AFTER DARK

SOCIAL-ECOLOGICAL PUBLIC SPACE FROM A DARKNESS PERSPECTIVE

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Social-ecological public space from a darkness perspective

CHALMERS
UNIVERSITY OF TECHNOLOGY

A master thesis by
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Direction of Urban Challenges

Chalmers School of Architecture
Department of Architecture and Civil Engineering ACE

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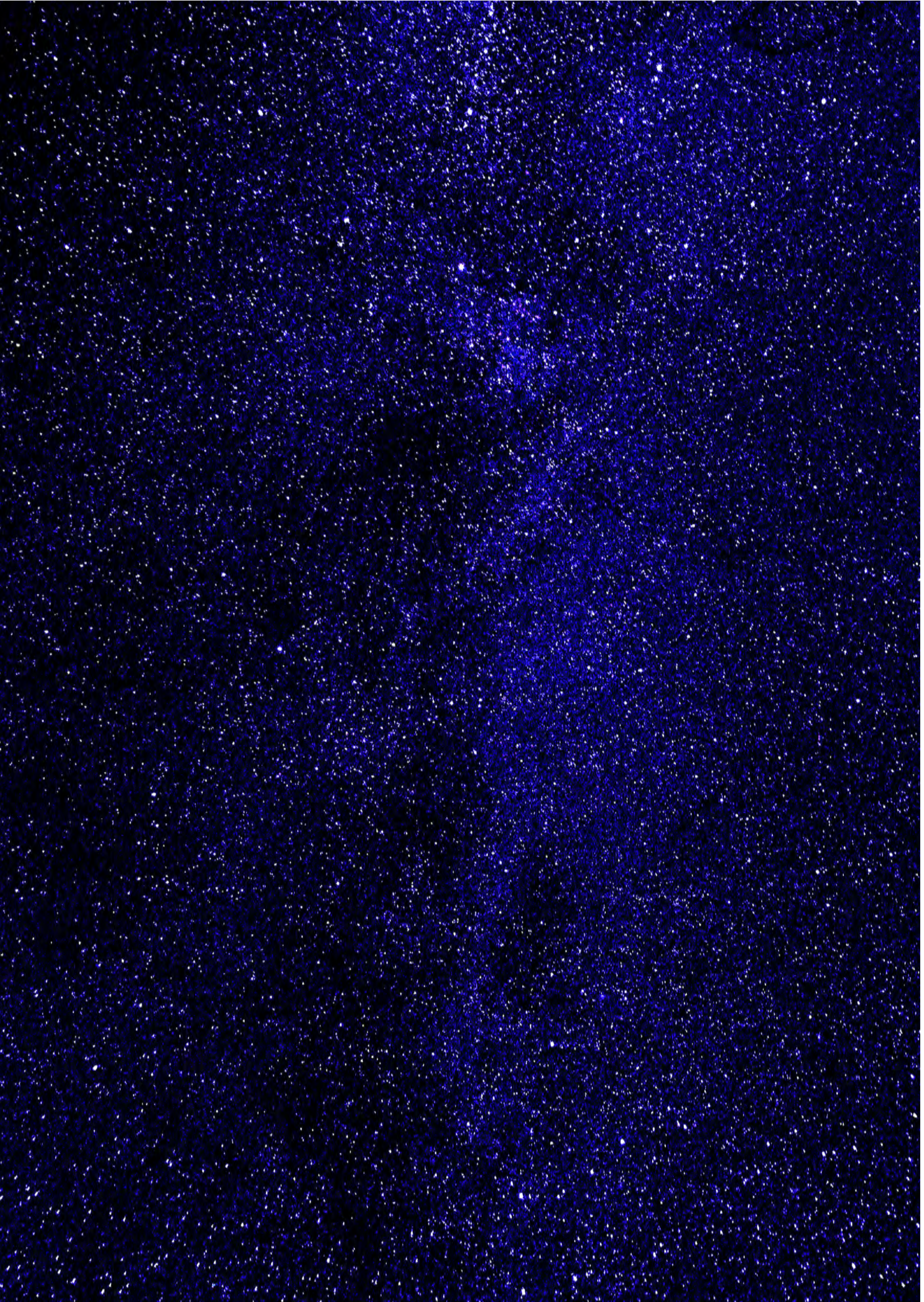


ABSTRACT

Sustainable urban development calls for urban planning and design supporting both society and ecology; human and non-human species. We need to think of ecology *in* cities in order to move beyond the traditional human-centred development and reconnect to natural systems. Social-Ecological Urbanism sets the background to address this challenge; identifying the conflicts but also the synergies that emerge from the meeting of social and ecological systems.

