural outcome in terms of social interaction, we proposed a socio-physical model, Figure 1, stipulating that the individual's appraisal after dark and therefore her behaviour is conditioned by the characteristics of lighting. A technical environmental assessment of the two squares, section 3.1, depicted two dissimilar visual scenes after dark; Kirseberg square has a high average illuminance level but very low uniformity resulting in large contrasts between dark and bright areas and particularly so in the social area (zone A). Lindeborg square has a low average illuminance but a higher level of uniformity across the whole square. Observations of social interaction at both squares also reveal different patterns; In Kirseberg square the rate of social interaction decreases in EL in the afternoon, but there are no significant differences in the evening. Lindeborg square displays the same pattern in both timeslots, with less people being alone and more people being in pairs and in groups of three or more in EL. This suggests that being in company of another person is important during darkness. However the pattern of active social interaction in groups of three or more is increased in the evening only in Lindeborg square. It implies that spatial light distribution is important to sustain patterns of social interaction.

Results suggests that teens have a higher presence in EL than in DL in Lindeborg square, while this pattern is not evident in Kirseberg square. Although this study is limited to two squares, it suggests that lighting may sustain social interaction and spatiotemporal pattern after dark, as was displayed for teens in Lindeborg square. However, the results also indicate that for small children and elderly the after dark conditions do not sustain their presence at any of the squares. Results for verbal and non-verbal interaction are contradictive. Research on pedestrians indicate that lighting may impede or facilitate walking through the support of accessibility, reassurance, comfort and pleasure.[15] Investigations on movements and stationary activities in local public squares also imply that lighting may sustain use of public squares.[11] However further attention and focus on how lighting may support social life in public space is needed, as the provision of inclusive and participatory public spaces are considered a universal right. Future research should strive to investigate user's appraisal in relation to the spatial, spectral, intensity and temporal characteristics of lit environments in relation to the afforded social and physical qualities of the settings.

5. Conclusion

This investigation indicates that EL may sustain spatiotemporal patterns of social interaction in local public squares after dark. Spatial distribution might be an important lighting characteristic for social interaction. However further research is required to confirm how different lighting characteristics might impede, facilitate or vitalize social interaction in public spaces.

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Appendix III

Social Interaction in Public Squares: The role of users' environmental appraisals during daylight and after dark

V.K.R. Hennig[a]*, N. Gentile[b] and M. Johansson[a]

[a] *Environmental Psychology, Department of Architecture and Built Environment, Lund University, Lund, Sweden;* [b] *Division of Energy and Building Design, Dept. of Building & Environmental Technology, Lund University, Lund, Sweden*

*corresponding author: V.K.R. Hennig, Environmental Psychology, Department of Architecture and Built Environment, Lund University, SE-221 00, Sweden, katarina.hennig@abm.lth.se

https://orcid.org/0000-0001-7714-7148

Social Interaction in Public Squares: The role of users' environmental appraisals during daylight and after dark

Abstract

Public squares are important spaces for social interaction, yet the influence of lighting on people's experience and social interaction in such spaces after dark is poorly understood. This study examines users' environmental appraisals and self-reported social interaction in two public squares in Sweden, comparing daylight with electric lighting after dark. The results show that perceived atmosphere is associated with self-reported social interaction in public squares after dark. In turn, the perceived atmosphere can be attributed to users' environmental appraisals of lighting quality, visual accessibility, and reassurance. It is argued that lighting design plays an important role in socially sustainable public squares.

Keywords: public squares, social interaction, lighting, environmental appraisals, user needs, social sustainability

Introduction

Light provides visual information and is a prerequisite for many human activities, including social interaction (Boyce 2019, p.1; de Kort and Veitch 2014). The luminous condition supports (or obstructs) the way we perceive and appraise (i.e. interpret and evaluate) our life spaces (Küller 1991; Veitch 2001; de Kort 2019; de Kort and Veitch 2014; Baron, Rea, and Daniels 1992). To advance our understanding of how lighting may facilitate social interactions in public spaces after dark, it is essential to investigate users' environmental appraisals in both daylight and after dark conditions (Casciani 2020).

In particular, in countries at northern latitudes where daylight hours are very limited during part of the year (Rahm, Sternudd, and Johansson 2021), the design of lighting is instrumental in sustaining social life in public spaces after dark (Boyce 2019).

A key objective of socially sustainable urban environments is the provision of quality public spaces, here defined as 'publicly accessible spaces' that are meaningful, responsive and protective of rights of different user groups (Carr et al. 1992). If well-designed, such spaces may generate public life, support social interaction (Mehta 2014), and foster sociality and community engagement (Carr et al. 1992; Crowhurst Lennard and Lennard 1987; Madanipour 1999; Francis et al. 2012). Moreover, public space that allow for social interaction may also support individuals' sense of belonging, well-being and health (Kent and Thompson 2014; Mouratidis 2021; Cattell et al. 2008).

This study investigates how users appraise luminous environments of public squares in daylight as compared to electric lighting after dark, and analyses to what extent environmental appraisals may contribute to explain social interaction. The focus is upon public squares in neighbourhood communities, i.e. public spaces that constitute everyday life spaces of the users, here defined as those who frequent public squares and rely on them for passive and active engagement (Francis 1989).

Social interaction in public squares

Public squares may provide opportunities for 'interrelatedness with other human beings' (Crowhurst Lennard and Lennard 1987). The prospect of social interactions ranges from between strangers to categorically known, acquainted and friends (Lofland 2009; Simões Aelbrecht 2016). Social interaction typically occurs while being co-present with others; it may be passive, without direct participation, presenting an opportunity 'to see and be seen', yet inducing a sense of belonging (Cattell et al. 2008), or active expressed as e.g., 'face engagement' (a mutual glance of recognition), and 'chance encounters' involving greeting, chatting or socializing (Goffman 1966).

Lighting research with a socially oriented scope argues that light, whether daylight or electric, provides a critical infrastructure by enabling people's daily routines of social interaction in public spaces (Bordonaro, Entwistle, and Slater 2019). Empirical studies confirm that lighting may sustain patterns of user behaviour in public squares after dark; e.g., movements and stationary activities (Boyce 2019; Hennig et al. 2023), and social interaction (Casciani 2020; Davoudian 2019; Hennig et al. 2022).

Programming to facilitate social interaction after dark

Public squares are proposed, built and assessed with assumptions about the activities they should support (Carr et al. 1992). The concept of 'programming' of a square relates the design (physical attributes) to intended function and use (Dovey 2016). Aligning the physical layout of a space with its intended activities is imperative to facilitate social interaction (Gaver 1996; Mehta 2009, 2007).

Research comparing daylight and after dark scenarios, has empirically shown that behaviours exhibit spatio-temporal patterns, i.e. they are associated with functional units, and occur within specific timeframes in a given square (Hennig et al. 2023). Hence, electric lighting needs to be integral to the programming to facilitate social interaction in public squares after dark across diurnal and seasonal variations in daylight.

Accommodating user needs after dark

Studying the needs and preferences of users is crucial to the understanding of how public squares are used and therefore an important prerequisite for urban design and management of public space (Francis 1989). User needs associated to the use of public squares include access, safety, comfort, pleasurability, and inclusiveness amongst other factors (Mehan 2017; Mehta 2014; Whyte 2001). Essentially, lighting design professionals strive to create luminous conditions to accommodate these user needs after dark, e.g., by ensuring visibility, way-finding, safety, comfort and enhancing atmosphere (Veitch 2001). Recently, lighting research points to the importance of supporting these user needs in order to sustain social interaction after dark (Casciani 2020).

A transactional-contextual perspective

Theoretically, this study employs a transactional-contextual perspective derived from the field of environmental psychology, which focuses on the dynamic interplay (transactions) between people and their every-day environmental settings (contexts) (Bonnes and Secchiaroli 1995).

This perspective is elaborated in a socio-physical conceptual model (Figure 1) to interpret the lighting-behaviour relationship of the individual (user), the setting (public square in daylight and after dark), the users' environmental appraisals, and the behavioural outcome in terms of social interaction (Hennig et al. 2022). The model departs from four modes of human-environment transactions; the interpretative, the evaluative, the responsive and operative mode (Stokols 1978). The model stipulates that lighting, characterised by its spatial, spectral, intensity and temporal characteristics, portrays the physical properties and social opportunities of the setting, shapes the individual's environmental appraisal (interpretative and evaluative modes) thereby influencing his/her behaviour (responsive and operative modes) (Hennig et al. 2022).

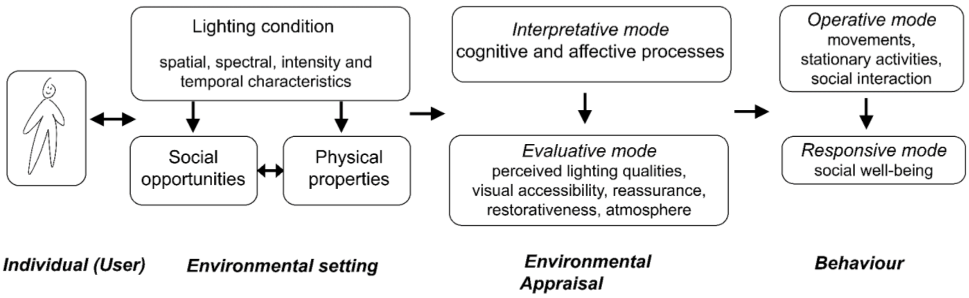

Figure 1. Socio-physical conceptual model of the behavioural relationship between the individual, the environmental setting, the environmental appraisal and the behavioural outcome. Adopted from Hennig et al. 2022.

Environmental Appraisals

In psychology, the concept of appraisal is rooted in the understanding that cognitive and affective processes are intrinsically intertwined, and are made at 'different levels of psychological processing'; at a psycho-physiological 'direct, immediate and intuitive level' and at more conscious and cognitively elaborated levels (Del Aguila, Ghavampour, and Vale 2019; Johansson, Gyllin, et al. 2014; Kappas 2006; Leventhal and Scherer 1987). Accordingly, environmental appraisals refer to cognitive, affective and emotional psychological processes through which an individual interpret and evaluate the characteristics of an environmental setting (Gifford 2014; Johansson, Gyllin, et al. 2014).

Luminous conditions have been associated to users' environmental appraisals of perceived outdoor lighting qualities (Johansson et al., 2014), perceived visual accessibility (Johansson, Küller, and Rosén 2011; Rahm and Johansson 2021), reassurance (safety) (Boomsma and Steg 2014; Haans and de Kort 2012; Fotios, Unwin, and Farrall 2015), and atmosphere (Stokkermans et al. 2018, 2017). Assessments of these environmental appraisals in the context of luminous conditions at public squares are rare, and the link to behavioural outcomes in terms of self-reported social interaction is not yet fully explored.

Aim

This study aims to investigate users' environmental appraisals in daylight (DL) and in electric lighting (EL) after dark of two public squares in Malmö, Sweden, and to identify environmental appraisals that may be associated with social interaction in squares after dark. Four objectives were targeted:

(1) To compare users' self-reported pattern of social interaction between lighting conditions and squares.

(2) To compare users' appraisals of perceived lighting qualities, visual accessibility, reassurance, and atmosphere between lighting conditions and squares.

(3) To identify any association between users' self-reported patterns of social interaction and appraisal of atmosphere in EL after dark.

(4) To identify any association between perceived atmosphere and perceived lighting qualities, visual accessibility, and reassurance in EL after dark.

Overview of investigated environmental appraisals

Based on previous empirical research, the environmental appraisals investigated in this study are expected to be of importance for facilitation of social interaction in public squares as outlined below (Johansson, Tsiakiris, and Rahm 2024; Hennig et al. 2022).

Perceived outdoor lighting quality (POLQ)

Perceived lighting quality in outdoor conditions may be described with two dimensions: 1) perceived strength quality, which captures brightness perception, and 2) perceived comfort quality which captures hedonic tone, i.e. the extent to which the light is perceived as soft, natural and warm (Johansson, Pedersen, et al. 2014). These two dimensions of perceived outdoor lighting quality have implications for perceived visual accessibility and perceived reassurance (Johansson, Küller, and Rosén 2011).

Perceived visual accessibility

Perceived visual accessibility refers to the individual's self-reported experience of seeing, e.g., performing visual task such as way-finding, detecting obstacles on the ground and recognizing people's faces (Johansson, Küller, and Rosén 2011). Lighting aids way-finding by revealing 'the immediate world in detail and the distant world in form' (Boyce 2014, 427). Facial recognition is an important visual task since it allows one to judge the intention of others (Fotios and Johansson 2019), and enables social interaction such as face-engagement. It is hypothesised that perceived visual accessibility is a prerequisite for enabling social interaction.

Perceived reassurance

Perceived reassurance encompasses both perceived safety and fear of crime. Reassurance is that which provides the comfort that makes someone feel less worried, less afraid and which restores confidence (Fotios, Unwin, and Farrall 2015). Reassurance is used here to describe the confidence a person might gain from lighting, i.e. feeling safe and being at ease when visiting a square. Several studies on the impact of lighting on reassurance/safety (Blobaum and Hunecke 2005; Haans and de Kort 2012; Boomsma and Steg 2014) (including the present) have a common denominator in utilizing prospect and refuge theory (Appleton 1975), which posits that the preference for a setting is dependent on the possibility to get an overview (prospect) from an advantage point (refuge). It is hypothesised that the greater the feeling of reassurance after dark, the greater the support of social interaction.

Perceived atmosphere

Atmosphere, here refers to affective qualities attributed to an environment (Stokkermans et al. 2017). Light significantly influences the visual appearance of a space and is associated to the appraisals of atmosphere (Stokkermans et al. 2018). Flynn et al. (1973) distinguished three main factors to differentiate the impression of an illuminated room, perceptual clarity, spaciousness and pleasantness, with pleasantness identified as an evaluative factor. In particular two perceptual attributes of light, brightness and uniformity, have been found to influence the atmosphere of a space (de Kort 2019). These perceptual attributes, in turn, depend on the intensity characteristics and the spatial distribution of light (Stokkermans et al. 2018; Veitch 2001). Stokkermans et al. (2018) proposed four dimensions to describe atmosphere, i.e. cosiness, liveliness, tenseness and detachment. The perceived brightness and uniformity of light showed a clear relationship with these dimensions (Stokkermans et al.

2018). Further, the spectral power distribution of the light affects brightness and the appreciation of a visual scene (Fotios and Cheal 2007; Bullough et al. 2014).

Böhme (2017) theorizes atmosphere as a 'tuned space', infused with a particular mood, produced by various agents in specific illumination. Hence, atmospheres can be 'produced' in architecture and design, and likewise 'illuminations are perceived as atmospheres' that unify the diverse elements within a space into a cohesive whole (Böhme 2017, pp.202-203). This means that atmospheres are also 'perceived' by the individual, reflecting his or hers subjective and overall impression of space (Böhme 2017). In line with Böhme's theory studies with a social-oriented lighting design approach suggest that the perceived atmosphere in a public square after dark is of importance for social interaction, i.e. lighting design is crucial in producing an atmosphere that can 'socially enhance a space' (Casciani 2020).

In this study 'perceived atmosphere' is considered as an overarching construct (e.g. appraisal), presumed to be associated with perceived lighting quality, visual accessibility, and reassurance. Following Casciani (2020), it is hypothesised that the appraisal of pleasant atmosphere is a prerequisite for social interaction.

Methods

A questionnaire survey on users' self-reported patterns of social interaction and users' environmental appraisals in daylight (DL) and in electric lighting (EL) after dark was conducted in two public squares in Malmö, Sweden. The socio-physical conceptual model (Figure 1) was applied in the survey based on validated constructs (environmental appraisals), enabling the investigation on the association between environmental appraisals and self-reported social interaction after dark. The survey follows from previous observational studies of the squares (Hennig et al., 2022; 2023).