After Dark is a thesis based on the social-ecological approach, rethinking the increasing yet overlooked issue of urban darkness-lighting imbalance. Excessive use of artificial light, light pollution, has slowly replaced the starry dark sky with a gray haze and altered the natural rhythms of dark and light. This has detrimental effects on human well-being and nocturnal species. Values of darkness seems forgotten, despite Earth being dark 50% of the time.

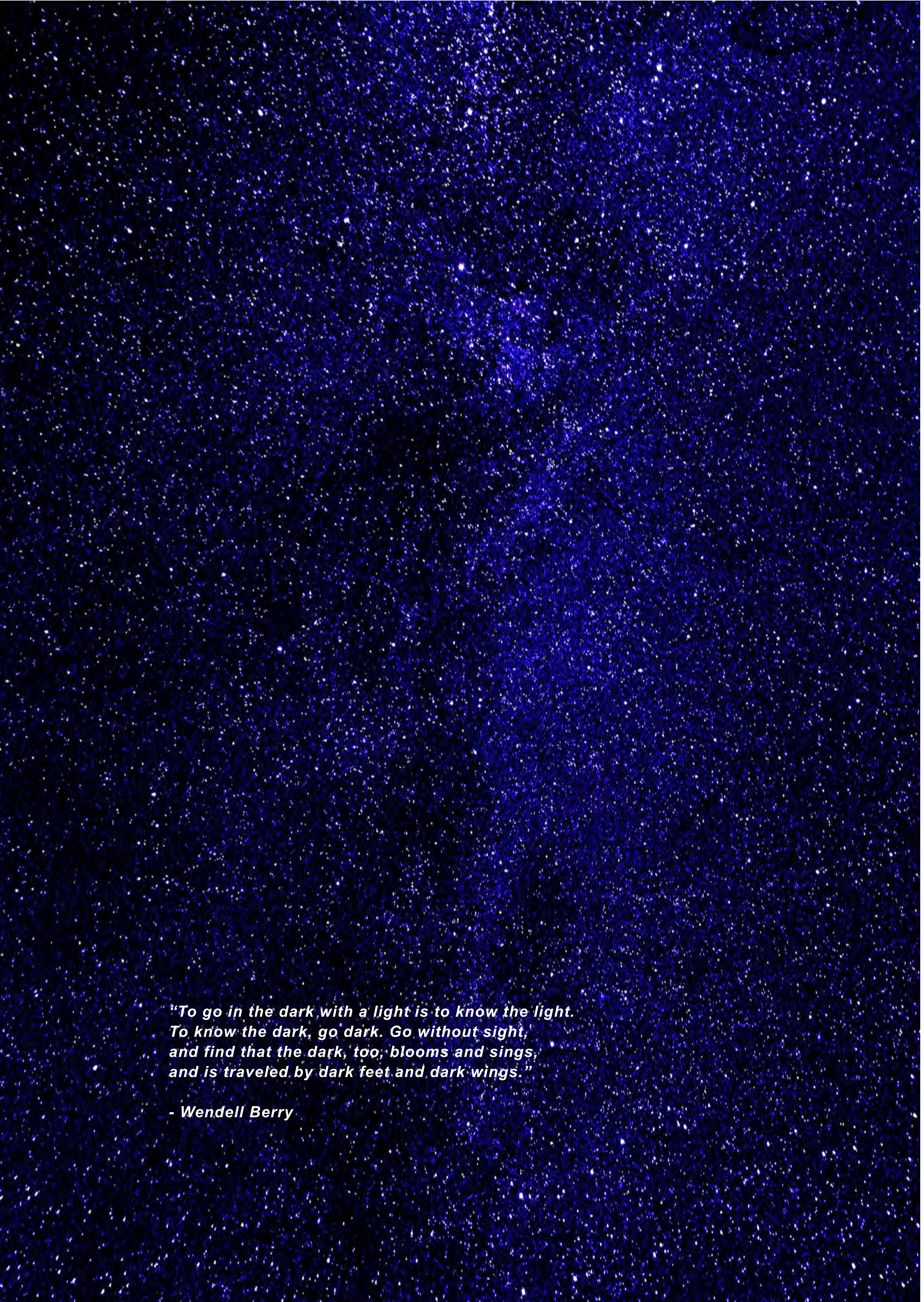
Theoretic research on both light pollution and the values of darkness has grown lately, however a lack of spatial translation beyond solely reducing excessive artificial light is evident. By shifting the perspective in planning and design from mitigating light pollution to focus on the values of darkness we aim to reintroduce darkness to our urban areas.

The project is multiscalar - city, district & site, illustrating the challenges and opportunities of designing with darkness for humans and other species. The theoretic concept of a *dark ecological network* has been implemented into the context of Gothenburg. The dark network is particularly relevant since one of the most important native species in the region, the bat, is nocturnal.

The potential for areas and corridors forming the network on city and district scale were found through data analysis observations. By overlaying data representations of systems in the city, synergies and conflicts between humans and bats are collected. A central development area with an intersection between an important and sensitive structure for nocturnal species and an attractive link for humans is explored in the site scale. The public space has a focus on the visual perception of space in darkness and illustrates the duality of social-ecological needs.

Keywords:

social-ecological urbanism,
values of darkness,
dark ecological network,
darkness design



*"To go in the dark with a light is to know the light.
To know the dark, go dark. Go without sight,
and find that the dark, too, blooms and sings,
and is traveled by dark feet and dark wings."*

- Wendell Berry

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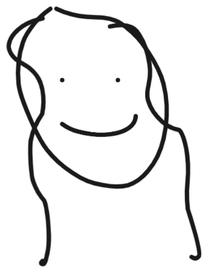

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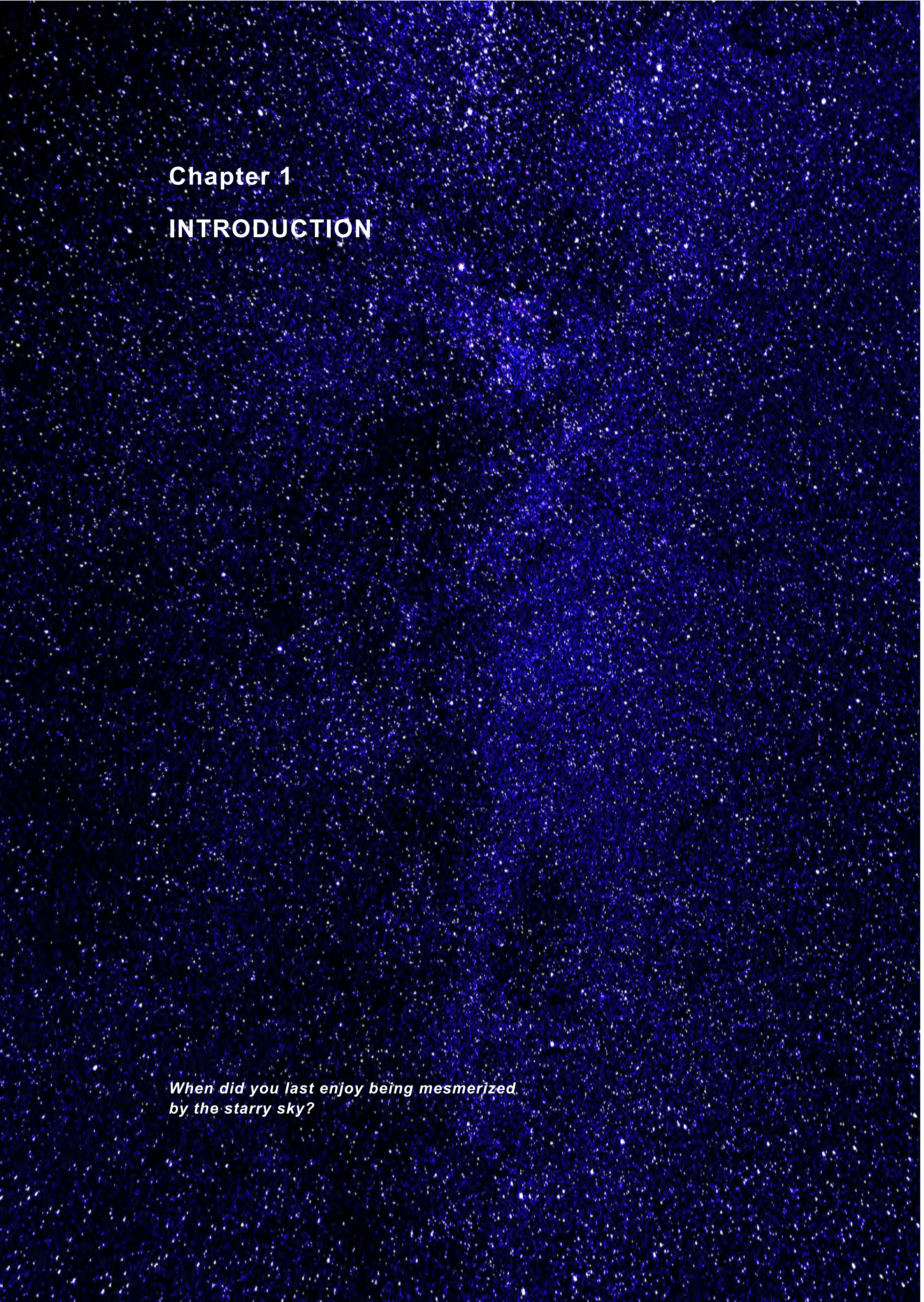