Settings

The two investigated squares, Kirseberg square (Figure 2) and Lindeborg square (Figure 3) have similar programming, that is physical settings with similar functional zones for stationary and social activities (zones A) arranged with benches, trees and planting, and paths for movements (zones B and C), and provide necessity-based commerce and services (zones B) in the respective neighbourhood. The Zones A are the predominant areas for stationary and social activities and zones B and C for movements (Hennig et al. 2022; Hennig et al. 2023). However, the lighting installations and therefore the after dark lighting conditions and appearances of the square are dissimilar.

Kirseberg Square (Figure 2) in northern Malmö is located in the centre of the neighbourhood Kirsebergsstaden, which has approximately 5300 inhabitants ("Statistikunderlag för Malmö," 2022). The demographic and socio-economic profiles of Kirsebergsstaden are shown in Table 1. The square and the surrounding buildings were constructed in the 1960s (Riksantikvarieämbetet). To the west, there is a four-storey residential building with balconies on each floor facing the square. To the east, there is a three-storey dark brick building that hosts a children's day-care centre and a pharmacy (open from 8.00 to 18.00). To the south, there is a one-storey building with a grocery store (open from 8.00 to 22.00) and the gable end of a seven-storey residential building. Along Vattenverksvägen to the north, there are small-scale, residential houses typical of the old street view of Kirseberg. The square has an area of approximately 3100 m², with a parking area to the south and a stationary occupancy area of around 700 m² to the north (zone A), with a soft-scape of cherry trees, lime trees, and rose bushes. Benches in each corner provide both shady and sunny seating in daylight. Additionally, there is a boule-court and a large sculpture. A pedestrian route paved with light concrete slabs runs along the south and west side of the square (zone B). Regular vehicle traffic is allowed in a one-way direction, mixed with pedestrians and cyclists (zone C), and this area is paved with concrete stones.

Table 1. Demographic and socio-economic profiles of the two neighbourhoods

	Age						
	0-19 yrs		20-64 yrs		> 65 yrs		Total
Kirsebergsstaden	997	19%	3661	69%	651	12%	5309
Lindeborg	1107	22%	2636	53%	1227	25%	4970
	Education (in age group 20-64 years)						
	Primary		Secondary		Post-secondary or higher		Other
Kirsebergsstaden	12%		36%		48%		4%
Lindeborg	11%		47%		38%		4%
	Economic facts						
	Average income		On welfare aid				
Kirsebergsstaden	249 000 SEK		8%				
Lindeborg	289 000 SEK		1%				
Malmö	297 000 SEK		7%				

Lindeborg Square (Figure 3) in southern Malmö is located in the centre of the neighbourhood Lindeborg, which has approximately 5000 inhabitants. The demographic and socio-economic profiles of Lindeborg are shown in Table 1. The square and its surrounding buildings were constructed in the 1970s (Riksantikvarieämbetet 2021). The square is approximately 3100 m². In the centre of the square there is a designated area for stationary occupancy (zone A) of around 1300 m². A pedestrian and bicycle path runs along the north side (zone B) and also along the west side of the square (zone C). The low commercial building to the north hosts a grocery store, a flower-shop, a pharmacy, a gym and a pizzeria (with opening hours from 8.00 to 22.00). Lindeborg elementary school (open at weekdays from 8.00 to 15.00) is situated in the south-east corner and a church (with daytime and occasionally evening activities) at the west side of the square. Both of these buildings have warm red brick walls which harmonizes with the red hardscape of the square. The soft-scape consists of lime trees and cherry trees, cut hedges of beach, and flowerbeds with perennials. There are plentiful seating, a central water feature, and a little sculpture.

Figure 2. Plan of Kirseberg square with photos of the functional zones A, B and C, in DL (above) and in EL (below).
Illuminance measurements in callouts show average illuminance (Ē) and uniformity of illuminance (U_o) after dark.

Figure 3. Plan of Lindeborg square, with phots of the functional zones A, B and C, in DL (above) and in EL (below).
Illuminance measurements in callouts show average illuminance ($\bar{E}$) and uniformity of illuminance (U_0) after dark.

After dark appearances and social performance of the squares after dark

The after dark appearance and ambience of the two squares are dissimilar, due to difference in the choice of luminaire types and characteristics of the lamps. These differences are notable in terms of spatial light distribution, level of uniformity, contrasts in the visual field and spectral characteristics (Technical descriptions are available in the Appendix Tables A3 and A4, light units are illustrated in Figure A1, and technical assessments of the visual impression in Figure 4). Kirseberg square (with Metal Halide lamps and direct distribution) has in general higher light levels (illuminances) but lower uniformity, resulting in large contrasts between very bright and very dark areas in the visual field, in specific in zone A (Hennig et al. 2022). The lit sign of the grocery story increases this contrast. Windows in the residential building give a lit impression to the façade and 'provide eyes on the square'. The adjacent dark brick wall façade is completely dark after 18.00 o'clock when services are closed.

Lindeborg square (with a diffuse light distribution from park lanterns and HPS lamps) instead has lower light levels (illuminances) but higher uniformity than Kirseberg. The lit scene has a warm ambiance, diffuse and soft, but with poor contrasts, poor modelling of objects and spatial elements and distorted colour appearance of plant materials (Hennig et al. 2022). Paths in zones B and C are uniformly lit and the commercial building provides a lit impression with higher lighting levels at entrances until 22.00 o'clock.

The preceding observational studies showed that stationary and social activities (zones A) were sensitive to the changes in lighting conditions from DL to EL. In Kirseberg, zone A, these activities were not sustained after dark, while in Lindeborg, zone A, social interaction was in fact increased after dark (Hennig et al. 2022; Hennig et al. 2023), with teens in the neighbourhood inhabiting the square both in DL and in EL. Previous research suggests that the lighting condition alter the environmental appraisals of the setting and may thereby facilitate or impede behaviours (Hennig et al. 2022; Rahm, Sternudd, and Johansson 2021;

Johansson, Tsiakiris, and Rahm 2024). Hence, the observational studies imply that spatial distribution of light, and a balance of contrasts in the visual field are salient features important for sustaining stationary activities, and social interaction in public squares (Hennig et al. 2022; Hennig et al. 2023).

A plausible explanation to the decrease in stationary activities and social interaction in zone A Kirseberg, would be the poor lighting condition (depicted in Figure 4, top). Large contrasts between dark and bright areas in the field of view may refrain users from visiting this area after dark.

Figure 4. HDR-images with corresponding luminance maps. Kirseberg (top): illustrating a high contrast between dark and bright areas in the field of view, with luminance levels between 0.1 cd/m^2 to 20.0 cd/m^2. Lindeborg (below): illustrating a uniform light distribution with low luminance levels between 0.3 cd/m^2 to 1.0 cd/m^2.

Participants

Participants were invited to assess the two squares on-site. The sample comprised in total 158 participants, with 68% female and 32% male, aged between 18 years and 85 years, with a mean age of 54 years. The participants were split into four groups, Kirseberg DL, Kirseberg EL, Lindeborg DL and Lindeborg EL, further described in Table 2.

Table 2. Demographic data of the participants: mean age, gender representation, and proportion who were local residents in the respective neighbourhood.

Sample		Age	Female		Male		Residents
	N	Mean yr.	N	%	N	%	%
Total	158	54	107	68	51	32	98
Kirseberg in DL ☼	37	55	26	70	11	30	100
Kirseberg in EL ☽	49	48	31	63	18	37	98
Lindeborg in DL ☼	38	62	26	68	12	32	98
Lindeborg in EL ☽	34	52	24	71	10	29	94

Procedure

Data were collected in the last two weeks of March 2022, on weekdays from Monday to Thursday (i.e. four weekdays per square), during two sessions per day; in the afternoon between 3 pm and 5 pm in DL and in the evening between 6.30 pm and 8.30 pm in EL. During the data collection period the weather conditions were stable with no precipitation and with an average temperature of 5^{o} C. Sky-conditions varied from clear sky to overcast. Participants were recruited on site and through advertisement in direct mail and social media.

Each sampling session started with a briefing about project aim, procedure and research ethics. Participants were informed that their participation would be anonymous and voluntary, with the option to withdraw at any time. Written informed consent was obtained from all participants. No formal ethical approval was needed since the questions did not address personal sensitive information as defined by the Swedish Ethical Review Authority (Etikprövningsmyndigheten 2023). Participants were asked to walk around a few minutes to reflect on how they perceived the setting before completing the questionnaire at the location marked with a triangle (representing a position of refuge) in zone A, Figures 2 and 3, (Johansson, Pedersen, and Weisner 2019). The viewing direction was marked with an arrow to ascertain equivalent assessments. All participants received a voucher of 100 SEK.

Measures

Appendix Table A1 summarises the employed scales and items of the questionnaire. Participants reported their social interaction in the square, ranging from passive engagement (e.g., being co-present and recognising others) to active engagement (e.g., greeting, chatting to others, and socialising with friends). Responses to four statements assessing social interaction were given on a 5-point Likert scale (1 = no, definitely not; 5 = yes, definitely). This scale was previously pilot-tested with regard to length and formulation of items among residents visiting the two squares.

Participants also assessed their environmental appraisals on established scales, i.e. questionnaire batteries previously shown to be valid and reliable for pedestrian perception in outdoor urban space (Appendix Table A1).

Ratings of the perceived lighting quality, *How do you perceive the light in this place?*, was captured using a 7-point bipolar semantic differential (SD) scale of 8 items (the perceived outdoor lighting quality scale) (POLQ) (Johansson, Pedersen, et al. 2014). Ratings on perceived visual accessibility, *How well can you see in this light?*, were given on 5 items, (Johansson, Küller, and Rosén 2011), and reassurance, *How do you perceive being in this place?*, (Blobaum and Hunecke 2005; Johansson, Küller, and Rosén 2011) were given on 7 items, on 5-point Likert scales (1 = no, definitely not; 5 = yes, definitely).

Perceived atmosphere, *How do you experience the atmosphere in this place?*, were rated on a single item 5-point Likert scale (1 = not at all; 5 = very much) adopted from Stokkermans et al., (Vogels 2008; Stokkermans et al. 2018) and expanded with items developed by Flynn et al. (Flynn et al. 1973) and (Casciani 2020).

Analyses

Statistical analyses were performed in IBM SPSS 29, in the following steps:

1) Possible sub-dimensions of atmosphere were investigated by an exploratory factor analysis. Two components had eigenvalues over Kaiser's criterion of 1 and in combination explained much of the variance (66% for factor loadings after rotation). Items that loaded on the first factor related to the perceived pleasantness of atmosphere, and account for 37% of the total variance. Items that loaded on the second factor relate to the perceived hostility of atmosphere. This factor accounts for 29% of the total variance.

2) Scale reliability tests (Cronbach's alpha) were performed for each scale (self-reported social interaction, POLQ, perceived visual accessibility, perceived reassurance, and perceived pleasantness and hostility of atmosphere respectively) and for both lighting conditions to establish the internal consistency (reliability) of the scale. A value of Cronbach's $\alpha > 0.7$ for the averaged index was considered acceptable, appendix Table A1.

3) Analyses of variance (ANOVA) were conducted to test for differences (between subjects' effects) in users' self-reports of social interaction between squares and lighting conditions (objective (1)), and to test for differences in users' environmental appraisals of perceived lighting quality, visual accessibility, reassurance and atmosphere between squares and lighting conditions (objective (2)). A value of $p < 0.05$ was interpreted as significant and the partial eta-squared η_p^2 was used to assess effect size.

4) Two hierarchical multiple regression analyses were carried out. The first analysis aimed to establish if self-reported social interaction in EL after dark is associated to appraisals of atmosphere (objective (3)), and the second analysis aimed to identify

associations between atmosphere in EL after dark, and the environmental appraisals of perceived lighting quality, visual accessibility, and reassurance (objective (4)).

Results

Users' self-reported social interaction

The results for self-reported social interaction are based on the averaged mean of passive to active engagement (as illustrated in Figure 5), i.e. being co-present recognizing others, to greeting, chatting, and socializing with friends (Please refer to Table A1 for exact formulations of included items). The mean values show that in DL and EL after dark, self-reported social interaction is rated higher in DL for both squares (as illustrated in Table 3 and Figure 6).

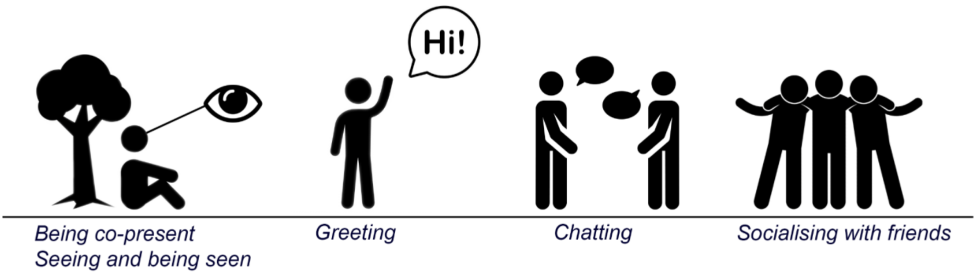

Figure 5. The continuum of social interaction from passive to active, including being co-present with others, greeting, chatting or socializing with friends.

Table 3. Descriptive statistics of self-reported social interaction in DL and EL after dark for Kirseberg square and Lindeborg square; showing the Mean (M), Standard Deviation (SD), Confidence Interval (CI) and Number (N) of participants per group.

	DL			EL		
Square	**N**	**M (SD)**	**CI 95%**	**N**	**M (SD)**	**CI 95%**
Kirseberg	37	3.58 (0.96)	3.28-3.88	49	3.47 (1.00)	3.21-3.73
Lindeborg	38	3.82 (0.83)	3.52-4.11	34	3.34 (0.84)	3.03-3.66

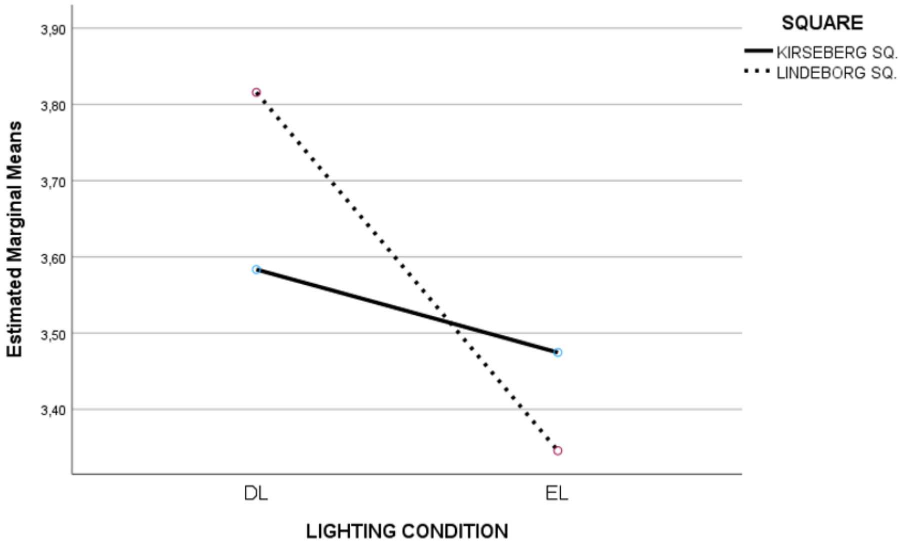

Figure 6. Estimated marginal mean of self-reported social interaction in DL and in EL after dark of Kirseberg square and Lindeborg square.