Chapter 1

INTRODUCTION

When did you last enjoy being mesmerized by the starry sky?

BACKGROUND

Since the beginning of time the natural darkness-light cycle has been the director of the rhythm of human life on earth (Garnert, 1993) as well as all other living organisms' (Helldin & Jägerbrand, 2020) on a daily and yearly basis. A hundred years ago the breakthrough of artificial light elongated the day (Garnert, 1993) for human bias, but also launched a process of rhythm imbalance.

Artificial light is an enabler for human orientation (Wänström Lindh, 2018). Dark spaces may be perceived as spatial barriers with implications on movement and safety, and are thus lit to overcome. At the same time lit spaces can make the darkness darker - contradictory one might think but an effect of night vision disturbance nonetheless. For nocturnal species, e.g. bats, darkness enables movement which is a crucial condition for their survival (Eklöf & Rydell, 2020). "Lighting in the landscape affects the balance of ecosystems to a very high degree and all measures that can be taken to minimize the impact are therefore important to implement." (Own translation, Jakobi et al., 2011, p. 14). Conflicting, one can say that one species' barrier is another species' corridor.

Artificial light is emitted everywhere - from buildings, streets, vehicles, signs and installations, the list of contributing components is long. When light falls where it is not intended it is called light pollution and it has consequences on wildlife, human health, safety, energy and heritage (International Dark Sky Association [IDA], n.d-a). Some examples of tangible consequences of light pollution are a blinding light, trespassing of light into the bedroom or bat nest and lit skies over urban areas obstructing star visibility. Other known intangible consequences on humans are the disruption of physiological processes and hormone cycles (Helldin & Jägerbrand, 2020) connected to sleep, stress and illness.

The "artificial darkness-light rhythm" is a recent human construct with detrimental effects on our own well-being and nocturnal species living conditions on a global and local scale, today and in the future. It is an issue we can no longer overlook. Because the pollutants emerge from components developed by designers we have an obligation to act. The development of planning or design projects in urban areas have the potential to provide space for the much-needed darkness by acknowledging its values for humans and other species, especially nocturnal animals as bats.

SCOPE

Knowledge gap
In recent years, there has been increased attention within research regarding both the values of darkness as well as the risks of light pollution. Even though theoretical concepts of establishing a dark ecological network and designing for darkness has been proposed, there seems to be a lack of spatial implementation. We claim that the absence of spatial translations is a knowledge gap within the field of urban planning and design and do see a potential to explore darkness beyond the overuse of artificial light.

Aim
The aim of this thesis is to translate theory into planning and spatial design and by that contribute to a discussion about balancing interests in relation to social and ecological sustainability (figure 1).

Purpose
The purpose of this thesis is to bring attention to issues of light pollution and its negative effects on both humans and non-humans and acknowledge the ecological activity during dark hours. This will highlight the conflicts and synergies that arise in the meeting of social and ecological systems derived from a darkness perspective. The thesis enables exploration of a side of urban planning and design we feel is missing in our education and add a new layer to our design toolbox.

Figure 1

Needed balance between social and ecological interests.

Research question

>> How can a darkness perspective affect the design of public space in Gothenburg, balancing the social and ecological interests and users?

Delimitations

Discourses
- Social-Ecological Urbanism
- Dark ecology
- Value of darkness
- Light pollution
- Urban planning & design
- Urbanization

This thesis is about...
- Darkness
- Balancing interests through design
- Public space
- Ecology in urban areas
- Bats
- Human and bat movement in urban areas
- Human perception of space
- Safe public space
- Gothenburg
- Time & rhythm
- Use of artificial light

This thesis is not about...
- User groups with impaired vision
- Political discussion about "right to space"
- How artificial light works
- Environmental impact of light fixtures
- Individual buildings
- All species within dark ecology
- All parameters of public space

THESIS OUTLINE

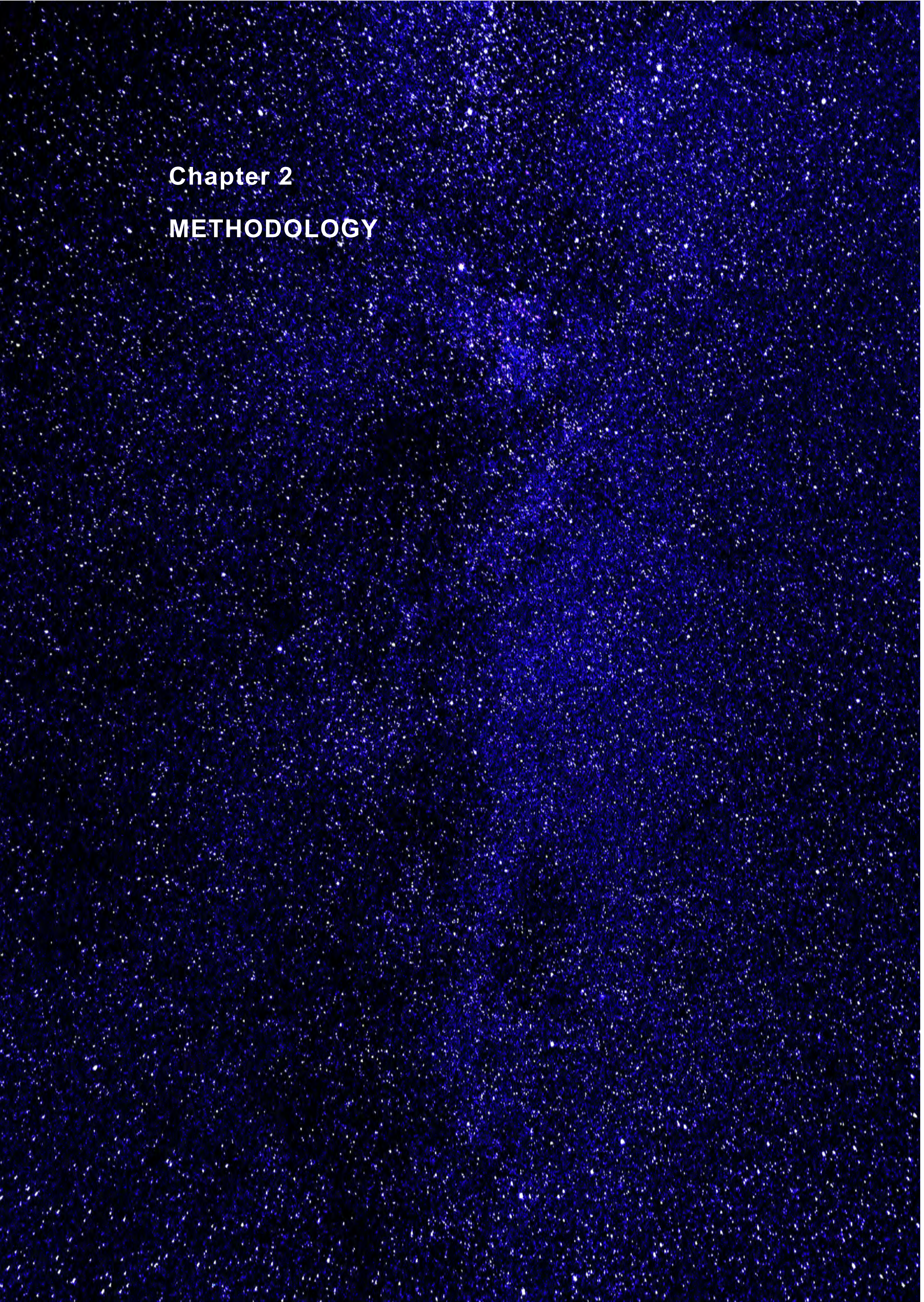
This first introduction chapter presents the starting point on which the thesis and the following chapters are based on.