When testing for an effect of lighting condition or the specific square on participant's self-reported social interaction, the statistical analyses showed no significant main effect of square (Kirseberg and Lindeborg). This means that that the differences in social interaction can not be attributed to the square per se. However, a statistical tendency for an effect of lighting condition (DL and EL) could be identified with a low effect size, on self-reported social interaction ((F (1,158) = 3.82, p = 0.052, η_p^2 = .024) (Table 4). These results give an indication that self-reported social interaction decline in both squares after dark. There was no significant interaction between square and lighting condition on self-reported social interaction.

Table 4. ANOVA-table for self-reported social interaction. Tests of between subjects effects.

Measure	**Effect**	***F***	***df***	***p***	**η_p^2**
Social Interaction	Square	.122	1	.727	.001
	DL / EL	3.821	1	.052	.024
	Square * (DL / EL)	1.488	1	.224	.010

Users' environmental appraisals in DL and in EL after dark

The results for users' environmental appraisal in DL and in EL after dark is based on the averaged mean of the respective scale for perceived outdoor lighting quality, visual accessibility, reassurance, and pleasant / hostile atmosphere (Please refer to Table A1 for exact formulations of included items). These mean values and the significant differences for all appraisals are illustrated in Figure 7. The results show that all appraisals are higher in DL than in EL for both squares, with the exception of hostile atmosphere for which the results are reverse, i.e. higher in EL than in DL for both squares. The descriptive statistics (including mean, SD and CI 95%) of each environmental appraisal in DL and in EL after dark for Kirseberg and Lindeborg are presented in Tables 5 and 6.

Table 5. Descriptive statistics of dependent variables in DL and in EL for Kirseberg square.

Measure	**DL**		**EL**	
	Mean (SD)	**CI 95%**	**Mean (SD)**	**CI 95%**
POLQ - PSQ	4.26 (1.16)	3.87-4.64	4.06 (1.23)	3.72-4.39
POLQ - PCQ	NA	NA	3.73 (1.25)	3.45-4.00
Visual Accessibility	4.72 (0.68)	4.89-4.96	3.99 (0.84)	3.78-4.19
Reassurance	4.23 (0.75)	3.97-4.49	3.47 (0.82)	3.24-3.69
Atmosphere - pleasant	2.99 (0.99)	2.71-3.28	2.37 (0.97)	2.13-2.62
Atmosphere - hostile	1.64 (0.84)	1.34-1.94	2.30 (1.03)	2.04-2.56

Note: Abbreviation POLQ – PSQ denotes Perceived Strength Quality and PSQ denotes Perceived Comfort Quality

Table 6. Descriptive statistics of dependent variables in DL and in EL for Lindeborg square.

Measure	**DL**		**EL**	
	Mean (SD)	**CI 95%**	**Mean (SD)**	**CI 95%**
POLQ - PSQ	3.61 (1.05)	3.23-3.99	2.97 (1.31)	2.57-3.38
POLQ - PCQ	NA	NA	4.55 (0.91)	4.22-4.88
Visual Accessibility	4.75 (0.42)	4.52-4.98	3.81 (0.84)	3.56-4.05
Reassurance	3.89 (0.71)	3.64-4.16	3.41 (0.96)	3.14-3.69
Atmosphere - pleasant	2.89 (0.75)	2.61-3.17	2.46 (0.72)	2.16-2.75
Atmosphere - hostile	1.95 (0.78)	1.66-2.25	2.21 (0.98)	1.89-2.52

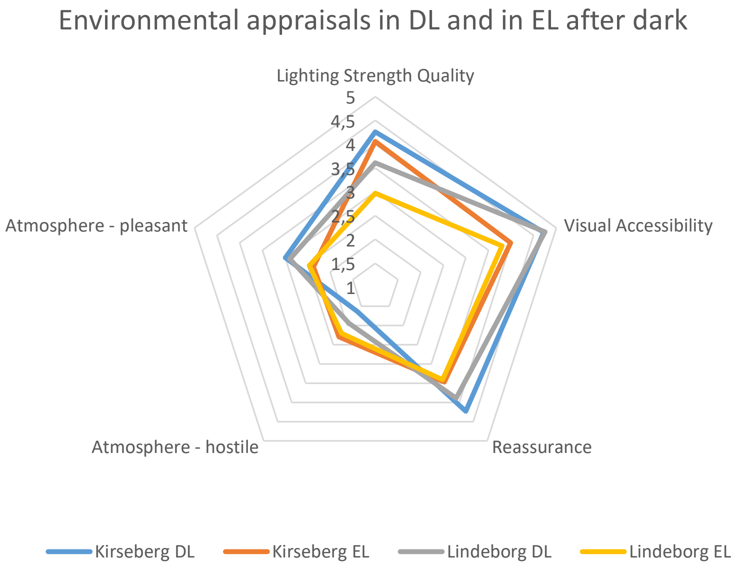

Figure 7. Estimated marginal mean of environmental appraisals in DL and in EL after dark of Kirseberg square and Lindeborg square. Significant differences (*p*-value < 0.05) and source (square, DL/EL) are shown in boxes.

Differences between users' appraisals of perceived lighting qualities, visual accessibility, reassurance, and atmosphere between DL and EL and between the two squares (objective 2) were also tested for statistically.

The ANOVA analyses revealed significant main effects of square (F (1,158) = 20.39, p < 0.001, η_p^2 = .117) and lighting condition (DL and EL) (F (1,158) = 4.83, p = 0.029, η_p^2 = 0.030) for users' appraisals of lighting quality (perceived strength dimension). This means that the light was perceived as stronger in DL than in EL, and as stronger in Kirseberg as compared to Lindeborg. There was no significant interaction effect.

The results also show significant main effects of lighting conditions for each of the assessed environmental appraisals, revealing more favourable assessments in DL than EL. Visual accessibility (F (1,158) = 52.29, p< 0.001, η_p^2 = .253), reassurance (F (1,158) = 23.00, p < 0.001, η_p^2 = .013), pleasant atmosphere (F (1,158) = 14.18, p < 0.001, η_p^2 = .084) were consistently assessed as higher in DL than in EL. As for hostile atmosphere (F (1,158) = 9.49, p = 0.0002, $\eta_p{}^2$ = 0.058), EL was assessed as higher than DL. These results were essentially the same for both squares as no main effects of square or interaction effects between lighting condition and square were identified. All statistics for ANOVAs with the different environmental appraisals as dependent variables are presented in the Appendix Table A2.

Association between appraisal of atmosphere and self-reported social interaction

In order to identify any association between appraisal of atmosphere and self-reported social interaction in EL after dark, and to identify any association between appraisals of visual accessibility, reassurance, lighting qualities and pleasant atmosphere in EL after dark, hierarchical multiple regression analyses were carried out.

In the hierarchical regression the choice of explanatory variables and the order they are entered into the analyses are based on theoretical assumptions. In our case this in relation to objective 3 refers to the idea that appraisal of atmosphere would predict self-reported social interaction (Casciani 2020, p.130). Furthermore in relation to objective 4 that lighting supporting visual accessibility and reassurance, hence 'socially enhance the space' would contribute to achieve the experienced atmosphere.

The hierarchical regression makes it possible to assess the incremental predictive power of the variables entered into the analyses in each model.

The result of the first hierarchical multiple regression analysis with *social interaction* as outcome variable, the setting (square) is introduced in model 1, and demographic variables (age and gender) are introduced in model 2, followed by the atmosphere in model 3 (Table 7).

Table 7. Co-efficient table of hierarchical multiple regression analysis with self-reported social interaction in EL after dark as outcome variable.

	Model 1 Square (*N* =83)			Model 2 Gender & Age (*N* =83)			Model 3 Atmosphere - pleasant (*N* =83)		
Self-reported Social Interaction	*B*	SE B	*β*	*B*	SE B	*β*	*B*	SE B	*β*
Constant	3.60	0.31		2.29	0.47		1.64	0.49	
Square Kirseberg = 1 Lindeborg = 2	-0.13	0.21	-0.68	-0.23	0.18	-0.12	-0.25	0.17	-1.32
Gender Male = 1 Female = 2				-0.01	0.19	-0.01	0.06	0.18	-0.03
Age (low – high)				0.30	0.01	0.51***	0.03	0.01	0.52***
Atmosphere - pleasant (Not at all = 1; Very much = 5)							0.31	0.10	0.29**
Model summary (Goodness of fit)	$F(1,81) = 0.376$, $p=0.542$, $R^2=0.005$, $R^2_{adj} = -0.008$			$F(3, 79)=9.52$, $p<.001$, $R^2=0.265$, $R^2_{adj} = 0.238$			$F(4, 78)=10.41$, $p=0.002$, $R^2=0.348$, $R^2_{adj} = 0.315$		

In model 1, square is entered as predictor variable. In model 2, gender and age are added, and in the final model 3, atmosphere (pleasant) is also entered. $^{*}p$ <.05, $^{**}p$ <.01, $^{***}p$ <.001.

The analysis with perceived social interaction as outcome variable suggests that age is a predictor at a significant level of $p < 0.001$, with an explanatory power of 24% of the variance explained in model 2, and that the appraisal of pleasant atmosphere is a predictor at a significant level of $p = 0.002$, increasing the explained variance to 31% in model 3. The direction of the beta-values show that participants of higher age and with higher assessments of pleasant atmosphere also report a higher level of social interaction

Also in the second hierarchical multiple regression analysis with *pleasant atmosphere* as outcome variable the setting (square) is introduced in model 1, and demographic variables (age and gender) are introduced in model 2. In model 3 the perceived lighting qualities were entered, and in model 4 the appraisals of visual accessibility and reassurance (Table 8).

Table 8. Co-efficient table of hierarchical multiple regression analysis with pleasant Atmosphere in EL after dark as outcome variable.

Atmosphere - pleasant	Model 1 Square, (*N* 83)			Model 2 Gender & Age (*N* 83)			Model 3 POLQ (*N* 83) Strength & Comfort			Model 4 Visual accessibility & Reassurance (*N* 83)		
	B	SE B	*β*	*B*	SE B	*β*	*B*	SE B	*β*	*B*	SE B	*β*
Constant	2.29	0.29		2.10	0.51		0.68	0.52		0.16	0.49	
Square Kirseberg = 1 Lindeborg = 2	0.08	0.19	0.05	0.08	0.19	0.04	-1.01	0.19	-0.58	-0.74	0.17	-0.42
Gender Male = 1 Female = 2				0.16	0.21	0.09	-0.53	0.17	-0.29	0.09	0.16	0.05
Age (low – high)				0.002	0.01	-0.03	-0.01	0.01	-0.09	0.00	0.01	-0.01
POLQ - strength							0.13	0.06	0.21*	0.12	0.06	0.19
POLQ - comfort							0.42	0.74	0.58***	0.31	0.71	0.43***
Visual accessibility										-0.29	0.11	-0.29**
Reassurance										0.49	0.10	0.49***
Model summary (Goodness of fit)	$F(1, 81)=0.185$, $p=.668$, $R^2=0.002$, $R^2_{adj}=-0.01$			$F(2,79)=0.290$, $p=0.833$, $R^2=0.011$, $R^2_{adj}=-0.027$			$F(2,77)=8.753$, $p<.001$, $R^2=0.362$, $R^2_{adj}=0.321$			$F(2,75)=11.60$, $p<.001$, $R^2=0.520$, $R^2_{adj}=0.475$		

In model I, square is entered as predictor variable. In model 2, gender and age are added. In the model 3 lighting qualities strength and comfort are added and in the final model 4 visual accessibility and reassurance are also entered.
$^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

The results suggest that the *perceived lighting quality* is significantly associated with; the perceived *strength quality* ($p < 0.05$) and the perceived *comfort* quality ($p < 0.001$), with 32% of the variance explained in model 3. Furthermore, adding *visual accessibility* ($p < 0.01$) and *reassurance* ($p < 0.001$), increased the explained variance in model 4 to 48%. Hence, a pleasant atmosphere is supported by (dependent on) the way lighting is perceived, with a higher assessment of perceived strength quality, visual accessibility and reassurance being associated with a pleasant atmosphere

Discussion

This study concerned the role of lighting in sustaining social interaction in public squares as mediated by users' environmental appraisals. The two squares investigated did not significantly differ with regard to the participants' self-reported social interaction. Neither did the DL and EL condition (cf. objective 1). However, the comparison of self-reported social interaction between DL and EL revealed a statistical tendency ($p = .052$) in the direction towards self-reported social interaction declining after dark. Two preceding observational studies conducted in the same squares (Hennig et al. 2022; Hennig et al. 2023), revealed a significant decrease in active social-interaction in the afternoon in EL after dark and also a significant decrease in stationary activities in the evening in EL after dark in Kirseberg square. On the contrary, stationary activities and social interaction increased in Lindeborg square after dark. Observations of presence per age group (Hennig et al. 2022), showed that the increase in social interaction refers to teens present in the square after dark. People below the age of 18 years were excluded from the present study, which may explain discrepancy in results between self-reported social interaction and observed social interaction.

The results of the ANOVA of users' environmental appraisals (cf. objective 2) in this study show a significant perceptual difference in the lighting quality between the two squares, and also between DL and EL. A comparison of the technical assessments of the electric lighting conditions in zones A of the squares – programmed for stationary and social activities – confirms perceptual differences between the squares. In comparison to Kirseberg, Lindeborg has much lower contrasts between dark and bright areas in the field of view (up to two order of magnitudes, with ranges from 0.1-3.0 cd/m^2 against and 1.0-20.0 cd/m^2 for Lindeborg and Kirseberg respectively). Additionally, in Lindeborg the average horizontal illuminance is lower but uniformity higher ($\bar{E} \approx 4.5$ lx and $U_o \approx 0.15$ against $\bar{E} \approx 16.0$ lx and $U_o \approx 0.03$), and the colour temperature is warmer (CCT ≈ 2000K and CCT ≈ 2800K respectively) (Hennig et al. 2023). The discrepancy in appraisals of lighting quality between squares support the idea that individuals use luminance distribution in their appraisals of the appearance of a scene, with brightness and interest (variability, non-uniformity) being the two dominant judgments (Veitch 2001).

The results of the ANOVA (cf. objective 2) of users' appraisals of visual accessibility, reassurance and of pleasant atmosphere show a significant difference between DL and EL, with all ratings in DL being significantly higher than in EL and the ratings of hostile atmosphere being significantly lower in DL than in EL. These results are well in line with previous studies showing that visual perception (Boyce 2014) and thus the feeling of reassurance (Fotios and Castleton 2016) and the appreciation of atmosphere in public squares (Nasar and Bokharaei 2016) alters as the sun sets.

The result of the first hierarchical multiple regression analysis (cf. objective 3) with social interaction as an outcome variable confirms that besides the participants' age, a pleasant atmosphere is also associated with social interaction. Moreover, the second regression analysis (objective 4) confirms that perceived lighting quality (strength and comfort), visual accessibility and reassurance are associated with pleasant atmosphere in public squares (Table 8). While a difference between DL and EL of users' appraisals were expected (cf. objective 2) the results of the regression analyses (cf. objectives 3 and 4) propose that in order to sustain social interaction in public squares after dark, the design of electric lighting must accommodate user needs of visual accessibility, reassurance and thereby provide a pleasant atmosphere. These findings aligns with previous empirical evaluations of the quality of public space (Mehta 2014), which highlights lighting quality and perceived safety in public space after dark as important variables for social interaction. With regard to atmosphere, it is previously shown that perceived atmosphere is associated to perceived brightness, spatial distribution as well as uniformity of light (Stokkermans et al. 2018; Haans and de Kort 2012).

Appraisals are suggested to be important links in the understanding of the lighting – behaviour relationship, as plausible predictors of operative outcomes, such as social interaction in public squares. The empirical results provide support for the socio-physical conceptual model (Figure 1) outlining how the characteristics of light mediate individual's appraisal and therefore their behaviour.