Chapter 2 introduces the methodological framework of the thesis and an overview of the methods.

Chapter 3 gives an overview of darkness and lighting from different perspectives to give a broad understanding of the topics. It covers the history of lighting, how it is used in cities and how this connects to human vision and perceived safety. Further it explains the negative side effects of excessive use of artificial light for humans and other species, the related legislations and gives some specifics about nocturnal animals and bats.

Chapter 4 presents the design study and the main findings of the thesis. It gives a suggestion with illustrations of a new dark ecological network in Gothenburg on city-, district- and site scale.

Chapter 5 summarizes the thesis with reflections of the process and thesis outcome.

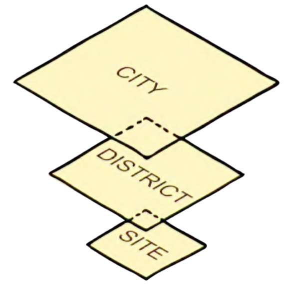


Chapter 2

METHODOLOGY

This project is developed mainly through research by design methodology. The input from current knowledge informs the thesis, and the thesis output contributes to the current knowledge.

Three representative scales.



The scope of this thesis calls for a multiscalar approach. Three scales are chosen for analysis and design of the urban environment spanning from strategic urban planning to the design of a public space. The scales are: *city, district* and *site*, which is also the order they are presented. The selected scales visualize different relevant levels of detail of the systems in the city. The scales only represent certain aspects, and all systems are intertwined in the actual city.

Theoretical and methodological framework: Social-Ecological Urbanism

Social-Ecological Urbanism is an approach to city planning that links social and ecological services. The concept builds on the understanding that social and ecological systems are intertwined and interdependent. In other words, it is not a question of social plus ecological systems, but one integrated system that is strongly connected (Biggs et al., 2021). ”Social-Ecological Urbanism looks for synergies between ecological and socio-spatial systems, acknowledges the existence of conflicts between them and expands the systems’ capacity, through design, to absorb shocks, utilize them, reorganize and continue to develop without losing fundamental functions and thus building resilience” (Chalmers Tekniska Högskola, 2020). The separation of the human and natural systems is a human construct and this simplified way of viewing them as two different systems have affected how humans understand their own conditions (Marcus & Colding, 2011).

The social-ecological systems have no clear boundaries. Due to their extensive interactions and connections is it difficult to tell which component belongs to a certain system and which belongs to a broader context. To understand the interplay, it is crucial to look at the cross-scale interaction over both space and time (Biggs et al., 2021). Cities are not only hard surfaces and constructed places but should be understood as living systems. The challenges within a city should therefore be approached in a holistic way, with system thinking, instead of breaking it down into individual components (Rómice et al., 2020).

Sustainable urban development calls for urban planning and design supporting both society and ecology; human and non-human species. We need to think of ecology *in* cities to move beyond the traditional human-centred development and reconnect to natural systems. The complex system thinking approach requires a transdisciplinary collaboration between researchers and practitioners with different knowledge and background. This brings a broader insight to and a mutual understanding between different actors in a project (Biggs et al., 2021).

Dark ecology

An ecological system comprises all living things and their habitat within an area (Nationalencyklopedin [NE], n.d-a.). Cities and humans are dependent on ecosystems within and beyond the urban environment for many services and goods that are important for economic, social and environmental sustainability (Secretariat of the Convention on Biological Diversity, 2012).