More specifically the results suggest that users' social interaction is dependent on the appraisal of a pleasant atmosphere, which in turn is intrinsically interwoven with the feeling of reassurance and the ability to interpret a space visually and cognitively after dark. Although the findings are limited to two squares only, the results offer arguments and justification for further empirical research, and theoretical development on the concept of atmosphere. Especially with regard to how lighting may serve as an agent to improve atmosphere and support social interaction after dark (Casciani 2020; Hennig et al. 2022).

Methodological reflection

The choice of method in the present study is theory-driven and based on the transactional-contextual perspective in environmental psychology. By adopting a pragmatic stance, this theory is viewed instrumentally. It is operationalized through the application of a socio-physical conceptual model (Figure 1), used as an analytic tool to interpret the relationship between lighting and behaviour in public squares after dark. The configuration of the model departs from Stokols (Stokols 1978), and is rooted in previous empirical research on human-environment transactions in the field of environmental psychology (Giuliani and Scopelliti 2009). The method for assessing users' environmental appraisals in the present study is conducted at a generic level, using a set of previously established constructs in a questionnaire survey. This approach allows for a systematic investigation, employing statistical analyses to establish associations between environmental appraisals and self-reported social interaction. It also ensures replicability. Reliability of the employed measures was ensured in scale reliability tests. However, the approach is limited with regard to people's contextual understanding of the lighting and the meaning of light (Maini Gerhardsson 2020). Hence methodological triangulation would be desirable and further studies should aim to gain a deeper and more nuanced understanding of each environmental appraisal, as well as of the nature of social interaction in public squares. Such studies would requires a flexible research approach relying on for example on-site walking interviews.

An understanding of environmental appraisals allow us to categorize luminous conditions, for the purpose of describing preferences of a scene (Veitch 2001), and to predict operative outcomes. Pointing to a further need to conduct interventions in public squares, to establish how specific lighting characteristics (e.g., spatial distribution) may influence appraisals and impede or facilitate social interaction.

Conclusion

This study reported on users' environmental appraisals and self-reported social interaction in daylight compared to electric lighting after dark in two public squares in the city of Malmö, Sweden.

The findings confirm that users' environmental appraisals of perceived lighting qualities, visual accessibility, reassurance, and atmosphere are central to interpreting the lighting-behaviour relationship in public squares after dark.

Thus, this study offers arguments for implementation in lighting practice stipulating that the provision of socially sustainable public squares requires lighting that apart from accommodating user needs (such as aiding way-finding and legibility for necessary activities) is designed to induce positive affective connotations aimed to improve feelings of reassurance and a pleasant atmosphere, which are essential for supporting social interaction.

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Appendix

Table A1 Overview of employed scales and items used in the questionnaire to assess self-reported social interaction and environmental appraisals; perceived outdoor lighting quality, visual accessibility, reassurance and atmosphere. The internal reliability, Cronbach's alpha, is presented for both daylight and electric lighting condition.

Measurement	Item	Statements	Response	Internal reliability
Self-reported Social interaction		*Please report your pattern of social interaction in the square*	5-point Likert scale (1=no, definitely not; 5 yes, definitely)	$\alpha_{DL} = 0.80$, $\alpha_{EL} = 0.75$
	Soc.1	I often recognize people in the square.		
	Soc.2	When I encounter someone in the square whom I recognize, I usually say "hi".		
	Soc.3	I often chat to people that I meet in the square.		
	Soc.4	I often spend time in the company of friends in the square.		
Perceived outdoor lighting quality (POLQ)		*How do you perceive the light in this place?*	7-point bipolar semantic differential (SD) scale	
		Perceived strength quality		$\alpha_{DL} = 0.68$, $\alpha_{EL} = 0.81$
	PSQ1 PSQ2 PSQ3 PSQ4	Dark - Light Intense - Weak (-) Diffuse- Focused Dim – Bright		
		Perceived comfort quality		$\alpha_{DL} = 0.20$, $\alpha_{EL} = 0.59$
	PCQ1 PCQ2 PCQ3 PCQ4	Warm - Cold Hard - Soft Natural – Unnatural (-) Glary – shielded		Note: PCQ only used for the EL condition.
Visual Accessibility		*How well can you see in this light?*	5-point Likert scale (1=no, definitely not; 5 yes, definitely)	$\alpha_{DL} = 0.89$, $\alpha_{EL} = 0.84$
	VA1	I can see well.		
	VA2	I can see an obstacle on the ground.		
	VA3	I can recognize people's faces.		
	VA4	I can see details in the surrounding.		
	VA5	It is easy to find my way around here.		
Reassurance		*How do you perceive being in this place?*	5-point Likert scale (1=no, definitely not; 5 yes, definitely)	$\alpha_{DL} = 0.78$, $\alpha_{EL} = 0.83$
	PR1	I feel uneasy in this place. (-)		
	PR2	It is pleasant to stay at this place.		
	PR3	It feels fine to stay unaccompanied at this		
	PR4	I would make haste to get away from this place.		
	PR5	I would rather avoid being in this place. (-)		
	PR6	I have a good overview of this place.		
	PR7	I can easily escape from this place.		
Atmosphere		*How do you experience the atmosphere in this place?*	Single item 5-point Likert scale (1=not at all; 5=very much)	Dimension1 - Pleasant $\alpha_{DL} = 0.92$, $\alpha_{EL} = 0.91$ Dimension 2 - Hostile $\alpha_{DL} = 0.87$, $\alpha_{EL} = 0.90$
	A1	Friendly		Dimension 1
	A2	Welcoming		Dimension 1
	A3	Sociable		Dimension 1
	A4	Pleasant		Dimension 1
	A5	Hostile		Dimension 2
	A6	Intimate		Dimension 1
	A7	Lively		Dimension 1
	A8	Stimulating		Dimension 1
	A9	Exiting		Dimension 1

	A10	Cosy		Dimension 1
	A11	Threatening		Dimension 2
	A12	Terrifying		Dimension 2
	A13	Enjoyable		Dimension 1
	A14	Safe (-)		Dimension 2
	~~A15~~	~~Relaxing~~ *		Item deleted
	A16	Tense		Dimension 2
	~~A17~~	~~Formal~~ *		Item deleted
	~~A18~~	~~Stern (business-like)~~ *		Item deleted

* Items deleted due to low internal reliability with a Cronbach's alpha $\alpha < 0.7$

Table A2. ANOVA-table for environmental appraisals. Tests of between subjects effects.

Measure	**Effect**	***F***	***df***	***p***	η_p^2
POLQ - Strength	Square	20.39	1	<.001	.117
	DL / EL	4.83	1	0.029	.030
	Square * (DL / EL)	1.35	1	0.246	.009
Visual Accessibility	Square	0.44	1	0.507	.003
	DL / EL	52.29	1	<.001	.253
	Square * (DL / EL)	0.807	1	0.371	.005
Reassurance	Square	2.26	1	0.135	.014
	DL / EL	23.00	1	<.001	.013
	Square * (DL / EL)	1.12	1	0.292	.007
Atmosphere - pleasant	Square	0.06	1	0.940	.000
	DL / EL	14.18	1	<.001	.084
	Square * (DL / EL)	0.45	1	0.501	.003
Atmosphere - hostile	Square	0.51	1	0.475	.003
	DL / EL	9.49	1	0.002	.058
	Square * (DL / EL)	1.86	1	0.175	.012

Table A3. Specification of Luminaire types

	Luminaire types						
Square	Type	Name	Light distribution	Optics	Shield	Height	Qty.
Kirseberg	road-luminaire	Philips, Copenhagen	direct asymmetric	reflector	upwards	3.7 m	2x12
	spotlight	SILL, Plane projector	rotational symmetric	reflector	louver		1
Lindeborg	park lantern	DEFA, Helena	omnidirectional	opal diffuser	glare rings	4.2 m	11

Table A4. Specification of Lamp types

	Lamp types						
Square	Type	Name	Luminous flux (lm)	CCT(K)	CRI (Ra)	S/P ratio	Qty.
Kirseberg	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x12
	HPS	HST-DE 150W	1500	2000	25	0.5	1
Lindeborg	HPS	SON Pia Plus 70W	6000	2000	25	0.5	9
	MH	CDO-ET 70W/828	7030	2800	84	1.3	2

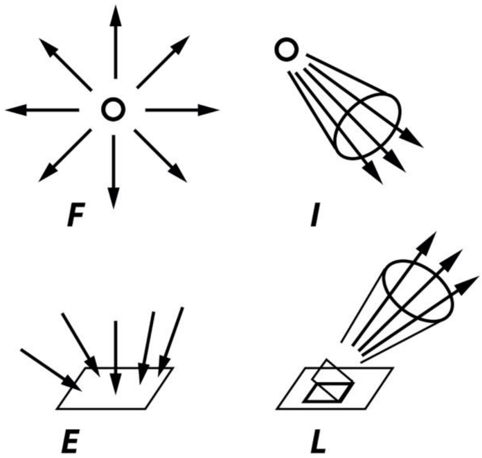


Figure A1 The units of light. Illustration adopted from (Tregenza and Loe 2013)

- Luminous flux (F) is measured in lumen (lm). It describes the total flow of light from a light source.
- Luminous intensity (I) is flux per solid angle measured in candela (cd). It describes the flow of light in a given direction.
- Illuminance (E) is flux / area measured in lux (lx). It is the amount of light falling on a surface. One lx is given by one lm on a square meter.
- Luminance (L) is intensity / projected area measured in candela per square meter (cd/m2). It is the emitted or reflected light from a surface.

Appendix IV

Lighting Design Intervention in Kirseberg square, Sweden: The influence of spatial light distribution on users' environmental appraisals

V.K.R. Hennig[a]*, N. Gentile[b], S. Fotios[c], and M. Johansson[a]

[a] *Environmental psychology, Dept. of Architecture & Built Environment, Lund University, Lund, Sweden;* [b] *Division of Energy and Building Design, Dept. od Building & Environmental Technology, Lund University, Lund, Sweden School of Architecture,* [c] *The University of Sheffield, Sheffield, UK;*

V.K.R. Hennig, Environmental Psychology, Department of Architecture and Built Environment, Lund University, SE-221 00, Sweden, katarina.hennig@abm.lth.se
*corresponding author

Lighting Design Intervention in Kirseberg square, Sweden: The influence of spatial light distribution on users' environmental appraisals

Public squares in neighbourhood communities are everyday life-spaces that may support social interaction and contribute to individuals' well-being and quality of life. Light shapes users' experiences of these spaces and may sustain behavioural patterns after dark. However, our understanding of how certain light characteristics influence users' experiences of public squares after dark is limited. This intervention study investigates users' environmental appraisals, previously identified as crucial for supporting social interaction in public squares after dark, including perceived outdoor lighting quality, visual accessibility, reassurance, restorativeness and atmosphere. The study explores spatial distribution of electric light, and was carried out in two phases. The first phase examines an intervention by Malmö municipality, a shift from ceramic metal halide (CMH) to LED, with an increase in the uniformity of horizontal illuminance. The second phase examines a spatial intervention with three lighting modes with different spatial distribution; horizontal, horizontal and vertical, and horizontal, vertical and accent lighting. Analyses of variance were used to compare users' environmental appraisals. No significant differences in users' appraisals were identified for the municipality intervention. On the contrary, for the spatial intervention, a linear increase in participants' assessments of visual accessibility, restorativeness and atmosphere, and a tendency in increase in ratings of perceived reassurance were identified. The findings offer insights on how spatial light characteristics can affect environmental appraisals that are imperative for supporting social life in public squares. Vertical illumination on walls, focal points and greenery, are identified as crucial elements to consider in lighting schemes of public squares.

Keywords: public squares; environmental appraisals; atmosphere; light distribution

1 Introduction

Socially sustainable cities and communities necessitates the provision of quality public spaces that are safe, inclusive and accessible (UN 2017a, 2017b). A quality public space, is a 'publicly accessible space' that is meaningful, responsive and protective of rights of different user groups (Carr et al. 1992). Such a space, e.g., a public square in a neighbourhood community, may function as social space that provides opportunities for social interaction (Mehta 2014), thereby affirming the 'interrelatedness with others' (Crowhurst Lennard and Lennard 1987). In a neighbourhood community the public square is experienced by its users' on a day to day basis (Hillier 2008; Crowhurst Lennard and Lennard 1987), and is therefore an important public space for promoting social well-being, and supporting the quality of life of individuals (Cattell et al. 2008; Francis et al. 2012; Low 2023). Users are here defined as people who frequent public squares and rely on them for both passive and active engagement (Francis 1989).

Lighting research with a socially oriented scope suggests that lighting is a crucial design element to support social life in urban public spaces after dark (Bordonaro, Entwistle, and Slater 2019; Casciani 2020a; Hennig et al. 2022). In countries at northern and southern latitudes where daylight hours are very limited for part of the year, the design of lighting is imperative for sustaining mobility (Rahm, Sternudd, and Johansson 2021), and for supporting stationary activities and social interaction after dark (Boyce 2019; Hennig et al. 2022; Hennig et al. 2023).

To advance knowledge on how users experience public squares after dark it is vital to understand the linkages between lighting design and social behaviour (Cattell et al. 2008; Johansson, Küller, and Rosén 2011; Mehta 2007; Rahm 2019).

Previous studies that have explored users' environmental appraisals in public space after dark, suggest that such appraisals are crucial links in the understanding of the lighting - behaviour relationship in public squares (Hennig, Gentile, and Johansson 2024; Johansson, Küller, and Rosén 2011; Johansson, Tsiakiris, and Rahm 2024; Hennig et al. 2022). Environmental appraisals refers to cognitive, affective and emotional psychological processes through which an individual interpret and evaluate (appraise) the characteristics of a setting (Johansson, Gyllin, et al. 2014; Kappas 2006). A study on the link between environmental appraisals and behaviour in public squares suggests that perceived atmosphere is associated to self-reported social interaction after dark, furthermore the study found that environmental appraisals of perceived outdoor lighting quality, visual accessibility, reassurance and after dark are associated to appraisals of atmosphere (Hennig, Gentile, and Johansson 2024).

Light provides visual cues that support our cognitive interpretation of the luminous environment, while also evoking affective responses and cognitive associations with the environment (de Vries et al. 2018). The lighting condition may influence the individual's perception of the luminous environment and thus influence behaviour (Baron, Rea, and Daniels 1992; de Kort and Veitch 2014; de Kort 2019; Küller 1991).

Spatial light distribution is a critical aspect in the appraisal and appreciation of a public space after dark (Wänström Lindh 2012). The spatial characteristics concern the relative geometric patterns of optical radiation (light) in the individual's field of view (Veitch, Fotios, and Houser 2019).

Studies, based on 3D-visualizations, investigating lighting modes and their effects of impression of public squares after dark, have proposed that perceived uniformity (non-uniform vs uniform) and brightness (dim vs bright) are important features of individuals' appraisals of squares (Nasar and Bokharaei 2016, 2017). These aspects are related to the spatial light distribution, here referred to as the 'visually perceived distribution' of light within a space (Wänström Lindh 2012).

While 3D-visualizations are useful tools to point out important aspects of lighting modes for impressions of public square, they are insufficient for understanding the influence of lighting on users' environmental appraisals in real-life settings such as a public squares due to their physical complexity. The field(s) of view in public square are dynamic depending on several aspects including: luminance distribution on all visible surfaces, size and shape of the field of view, size and shape of visual targets, eccentricity of visual targets (which may be foveal or para-foveal), any condition that may surround the visual task, movement of visual tasks and the individual's viewing position (Veitch, Fotios, and Houser 2019).
To ascertain ecological validity (Robson and McCartan 2016), empirical investigations of light interventions conducted in real life settings are needed. Moreover, a lighting design intervention would ensure relevancy of research findings for lighting practice.

This intervention study focuses on the influence of different lighting modes, with changes in spatial distribution, on users' environmental appraisals of a public square, set in a neighbourhood community, in Malmö, Sweden.

1.1 Environmental appraisals

The environmental appraisals, assessed in this study, were selected based on their proposed relevance for electric lighting conditions in urban public space (Hennig, Gentile, and Johansson 2024; Johansson, Tsiakiris, and Rahm 2024; Rahm, Niska, and Johansson 2024).

Perceived lighting quality in outdoor conditions, such as a public square, have previously been described with two dimensions; strength quality which captures brightness and comfort quality which captures hedonic tone, i.e. the extent to which light is perceived as soft, natural, warm and non-glary (Johansson, Pedersen, et al. 2014; Hennig, Gentile, and Johansson 2024). The perceived outdoor lighting quality (POLQ) influences appraisals of visual accessibility and reassurance (Johansson, Küller, and Rosén 2011), and may therefore impede or support behavioural patterns in outdoor environments.

Visual accessibility refers here to the individual's subjective experience of seeing, when in a public square performing visual tasks such as way-finding, detecting obstacles on the ground, and recognizing people's faces (Fotios and Johansson 2019; Johansson, Küller, and Rosén 2011).

Perceived reassurance may be defined as that which provides the comfort that makes someone feel less worried, less afraid and which restore confidence (Fotios, Unwin, and Farrall 2015). A feeling of reassurance, in the context of a public square, describes the confidence a person might gain from lighting, i.e. being at ease when visiting the square after dark (Hennig, Gentile, and Johansson 2024).

Perceived restorativeness of a setting refers to what extent the setting is perceived as fascinating, compatible, extent, and giving a sense of being away (and thereby giving relief from everyday demands and routines) (Kaplan 1995). These four interrelated factors are deemed important for the individual's sense of restorativeness. Lighting which enhances restorative elements, e.g. greenery, may increase perceived restorativeness after dark (Nikunen and Korpela 2012). It is argued that lighting that improves the visual experience after dark by enhancing 'scene content' may provide stress recovery (Nikunen et al. 2014).

Perceived atmosphere is considered an over-arching construct. It is previously theorized as 'tuned space', i.e. a space infused with a particular mood, produced by various agents, e.g. illumination (Böhme 2017). Atmosphere according to Böhme translates into the individual's cohesive experiences of a setting (Böhme 2017). This implies that perceived atmosphere reflects the individual's subjective and overall impression of a space. Atmosphere is here defined as the affective qualities attributed to an environment (Stokkermans et al. 2017). For outdoor spaces, such as a public square, atmosphere has been described with two dimensions, pleasant and hostile (Hennig, Gentile, and Johansson 2024).

Light has been found to significantly influence the visual appearance of a space and the appraisal of atmosphere (Stokkermans et al. 2018). It is previously shown that individuals use luminance distribution in their appraisals of atmosphere (Veitch 2001). In particular two attributes of light that have been found to affect the appraisal of atmosphere, are brightness and uniformity, these in turn are dependent on the intensity characteristics of light and the spatial distribution of light (Veitch 2001).

1.2 Perceptual attributes of light: brightness and perceived uniformity

Spatial light distribution is related to both brightness and to the perception of uniformity. CIE defines 'brightness' as an attribute to visual perception according to which an area appears to emit, transmit or reflect more or less light (CIE 2020). Over time brightness have been approached in a variety of ways. There is an apparent consensus though, that spatial distribution of light and luminance within the field of view may alter the perception of brightness (Boyce 2014). Further, brightness depends on the state of adaptation of the visual system (Stokkermans et al. 2017). The relationship between luminance and brightness is dependent on the context (Rea, Radetsky, and Bullough 2011). For an outdoor space, such as a public square after dark, the visual system typically operates under mesopic conditions resulting in reduced colour vision and resolution (Boyce 2014) and the perception of brightness at different light-levels (btw. approx. 2 and 20 lx) exhibits a shift in spectral-sensitivity, i.e., an increased short-wavelength spectral sensitivity at higher light levels (Bullough et al. 2014).

The term 'spatial brightness' is related to brightness. A consensual definition by CIE is 'an attribute of visual perception according to which a luminous environment appears to contain more or less light' (CIE 2020). Spatial brightness can either be perceived while immersed within a space or when a space is observed remotely but fills a large part of the visual field (CIE 2020). Spatial brightness encompass an overall visual sensation based on the response of a large part of the visual field extending beyond the fovea, defined as the magnitude of the ambient lighting in an environment (Fotios and Atli 2013).

Spatial light distribution effects the individual's perception of uniformity (Veitch 2001). The uniformity of luminance is defined as a quotient of minimum luminance and average luminance of a surface (CIE 2020). 'The visual system is very tolerant of variations in luminance in the visual field, indeed it is such variation that make vision possible' (Boyce 2014, p.165). Different degrees of uniformity are desirable in different locations (Boyce 2014). The level of perceived uniformity will determine whether this space is experienced as monotonous (uniform) or provides variability / interest (non-uniform) (Veitch 2001).
A study on the impression of squares (conducted using visualizations), suggested higher preference for uniform and bright over uniform and dim (Nasar and Bokharaei 2017).

1.3 Theory of visual spatial boundaries

This study draws on a theory of visual spatial boundaries, which posits that visual spatial boundaries made visible by vertical illumination is beneficial for appreciation of space, atmosphere and for a feeling of reassurance in urban environments (Wänström Lindh 2013).

A study on spatial distribution in line with this theory investigated how different lighting modes in promenades with horizontal (H), horizontal and vertical (HV) and horizontal, vertical and accent lighting (HVA) affected participants judgments including spaciousness and sociability (Casciani 2020c). It was found that the lighting mode HVA made the promenade to be perceived as more spacious and the HVA was the preferred lighting mode with respect to social behavioural intent.

It is here stipulated that the distribution of light with vertically illuminated walls and structural elements mediates ‘a tangible experience of space’, and hence that vertical lighting would be important to users’ environmental appraisals of a public square after dark. This also agrees with theories of environmental preference described below.

1.4 Theories of environmental preference

This study also draws on theories of environmental preference derived from the field of environmental psychology; prospect - refuge theory (Appleton 1975, 1984; Dosen and Ostwald 2016), theory of environmental preference (Kaplan 1987) and restorative potential of settings (Kaplan 1995). Prospect - refuge theory posits that the preference for a setting is dependent on the possibility to get an overview of the setting (prospect) from a safe enclosure (refuge) (Appleton 1975, 1984). The present, and other previous studies, argue that the impact of lighting on individuals’ sense of reassurance/safety is mediated by proximate cues of prospect and refuge in an environmental setting (Blobaum and Hunecke 2005; Boomsma and Steg 2014; Haans and de Kort 2012; Fotios, Unwin, and Farrall 2015). It is argued that prospect - refuge characteristics of the setting is fundamental to individuals’ preference as well as a feeling of reassurance. Site characteristics which extend the typology of reassurance

/ safety are ease of ‘escape’ (for potential victims) and ‘concealment’ (offering potential offenders a hiding place) (Fisher and Nasar 1992; van Rijswijk, Rooks, and Haans 2016).

The environmental preference model by Kaplan, posits that our preference for a scene is a function of the individual’s need to make sense (coherence and legibility) of the scene and the need to be involved (complexity and mystery) in the setting (Kaplan 1987). The preference model have been applied in lighting research. A study conducted in a lab environment, which investigated the influence of lighting modes of different spatial light distribution and CCT, suggested that spatial perception of the lit environment, can be assessed through the preference model (using evaluative descriptors legibility, coherence, complexity and mystery) (Casciani 2020b). An insight from the study regards the spatial distribution of light. The level of uniformity was correlated to coherence and complexity and balance in luminance contrast ratio of light and darkness was identified as important for legibility (Casciani 2020b). In design practice, legibility and coherence are considered crucial design objectives (Dovey 2016; Casciani 2020a).

2 Aim

The present study aimed to investigate the influence of different lighting modes, with differences in spatial light distribution, on users’ environmental appraisals after dark of a public square, in Malmö, Sweden. The specific objectives were to compare *perceived outdoor lighting qualities*, *perceived visual accessibility*, *reassurance*, *restorativeness* and *atmosphere*, between the different lighting modes:

(O1) Firstly a comparison between a Horizontal Reference (RH), utilizing the original permanent lighting installation which has a non-uniform horizontal distribution, and an updated permanent lighting installation, which has an increased horizontal uniformity, Horizontal (H).

Hypothesis 1: It was expected that increasing the horizontal uniformity from lighting mode RH to lighting mode H, would result in higher ratings of the appraisals of perceived lighting comfort, visual accessibility, and thus perceived reassurance. No improvements were expected with regard to assessments of perceived restorativeness or atmosphere.

(O2) Secondly a comparison between Horizontal (H), Horizontal + Vertical (HV), and Horizontal + Vertical + Accent lighting (HVA), and to test for linear trends in the appraisals of the three lighting modes. The horizontal distribution (H) was held approximately constant.

Hypothesis 2: It was expected that compared to the lighting mode H, a combination of horizontal and vertical light (HV) would result in higher ratings in all investigated appraisals, i.e. in perceived lighting quality, visual accessibility, reassurance, restorativeness, and atmosphere (pleasant dimension). A combination of horizontal, vertical and accent lighting (HVA) will result in even higher ratings of the appraisals. In other words, a linear increase from H, HV to HVA is expected for all investigated appraisals, with the exception of perceived atmosphere (hostile dimension) where instead a linear decrease is expected.

An additional objective was to make an assessment of users' narrative of their experience of the three different lighting modes H, HV, HVA.

3 Method

A survey was conducted to assess users' environmental appraisals after dark of perceived lighting quality visual accessibility, reassurance, restorativeness and perceived atmosphere in Kirseberg square, a local neighbourhood square, in Malmö, Sweden. The survey follows from three preceding studies also conducted in Kirseberg square; an observational study on user behaviour (Hennig et al. 2023), an observational study on social interaction (Hennig et al. 2022), and a correlational study on self-reported social interaction related to users' environmental appraisals in daylight and in electric lighting after dark (Hennig, Gentile, and Johansson 2024).

3.1 Setting

Kirseberg square, Figure 1, is a local neighbourhood square in Malmö, Sweden. The square has three zones. These are a functional zone for stationary and social activities (zone A), arranged with benches trees and planting, and functional zones (paths) for movements in different directions (zones B and C). For a detailed description of physical attributes see Hennig et al. (2023). The square provides necessity-based commerce and services such as a grocery store, a pharmacy and a day-care for children, and is a social space for the local residents in daylight hours (Hennig et al. 2022; Hennig et al. 2023). Previous observational studies suggest that zone A is the predominant area for stationary activities and social interaction in daylight (Hennig et al. 2023; Hennig et al. 2022). Under lighting condition RH - neither stationary activities nor social interaction were sustained in zone A after dark, but movements to commerce and services were sustained (Hennig et al. 2023; Hennig et al. 2022). Tables 1 and 2 and Figure 1 describe the lighting systems used in Kirseberg square. Based on these findings the municipality of Malmö updated the original permanent lighting in zone A, in an intent to create a light distribution with an increased horizontal uniformity and to reduce energy use; shifting from a layout with three luminaires with an asymmetric direct distribution fitted with metal halide, to a layout with four park-lanterns with rotational-symmetric distribution fitted with LED, referred to as H in this study. (A technical description of the lighting installation is provided in Tables 1 and 2, and Figure 3).

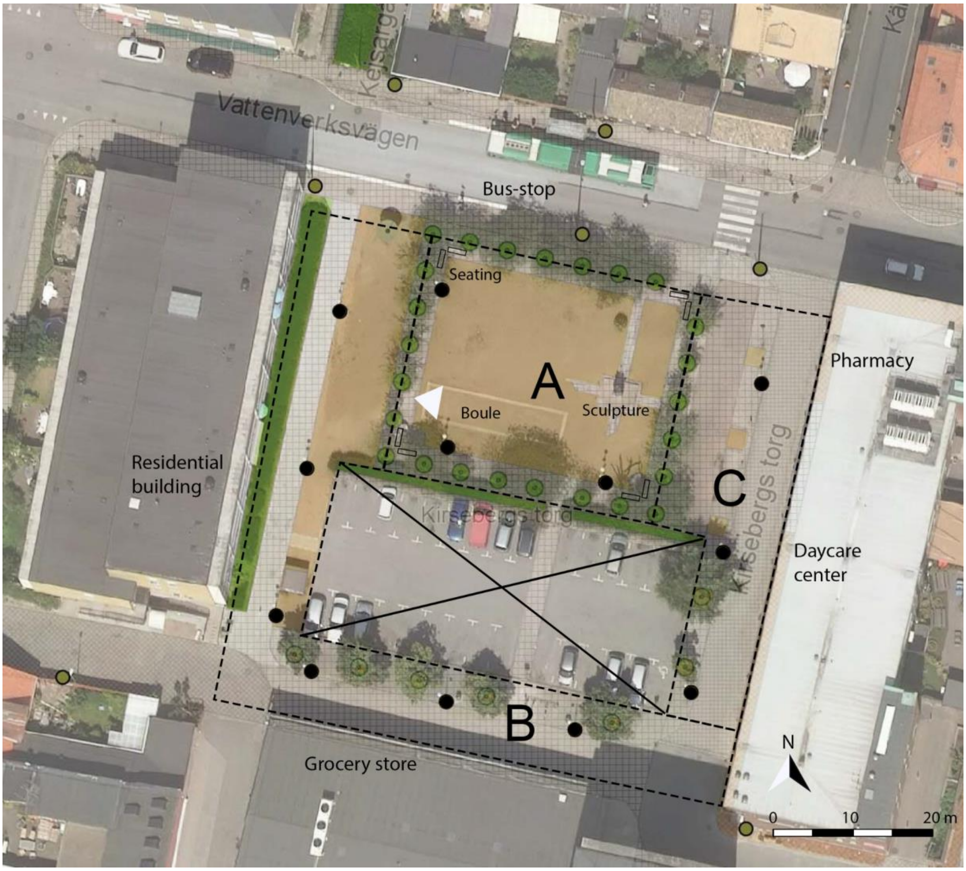


Figure 1. Plan of Kirseberg square. A, B and C denote the three functional zones. Zone A is a designated area for stationary and social activities, and zones B and C, are paths for movements to necessity-based commerce and services. Sampling was conducted in zone A. The white triangle symbolizes the sampling position. Black dots symbolize lamp posts, with a layout corresponding to the permanent lighting installation, reference RH.

3.2 Evaluation of different lighting modes

This field experiment followed a between-subjects design and was conducted in two phases to evaluate the different lighting modes. The first phase was an evaluation before and after the ‘municipality intervention’, i.e. comparing the environmental appraisals between the two lighting modes with horizontal distribution only, RH and H. In the second phase spatial interventions were introduced, i.e. the investigation of environmental appraisals of lighting modes H, HV and HVA, in which the horizontal distribution is held approximately constant (a minor contribution due to reflected lighting in HVA is expected), and vertical and accent lighting is added in increments.

The reference for these evaluations is lighting condition, RH, the non-uniform horizontal distribution of the previous permanent lighting installation at Kirseberg square. Evaluations in this condition were recorded in March 2022 and reported in a previous study (Hennig, Gentile, and Johansson 2024). The current study adds users’ appraisals of the updated permanent lighting, H, and, spatial interventions HV and HVA, conducted in February and March 2023. During this period, on data collection days, the respective lighting modes H, HV and HVA were alternated in order to achieve a balance number of respondents for each lighting mode, and to ensure equal exposure to the neighbourhood community.

3.2.1 Design of the Spatial Intervention: A step-by-step model

The design of the intervention draws on the investigation on spaciousness and sociability by (Casciani 2020c), where lighting modes are added step-by-step, i.e., from an isolated mode to a combination of modes; from a horizontal distribution, to a mode with added vertical illumination, to a ‘complete mode’, combining horizontal, vertical and accent lighting.

The lighting mode HV aimed to balance lighting levels in the vertical plane relative to the horizontal plane, and to balance the luminance of the light post luminaires relative to the luminance of the background (the adjacent façade) of the setting, thus intended to reduce any uncomfortable contrast in the visual field. Compared to lighting mode H, a combination of horizontal and vertical illumination, HV, intended to increase spatial brightness of the setting (Boyce 2014, pp 197-201.). Furthermore, the intent of HV was to define spatial limits of the square.

Lighting mode HVA added accent lighting (vertical illumination) to focal points and the sculpture and cherry trees. This intended to focus the after dark experience on scene contents (Nikunen and Korpela 2012). Lighting greenery intended to enhance restorativeness (Nikunen and Korpela 2009). Lighting mode HVA further intended to enhance zone A as a 'refuge', here interpreted as a functional zone aimed at enhancing social interaction (Appleton 1984).

3.3 Lighting installations in the different modes

3.3.1 Technical descriptions

Technical descriptions of the lighting installations including specification of luminaires, specification of lamp-types and drawings illustrating luminaire positions, are provided in Tables 1 and 2, and Figures 2 and 3.

Table 1. Specification of luminaire types utilized in the respective lighting mode

Lighting Mode	Function	Luminaire types						
		ID	Type	Name	Light Distribution	Optics	Mounting height	Qty.
RH	Functional Horizontal	P1	Road-luminaire	Philips, Copenhagen	asymmetric	reflector	Top mounted 3.7 m	2x12
H, HV, HVA	Functional Horizontal	P1	Road-luminaire	Philips, Copenhagen	asymmetric	reflector	Top mounted 3.7 m	2x9
H, HV, HVA	Functional Horizontal light	P2	Park lantern	Ateljé Lyktan, Linx	Rot. symmetric	Lens + opal diffuser	Top mounted 4.0 m	4
HV, HVA	Façade lighting-Vertical	T1	Compact flood	Meyer, Monocube 4	16° x 33° Linear horizontal	Narrow beam + linear lens	Top of façade 10m	11
HVA	Accent lighting Trees, Sculpture	M1	Flood light	Cameo, FLOOD 600	40°	Lens optic	Ground based	12

Table 2. Specification of lamp types utilized in the respective lighting mode. Lamp characteristics as reported by the manufacturer.

Lighting Mode	Lamp types							
	ID	Type	Name	Luminous flux (lm)	CCT(K)	CRI (Ra)	S/P	Qty.
RH	P1	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x12
H, HV, HVA	P1	MH	CDO-ET 70W/828	7030	2800	84	1.3	2x9
H, HV, HVA	P2	LED	LED, 37 W, 830	3800	3000	80		4
HV, HVA	T1	LED	LED, RGBW, 20-50W	1500-2500	RGBW (3000)			11
HVA	M1	LED	LED, RGBWA, 9 x12 W	2042	RGBWA			12

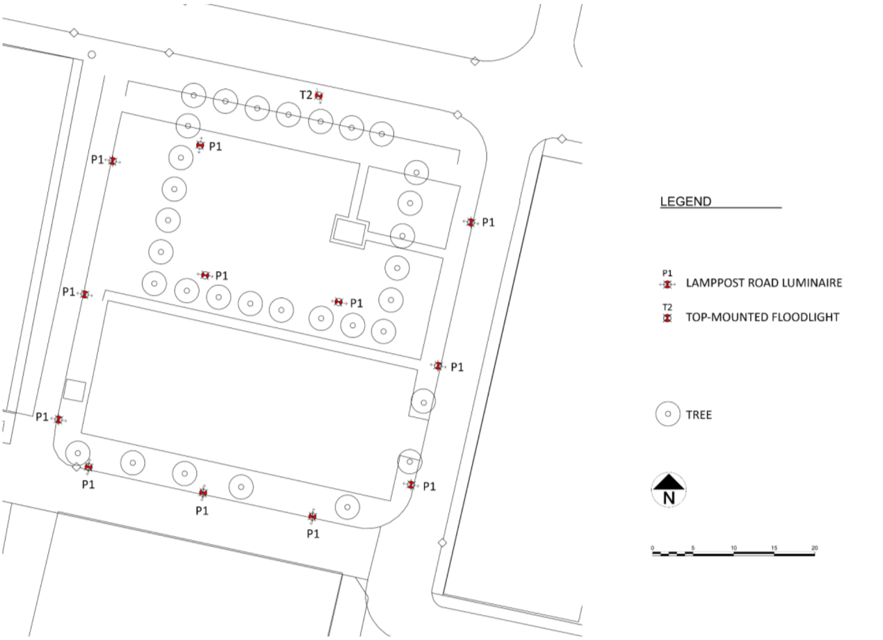


Figure 2. Lighting installation RH

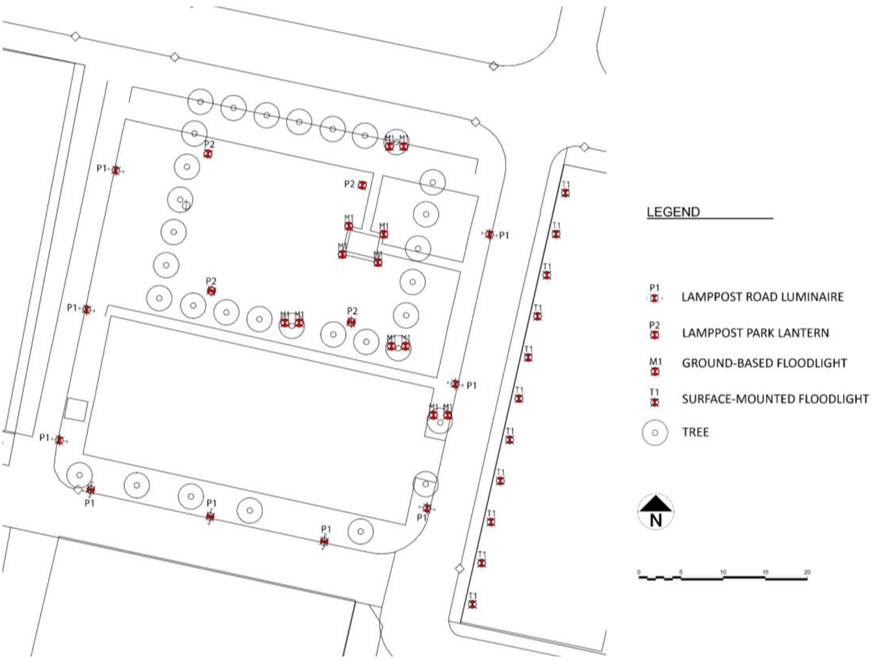


Figure 3. Lighting installation H, HV, HVA.

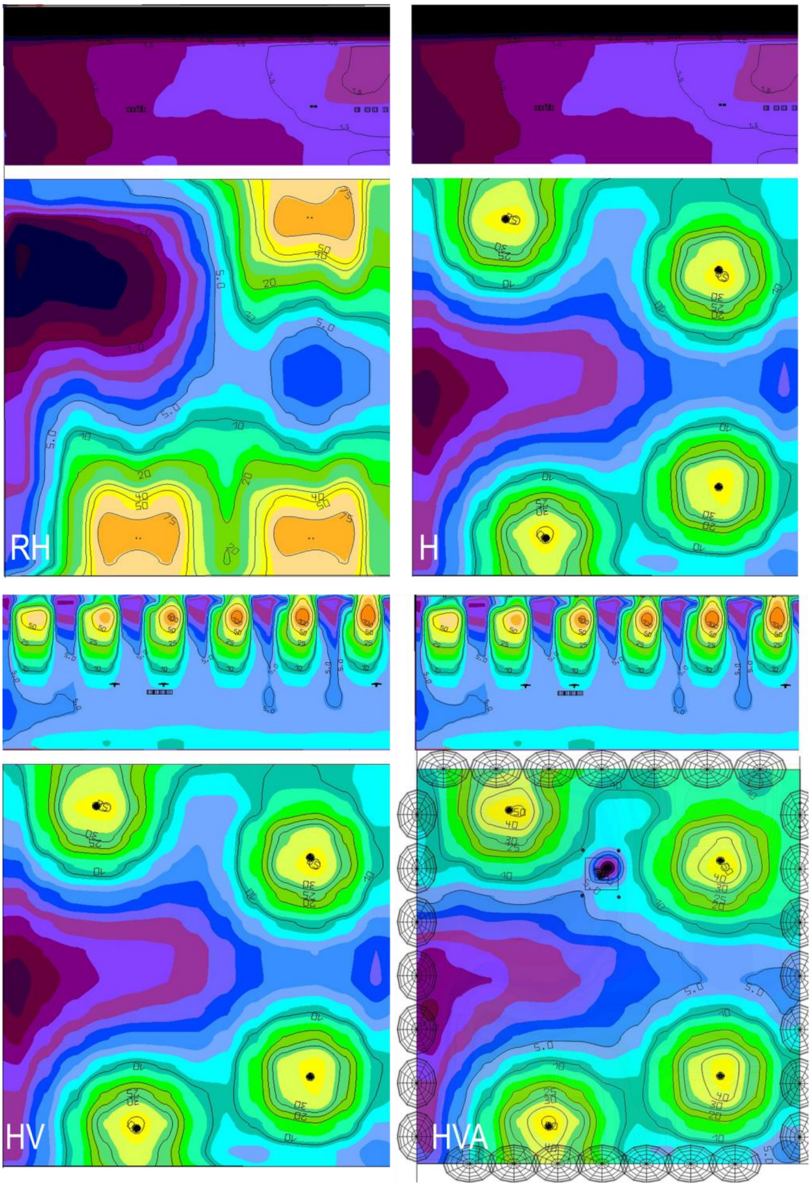


Figure 4. Illuminance plots illustrating the horizontal illuminance distribution (ground level) (below) and the vertical illuminance distribution on the adjacent façade (background in the experimental setting) (above) for the different lighting modes, (A) RH, (B) H, (C) HV, and (D) HVA. The illuminance distributions are retrieved from simulations in DIAlux evo 12.1. Isobars indicate ranges in illuminances from 0.25 lx to 100 lx.

Table 3. Horizontal illuminances and uniformity on ground level and vertical illuminances and uniformity on the adjacent wall of the different lighting modes.

Lighting mode	Horizontal illuminances			Vertical illuminances		
	$\bar{E}_h$ (lx)	$E_{h\,\min}$ (lx)	U_o	$\bar{E}_v$ (lx)	$E_{v\,\min}$ (lx)	U_o
RH	20.1	0.38	0.01	1.08	0	0
H	12.0	0.87	0.07	0.99	0	0
HV	12.0	0.87	0.07	12.1	1.0	0.08
HVA	12.4	0.91	0.07	12.1	1.0	0.08

Second, luminance maps were used to report the luminance in the field of view. High-Dynamic Range (HDR) images of each lighting mode (H, HV and HVA) were captured to record the luminance distribution. These images were taken at the viewpoint of the location for assessments, as shown in Figures 5 and 7. A calibrated DSLR Canon EOS 5D Mark II camera with 180° fisheye lens was used to record the images, and was calibrated following the procedure described by Pierson et al (Pierson et al. 2021). These images were converted into luminance maps using Photosphere v2.0, a Radiance-based graphical user interface, and verified using spot luminance measurements using a diffusive cardboard placed in the viewpoint. Luminance maps for lighting modes H, HV and HVA were assessed and compared by measuring luminance in the horizontal and vertical plane respectively. The area at focus included areas in the field of view directly affected by the lighting intervention, Figure 5.

To describe the luminance patterns in the field of view for lighting mode, H, HV and HVA respectively, assessment of the mean and median values of luminance at each pixel, and their ratios of vertical over horizontal luminance were performed. The values were extracted via the software HDRScope using a mask for the two areas, horizontal and vertical, shown in Figure 5. The measured values of luminance for the two masked areas are provided in Table 4. Luminance maps with false colours are provided in Figure 6.

Figure 5. HDR image showing the masked areas for assessing luminance in the vertical and in the horizontal plane used to characterize the three lighting modes.

Table 4. Measured values of luminance for lighting modes H, HV and HV. The mean and median luminance values at every pixel for the area at focus are provided for the horizontal plane and the vertical plane, as well as the ratio between mean vertical over mean horizontal.

Intervention	Lighting mode H			Lighting mode HV			Lighting mode HVA		
Measurement	Horizontal	Vertical	Ratio	Horizontal	Vertical	Ratio	Horizontal	Vertical	Ratio
Luminance	(cd/m^2)	(cd/m^2)		(cd/m^2)	(cd/m^2)		(cd/m^2)	(cd/m^2)	
Mean	0.27	0.23	0.85	0.28	0.31	1.12	0.27	0.50	1.87
Median	0.23	0.08	0.35	0.21	0.11	0.52	0.21	0.20	0.95

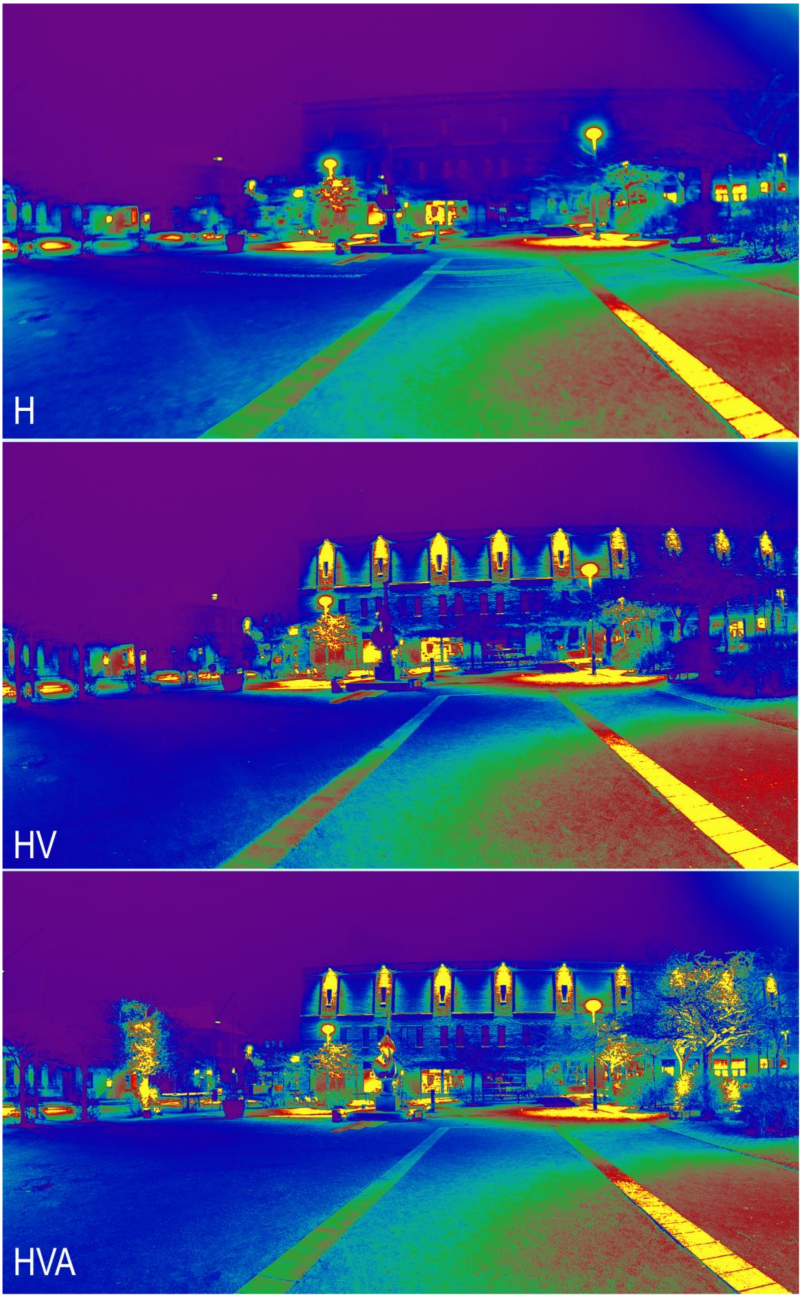


Figure 6. Cut-off of the fisheye luminance maps with false colours of the three lighting modes from the top H, HV and HVA.

3.4 Participants

The total sample comprised 177 participants. Table 5 shows the number of participants who evaluated each lighting condition and the age and gender distribution of the sample, as well as the proportion being residents in the area.

Table 5. Participant Demographics; Mean Age, Gender Representation, and Proportion of local Residents

Mode	N	Age (y)		Female		Male		Residents	
		Mean	SD	N	%	N	%	%	Mean yr.
Total	177	50	17	68	39	107	61	86	14
RH	49	48	16	18	37	31	63	96	15
H	39	52	19	16	42	22	58	90	17
HV	42	48	17	17	40	24	57	90	11
HVA	47	53	18	17	36	30	64	70	14

The internal drop-out was low (at the highest 3% for a single item). Missing values were replaced with the mean value of the group for the specific item.

3.5 Procedure

During data collection the intervention modes of the updated permanent lighting, H, and the temporary installations, intervention HV and HVA were altered on a daily basis following a pre-set schedule (H, HV, HVA). Data-collection on users' appraisals, were conducted from February 27 to March 23, 2023, sessions were scheduled on four weekdays, from Monday to Thursday, 6:30 pm to 8:00 pm. The weather conditions during the data collection sessions were typical for the time of year, with temperatures varying from 0 - 12 degrees Celsius, and averaging 5 degrees. Precipitation levels were normal for the time of year and evenly distributed across the intervention modes. No heavy rainfall occurred, and since the ground in zone A is covered with gravel, a slightly wet surface was not expected to affect reflection.

Participants were recruited through advertisements in social media by Malmö municipality, via direct mail, and onsite. Each session began with a briefing on the background, procedures, and research ethics of the study. Participants were informed that their participation would be anonymous and voluntary, with the option to withdraw at any time. Written informed consent was obtained from all participants. Ethical approval was not required as the study did not involve questions regarding sensitive personal data, as defined by the Swedish Ethical Review Authority (Etikprövningsmyndigheten 2023).

Participants were instructed to walk around the setting (in zone A) to reflect upon how they perceived the setting, before completion of the questionnaire. To ascertain equivalent assessment the viewing direction (facing the opposite façade) was marked with a triangle. Please see Figure 7, which illustrates the experimental setup and depicts the participant's position and viewing direction during the assessment.

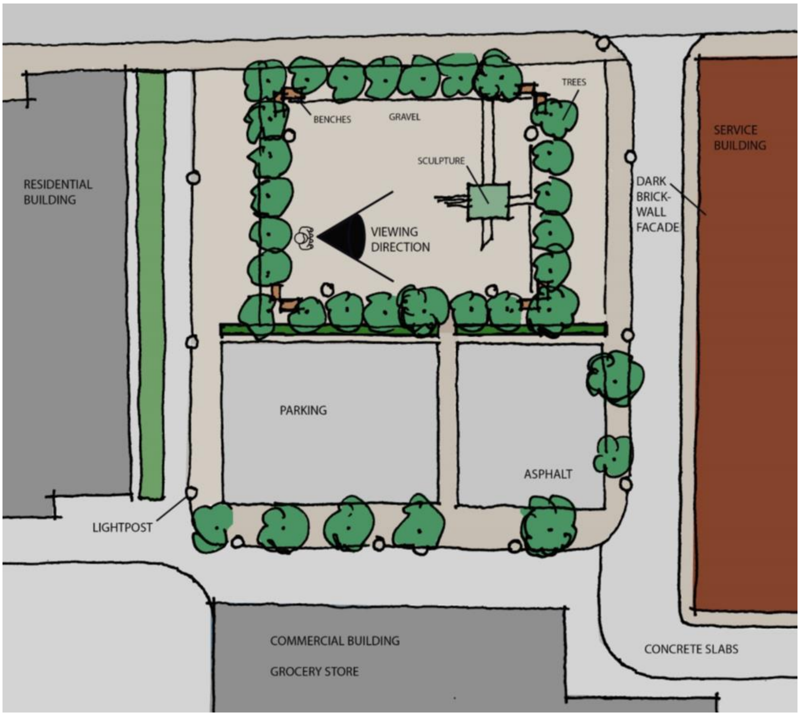


Figure 7. Illustration of the experiment depicting the participant's positioning and viewing direction during questionnaire completion in Kirseberg square.

3.6 Assessment of environmental appraisals

Participants' environmental appraisals were assessed using established questionnaires. An overview of individual items, response scales and the internal reliability of indices is provided in the appendix, Table A1. Perceived lighting quality, captured by asking "How do you perceive the light in this place?", was rated using a 7-point bipolar semantic differential (SD) scale, consisting of 8 items (the perceived outdoor lighting quality scale) (POLQ) (Johansson, Pedersen, et al. 2014). Perceived visual accessibility, captured by asking "How well can you see in this light?", was rated on a 5-point Likert scale (1 = no, definitely not; 5 = yes, definitely), consisting of 5 items (Johansson, Küller, and Rosén 2011). Reassurance, captured by asking "How do you perceive being in this place?", was rated on a 7-item, 5-point Likert scale (1 = no, definitely not; 5 = yes, definitely) (Blobaum and Hunecke 2005; Johansson, Küller, and Rosén 2011). Perceived restorativeness, captured by asking, "How do you find this place?", was assessed by 7 items and responses were indicated on a 5 point Likert scale (1 = no, definitely not; 5 = yes, definitely), (a shortened Perceived Restorativeness Scale (PRS) (Hartig et al. 1997; Rahm, Niska, and Johansson 2024). Finally, perceived atmosphere, was captured by asking "How do you experience the atmosphere in this place?", and rated on a 5-point Likert scale (1 = not at all; 5 = very much), consisting of 15 items (Hennig, Gentile, and Johansson 2024).

Furthermore, participants' appraisals were captured through an open-ended question: "How do you experience the square in this lighting?" Participants provided written statements expressing their own experiences of the square under the specific lighting condition.

4 Analyses

Statistical analysis were performed in IBM SPSS 29, in the following steps:

1) Scale reliability tests were performed for each of the employed scales with sub-dimensions (POLQ, perceived visual accessibility, reassurance, restorativeness and atmosphere) to establish the internal consistency. A value of Cronbach's alpha, $\alpha > 0.7$ for the averaged index was considered acceptable, see appendix Table A1.
2) Univariate analysis of variance (ANOVA) were conducted to address objective O1, i.e. to test for differences (between subjects' effects) in users' environmental appraisals of perceived lighting quality, visual accessibility, reassurance,

restorativeness and atmosphere between lighting modes RH and H. The level of significance was set to p = 0.05. A value of $p < 0.05$ was interpret as significant difference. The partial Eta squared (η_p^2) indicate the effect size; with 0.01 interpreted as a small effect, 0.06 as medium and 0.14 as a large effect (Cohen 1988).

3) Univariate ANOVA, testing for polynomial contrasts, was used to address objective O2, i.e. to test for linear increase in the environmental appraisals of perceived lighting quality, visual accessibility, reassurance, restorativeness and atmosphere, from lighting modes H, HV to HVA.

Moreover, a qualitative assessment of users' descriptive narratives on how they experienced the square in the respective lighting mode H, HV and HVA. This assessment was carried out by identifying if any statements regarding the respective lighting modes had a positive tone, a negative tone or an indifferent tone. Common descriptors in the narratives for each lighting mode were also identified.

5 Results

5.1 Users' environmental appraisals of the municipality intervention; horizontal lighting modes, RH and H

Descriptive statistics for the users' appraisals of perceived lighting quality, visual accessibility, reassurance, restorativeness and atmosphere (including mean, SD and 95% CI) are presented in Table 6. The ratings of RH was retrieved in a precedent study (Hennig, Gentile, and Johansson 2024). The results of the ANOVA with the lighting modes RH and H as independent variables and the different environmental appraisals as dependent variables and are presented in Table 7. No significant effects of lighting modes (RH and H) were identified for any of the assessed environmental appraisals, but a tendency was identified for appraisal of the perceived strength quality of light as assessed by POLQ, (F (1, 88) = 3.62, p = 0.06, η_p^2 = 0.04), indicating a lower assessment of the perceived strength quality for lighting mode H as compared to the original RH.

Table 6. Descriptive statistics of dependent variables, environmental appraisals of the municipality intervention, of lighting mode RH and H; showing the Mean (M), Standard Deviation (SD), Confidence Intervals (CI) and Number (N) of participants per group.

Lighting mode	RH		H	
Number of participants	*N* = 49		*N* = 39	
Measure	Mean (SD)	95% CI	Mean (SD)	95% CI
POLQ: PSQ (strength)	4.06 (1.23)	3.73 - 4.39	3.58 (1.08)	3.21 - 3.95
POLQ: PCQ (comfort)	3.73 (1.25)	3.41 - 4.04	3.91 (0.92)	3.56 - 4.27
Visual Accessibility	3.99 (0.84)	3.75 - 4.23	3.83 (0.86)	3.57 - 4.11
Reassurance	3.47 (0.82)	3.25 - 3.69	3.40 (0.69)	3.16 - 3.64
Restorativeness	2.39 (0.93)	2.16 - 2.61	2.28 (0.60)	2.03 - 2.54
Atmosphere: Pleasant	2.37 (0.97)	2.13 - 2.61	2.23 (0.64)	1.96 - 2.50
Atmosphere: Hostile	2.30 (1.03)	2.05 - 2.55	2.34 (0.66)	2.06 - 2.62

Table 7. ANOVA-table for environmental appraisals, showing tests of between subjects' effects of lighting mode RH and H.

Measure	F (1, 88)	p	η_p^2
POLQ: PSQ (strength)	3.622	0.060	0.040
POLQ: PCQ (comfort)	0.628	0.430	0.007
Visual Accessibility	0.673	0.414	0.008
Reassurance	0.171	0.680	0.002
Restorativeness	0.366	0.547	0.004
Atmosphere: Pleasant	0.633	0.428	0.007
Atmosphere: Hostile	0.037	0.847	0.000

The results did not confirm the a priory hypothesis 1, i.e. increasing the horizontal uniformity from RH to H would lead to higher ratings of perceived lighting comfort, visual accessibility and reassurance. However, the results align with the expectation of no improvements in perceived restorativeness and atmosphere.

5.2 *Users' environmental appraisals of the spatial intervention; lighting modes H, HV, and HVA*

In the analysis of the spatial intervention we tested for if any significant increasing levels of participants' ratings from H to HV and HVA followed a linear trend.

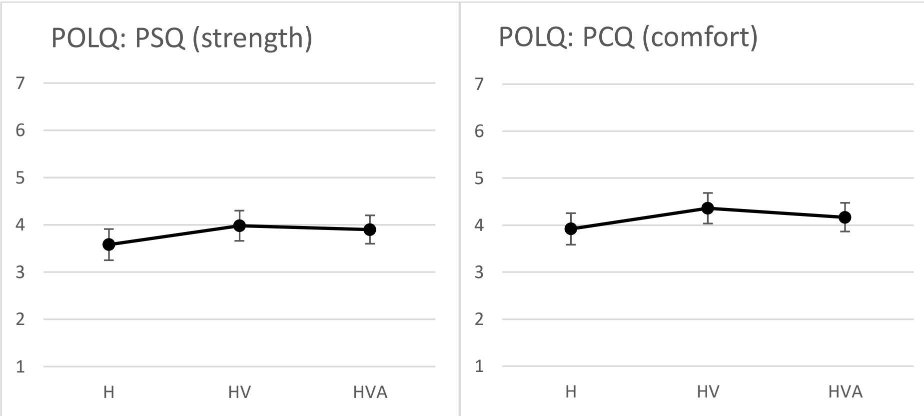
In the analysis the lighting mode is treated as a quantitative independent variable (H, HV, and HVA) and the measures of appraisal as the dependent variables.

Descriptive statistics of the participants' ratings of the respective environmental appraisal (including mean, SD and 95% CI) of lighting modes H, HV, and HVA are shown in Table 8.

Table 8. Descriptive statistics of dependent variables, the environmental appraisals of the spatial intervention, lighting mode H, HV and HVA; showing the Mean (M), Standard Deviation (SD), Confidence Interval (CI) and Number (N) of participants per group.

Lighting mode	H		HV		HVA	
No. of participants	*N* = 39		*N* = 42		*N* = 47	
Measure	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
POLQ: PSQ (strength)	3.58 (1.08)	3.25 - 3.91	3.98 (1.27)	3.66 - 4.30	3.90 (0.75)	3.60 - 4.20
POLQ: PCQ (comfort)	3.92 (0.92)	3.58 - 4.25	4.36 (1.21)	4.04 - 4.69	4.17 (1.03)	3.87 - 4.48
Visual Accessibility	3.84 (0.86)	3.61 - 4.07	4.04 (0.72)	3.82 - 4.26	4.18 (0.57)	3.97 - 4.39
Reassurance	3.40 (0.69)	3.18 - 3.62	3.55 (0.78)	3.33 - 3.76	3.69 (0.63)	3.33 - 3.76
Restorativeness	2.28 (0.60)	2.07 - 2.50	2.45 (0.77)	2.24 - 2.66	2.59 (0.64)	2.39 - 2.78
Atmosphere: Pleasant	2.23 (0.64)	1.99 - 2.46	2.51 (0.86)	2.28 - 2.73	2.63 (0.68)	2.42 - 2.84
Atmosphere: Hostile	2.34 (0.66)	2.08 - 2.60	2.21 (0.95)	1.96 - 2.46	2.15 (0.80)	1.91 - 2.34

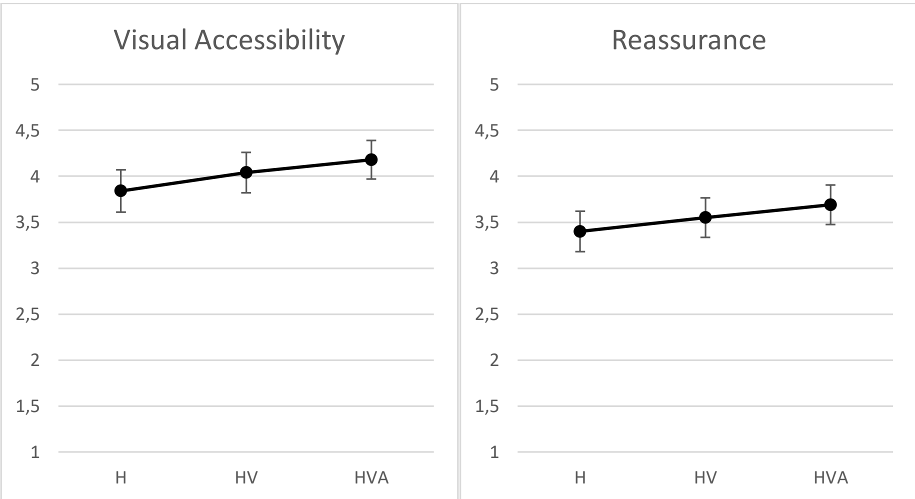
The ratings of perceived lighting quality, dimensions strength and comfort, are illustrated in Figure 8. The results of the polynomial contrasts, testing for a linear increase in the ratings of the respective appraisal are shown in Table 9. With regard to POLQ no linear trends were identified.



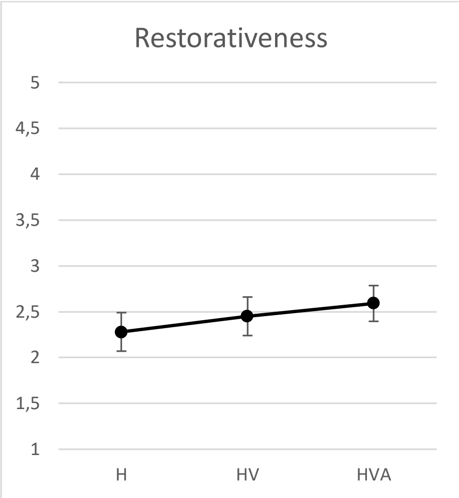
(A) (B)

Figure 8. Estimated marginal means, with 95% CI, of participants' ratings of perceived lighting quality of lighting modes H, HV and HVA. (A) Strength quality (PSQ) is shown to the left, and (B) comfort quality (PCQ) to the right. Responses were given on the POLQ-scale, a seven point bi-polar Semantic Differential scale.

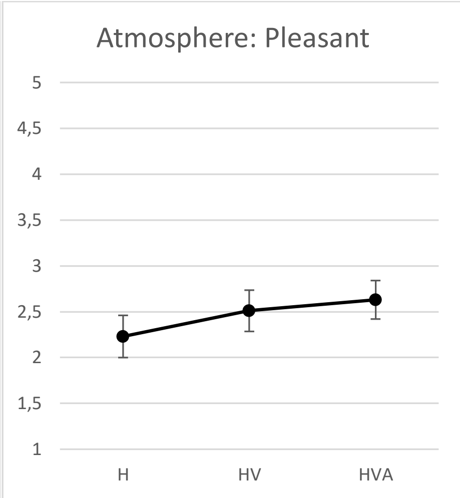
The participants' ratings of the environmental appraisals visual accessibility, reassurance, restorativeness and pleasant atmosphere are illustrated in Figure 9, A to D.



(A) (B)



(C)



(D)

Figure 9. Estimated marginal means, with 95% CI, of participants' ratings of (A) Perceived Visual Accessibility, (B) Perceived Reassurance, (C) Perceived Restorativeness, (D) Perceived Atmosphere: Pleasant, of the lighting modes H, HV and HVA. Responses were given on 5-point Likert scales, (1=no, definitely not; 5 yes, definitely).

The results of the ANOVA testing for polynomial contrasts show significant linear increase in the ratings of visual accessibility (F (1, 125) = 4.87, p = 0.03, η_p^2 = 0.04), restorativeness (F (1, 125) = 4.38, p = 0.04, η_p^2 = 0.03), and pleasant atmosphere (F (1, 125) = 6.54, p = 0.012, η_p^2 = 0.05) from H, HV to HVA. This aligns with the 'a priory' hypothesis 2, suggesting that a combination of horizontal and vertical light distribution (HV) and a combination of horizontal, vertical and accent lighting, (HVA) compared to H show a linear increase in the participants' ratings for these appraisals. With regard to reassurance, a tendency (F (1, 125) = 3.59, p = 0.06, η_p^2 = 0.03) in linear contrast was identified. With regard to the dimension hostile atmosphere, the level of linear decrease was not significant.

Table 9. ANOVA-table with Polynomial Contrasts for the dependent variables, the environmental appraisals.

Measure	*F* (1,125)	*p*	η_p^2
POLQ: PSQ (strength)	2.00	0.159	0.03
POLQ: PCQ (comfort)	1.24	0.268	0.03
Visual Accessibility	4.87	0.029	0.04
Reassurance	3.59	0.060	0.03
Restorativeness	4.38	0.038	0.03
Atmosphere: Pleasant	6.54	0.012	0.05
Atmosphere: Hostile	1.10	0.296	0.01

5.3 Qualitative assessment of narratives across the three groups H, HV and HVA

Most participants took the opportunity to describe in their own words their experience of the respective lighting-modes. The response rate was H: 69%; HV: 81%, and HVA: 94%.

Narratives regarding lighting mode H were terse and in general had a negative tone. Common descriptors were: dark, boring, uneven, uninviting, uninteresting, and unsafe, as exemplified by the following citations:

H: '*Boring, enough light to ward off the darkness but not enough to create a feeling of safety', 'I don't want to walk alone here in the evening, because the lighting feels spotty and it is very dark in some areas', 'Rather gloomy, it is very uninviting'*, '*Boring, cold, dark, not a place to be in order to relax!'*. Fewer narratives regarding H were neutral or indifferent as seen in comments such as: '*OK'.*

Narratives regarding lighting mode HV in general had a positive tone. Common descriptors were: good visibility, bright, comfortable, safe, cosy, appreciative comments on the facade lighting, dark and boring, as illustrated by the following citations:

HV: '*The lighting is comfortable',* '*In general I have poor sight in darkness, but here I can see very well', 'I love the brown brick-wall façade. As soon as I entered the square I* *experienced it as beautiful and spacious'*. Few statements regarding HV had an indifferent tone: '*As I look straight forward I appreciate the even light on the facade. It makes me feel safe. The light from the light posts are harsh in comparison'*. Few statements regarding HV had a negative tone: '*It is dark in some places'*, '*It is dark and unexciting'*.

Narratives regarding lighting mode HVA were explicit and mostly positive, but the spectrum of responses were more diverse. Common denominators were: inviting, nice, pleasant, glary light posts, theatrical, positive comments regarding the façade, trees and sculpture, and negative comments regarding crimes, noise from traffic.

Positive narratives regarding HVA included: *'I experience that the square is inviting and pleasant. I feel at ease', 'The lighting on the façade, the art peace, the greenery, it gives a soft, welcoming feeling'*, '*I experience that the square is more cosy and pleasant with this lighting. I feel comfortable and safe'*.

Negative narrative regarding HVA included: '*It can be improved, a lot of crime, open drug dealing and shootings occur just a stone's throw away. More than just lighting is needed, and definitely better security'*.

6 Discussion

This study investigated the influence of spatial light distribution of electric lighting in a public square in a neighbourhood community on users' environmental appraisals. In a field experiment lighting interventions were introduced and compared horizontal (H), horizontal and vertical (HV) and horizontal, vertical and accent lighting (HVA). The main findings of the study are in support of hypothesis 2 as a linear increase in users' environmental appraisals were revealed for the perceived visual accessibility, restorativeness and of perceived pleasant atmosphere, from lighting mode H, HV to HVA. Moreover, a tendency in the same direction was identified for perceived reassurance. However, the expected decrease in perceived hostile atmosphere could not be confirmed.

The theoretical underpinning of the study draws on a framework in environmental psychology on environmental appraisals in public space (Johansson, Tsiakiris, and Rahm 2024), and a theory of visual spatial boundaries in lighting design research which emanates from lighting practise was employed (Wänström Lindh 2012). A plausible explanation of the findings is that a combination of horizontal light with vertical light onto the prominent façade in the field of view improves the apparent brightness of the space, and balances luminance contrasts in the visual field, e.g. the brightness of the lamppost towards the background luminance (Boyce 2014). Furthermore, illumination on the rear wall defines the spatial limits of the square, enhancing the perception of depth and gives a better visual overview (prospect) of the square (Fisher and Nasar 1992; Wänström Lindh 2013). This according to Wänström translates into 'a tangible experience of space' and improves reassurance in urban environments (Wänström Lindh 2013). A space with improved legibility and coherence will affect individuals cognitive and affective appraisals (Kaplan 1987). Lighting on important focal points and trees, provides 'scene contents' (Nikunen and Korpela 2012), previously shown to increase perceived restorativeness. The increase in ratings of perceived restorativeness of lighting mode HVA might be explained by positively affective connotations related to the illuminated greenery (Nikunen and Korpela 2009). Since lighting mode HVA is more varied (in comparison to H and HV), it is possibly perceived as more distracting (Boyce 2014, p.165), spots of darker areas around unlit trees could be interpreted as 'concealment' (Nasar and Fisher 1993; Nasar, Grannis, and Fisher 1993), hence merely a tendency in linear increase of reassurance.

Interestingly, the photometric assessment showed that the horizontal illuminance was kept constant (as intended), see Table 3, while the ratios of vertical over horizontal luminance showed a linear increase from H, HV to HVA, see Table 4. Hence, the linear increase in the ratings of the dependent variables (the environmental appraisals of visual accessibility, restorativeness and atmosphere) from H, to HV and HVA, can not be attributed to a change in the horizontal distribution of light. Rather the affect is likely attributed to the change in the spatial brightness obtained by the lighting on the wall and the accent lighting.

The findings of the municipality intervention did not support a priory hypothesis 1. The increase in horizontal illuminance uniformity from RH to H, did not affect the ratings of perceived lighting comfort, visual accessibility and reassurance positively. The photometric assessment showed that the uniformity of the horizontal illuminance U_o was increased from $U_o \sim 0.01$ in lighting mode RH to $U_o \sim 0.07$ in lighting mode H, Table 3. The choice of lamp type shifting from CMH to LED also significantly reduced intensity, Table 2.

The results support previous research suggesting that spatial light distribution influence users' perception and appreciation of public squares (Casciani 2020c; Stokkermans et al. 2018; Nasar and Bokharaei 2017). The results also go hand in hand with experiences from lighting practice advocating that horizontal illuminance levels from street lighting can be reduced when 'vertical facades' are carefully lit, furthermore that spatial brightness depends on the context (Olaisen and Bredal 2022).

A precedent study showed that users' self-reported social interaction in the square after dark was associated with their environmental appraisals of perceived atmosphere (Hennig, Gentile, and Johansson 2024). In turn, atmosphere was associated with the environmental appraisals of perceived lighting quality, visual accessibility, and reassurance (Hennig, Gentile, and Johansson 2024).

The current study suggests that spatial distribution of light in public squares could be a salient feature influencing users' environmental appraisals of visual accessibility, restorativeness, and atmosphere. In line with Böhme's theorization of atmosphere it is something spatial and emotional produced by the agents such as illumination (Böhme 2017). The findings of an increase in the ratings of pleasant atmosphere suggest that the perceived brightness is improved in lighting mode HVA, which possibly translates into the appreciation of a pleasant atmosphere. Hence, vertical illumination on walls, focal points and greenery are crucial elements to consider in lighting schemes of public squares. As such the findings of this study provide arguments for implication in practise. That is beyond offering visibility, lighting must be extended 'to a practice of attuning atmospheres' for the variety of activities and to support social interaction in public squares after dark (Sumartojo, Edensor, and Pink 2019; Böhme 2017).

Although the primary objective of this study was to investigate different spatial distribution, it must also be stated that spectral power distribution is known to effect brightness (Rea, Radetsky, and Bullough 2011; Bullough et al. 2014; Fotios and Cheal 2009; Stokkermans et al. 2017). The temporary lighting installation of the adjacent façade was achieved with LED with adjustable RGBW. The colour-mixing of the light (R: 255, G: 238, B: 143, W: 255) was adjusted to match the warm colour appearance of the red brick-wall façade.

Due to cost-restrains it was not feasible to run the temporary installation more than a month. Observations of any change in behavioural patterns due to the intervention would require a longer period of installation and data-collection, which was not feasible in this project.

Furthermore, the possibility to change illuminance levels both horizontally and vertically, rather than assessing only on / off modes (i.e. with or without vertical lighting on the façade, and / or accent lighting) would have been desirable.

From a lighting practice point of view a temporary lighting installation needs to be robust, meaning that any attempt to replicate the design for a permanent installation, the choice of luminaires would need to be more refined.

7 Conclusion

This intervention study reported on users' environmental appraisals after dark of perceived lighting qualities, visual accessibility, reassurance, restorativeness and atmosphere, in a pulic square, Malmö Sweden. It compared how people's assessed different lighting modes with different spatial light distribution with regard to these environmental appraisals.

The findings suggest that vertical illumination combined with accent lighting support users' appraisals of perceived visual accessibility, reassurance, restorativeness and atmosphere. These environmental appraisals have previously been shown to be associated to social interaction.

A primary implication of this research for lighting design in practise is hence that defining spatial limits of squares through vertical illumination and enhancing scene content with balanced luminance levels could effect users' environmental appraisals in a positive direction.

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Declaration of interest statement

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Appendix

Table A1 Overview of employed scales and items used in the questionnaire to assess environmental appraisals; perceived outdoor lighting quality, visual accessibility, reassurance, restorativeness and atmosphere. The internal reliability, Cronbach's alpha, is presented for each scale.

Measurement	Item	Statements	Response scale	Internal reliability Cronbach's α
Perceived outdoor lighting quality (POLQ) [a]		*How do you perceive the light in this place?*	7-point bipolar semantic differential (SD) scale	
		Perceived strength quality (PSQ)		α = 0.73
	PSQ1	Dark - Light		
	PSQ2	Intense - Weak (-)		
	PSQ3	Diffuse - Focused		
	PSQ4	Dim - Bright		
		Perceived comfort quality (PCQ)		α= 0.69
	PCQ1	Warm - Cold		
	PCQ2	Hard - Soft		
	PCQ3	Natural - Unnatural (-)		
	PCQ4	Glary - Shielded		
Visual Accessibility [b]		*How well can you see in this light?*	5-point Likert scale (1=no, definitely not; 5 yes, definitely)	α = 0.85
	VA1	I can see well.		
	VA2	I can see an obstacle on the ground.		
	VA3	I can recognize people's faces.		
	VA4	I can see details in the surrounding.		
	VA5	It is easy to find my way around here.		
Reassurance [c]		*How do you perceive being in this place?*	5-point Likert scale (1=no, definitely not; 5 yes, definitely)	α = 0.78
	PR1	I feel uneasy in this place. (-)		
	PR2	It is pleasant to stay at this place.		
	PR3	It feels fine to stay unaccompanied at this.		
	PR4	I would make haste to get away from this. (-)		
	PR5	I would rather avoid being in this place. (-)		
	PR6	I have a good overview of this place.		
	PR7	I can easily escape from this place.		
Restorativeness [d]		*What are your thoughts about this place?*	5-point Likert scale (1=no, definitely not; 5 yes, definitely)	α = 0.85
	PRS1	There is much to explore and discover here.		
	PRS2	Coming here helps me to get relief from unwanted demands on my attention.		
	PRS3	Spending time here gives me a break from my daily routines.		
	PRS4	The place has fascinating qualities.		
	PRS5	The place is boring. (-)		
	PRS6	I like this place.		
	PRS7	This place is nice.		
Atmosphere [e]		*How do you experience the atmosphere in this place?*		Dimension1 - Pleasant α = 0.88

Atmosphere [e]			Single item 5-point Likert scale (1=not at all; 5=very much)	Dimension 2 – Hostile α = 0.89
	A1	Friendly		Dimension 1
	A2	Welcoming		Dimension 1
	A3	Sociable		Dimension 1
	A4	Pleasant		Dimension 1
	A5	Hostile		Dimension 2
	A6	Intimate		Dimension 1
	A7	Lively		Dimension 1
	A8	Stimulating		Dimension 1
	A9	Exiting		Dimension 1
	A10	Cosy		Dimension 1
	A11	Threatening		Dimension 2
	A12	Terrifying		Dimension 2
	A13	Enjoyable		Dimension 1
	A14	Safe (-)		Dimension 2
	A16	Tense		Dimension 2

Note. Items with (-) indicate reversed in coding.
[a] Perceived outdoor lighting quality scale (POLQ) (Johansson, Pedersen, et al. 2014)
[b] Perceived Visual Accessibility (Johansson, Küller, and Rosén 2011)
[c] Perceived Reassurance (Johansson, Küller, and Rosén 2011) (Blobaum and Hunecke 2005)
[d] Perceived Restorativeness Scale (a shortened version) (Hartig et al. 1997)
[e] Perceived Atmosphere (Hennig, Gentile, and Johansson 2024)