The current rate of urbanizations has increased the importance of conserving native ecosystems. Connecting ecosystems that have been fragmented during urban expansion will likely increase their ecological functionality and thereby maximize the service which the ecosystem offers i.e. pollination, biodiversity. Even though many cities have a rich biodiversity (Secretariat of the Convention on Biological Diversity, 2012) integrating cities and nature is a big challenge (Marcus, 2021).

'Dark ecology'
The notion 'dark ecology' is sometimes used to describe 'night-time ecology'.

Dark ecology is the study of the population, distribution and interaction of species during the night. As a cohesive field, the study of ecology during the night has been quite neglected. This can be traced back to humans' own bias as a diurnal species and the technological challenges that come with working in night-time environments (Gaston, n.d.).

A dark ecological network is a concept to implement for protecting and preserving the benefits of darkness. It takes a holistic approach of seeing the multiple issues related to darkness preservation (Challéat et al., 2021). When protecting and preserving darkness through the dark ecological network the goal is not to eliminate artificial light at all times, but to keep a level of darkness that is as natural as possible to reduce biodiversity loss (Sordello et al., 2022) and species disturbance.

Challéat et al. (2021) point out the connection between the concept of a dark ecological network and the Social-Ecological Urbanism framework when they state that "The ecological network, i.e., the physical and functional combination of natural elements that promote habitat connectivity, provides a valuable framework for that purpose. Understood as a social-ecological framework, it offers the opportunity to consider the multiple uses of nocturnal spaces and times, by humans and nonhumans alike" (p. 1).

The value of darkness

According to Dr. Taylor Stone, scientific research has had a focus on the negative effects of light pollution, but not on what is valuable with darkness. In his paper published in 2018, "The Value of Darkness: A Moral Framework for Urban Night-time Lighting", nine values of darkness are identified through an assessment to inform decision making. The means to "start designing with darkness" (p. 626) in order to "preserve, protect and promote darkness" (p. 614) are key distinctions in the darkness approach. "Utilizing the value of darkness to inform our decision-making offers a framework that encapsulates, but goes beyond, simply dealing with the negative effects of light pollution. It asks that we reconsider darkness, not as an opponent of lighting, but as an equal consideration in the design of night-time spaces" (Stone, 2018, p. 626).

The assessment consists of a categorization of the values of darkness, a 2-step systematic analysis of the values of darkness and a concluding theoretic translation of the analysis. Figure 2 illustrates an original table from the paper with added information of the environmental values of darkness and other notions from the text.

THE VALUE OF DARKNESS	INSTRUMENTAL	INHERENT	PRESENT	IMPERATIVE	FUTURE	TERRESTRIAL	ATMOSPHERIC	THE ENVIRONMENTAL VALUE OF DARKNESS
EFFICIENCY	●		●					*The responsible use of lighting where and when needed; money-saving.*
SUSTAINABILITY	●			●				*The responsible use of lighting where and when needed; energy-saving and preserving non-renewable resources.*
ECOLOGY		●		●		●	●	*The protection and preservation of species and biodiversity; habitat conservation efforts.*
HEALTHINESS	●		●			●		*Promoting and fostering human health; physiological well-being.*
HAPPINESS	●		●				●	*Promoting and fostering happiness; emotional well-being.*
CONNECTION TO NATURE		●			●		●	*Preserving a connection to the more-than-human world.*
STELLAR VISIBILITY		●			●		●	*Preserving conditions for access to the firmament.*
HERITAGE & TRADITION		●			●		●	*Preserving the cultural heritage of the night sky for future generations.*
WONDER & BEAUTY		●			●		●	*Efficiency - Preserving the aesthetic appeal of the natural night sky.*

TYPE OF GOOD
"WHAT"
Clearifies the meaning and importance of darkness in relation to desired ends.
Instrumental - darkness as a means to an end. Instrumental values are much less robust than inherent since e.g. technology development might fulfill the same goals.
Inherent - darkness as a component of the end itself.

TEMPORAL CHARACTERISTICS
"WHEN"
Categorizes the values in relation to time.
Present - actions taken now have a direct positive effect.
Imperative - actions taken now have an ongoing outlook spanning over several years or decades. These are of the highest importance because their negative effects are irreversable.
Future - actions taken now can reverse current negative development.

SPATIAL CHARACTERISTICS
"WHERE"
Darkness as both an abstract concept and a tangible feature, categorized in two broad spatial scales to highlight where, spatially, the values are.
Terrestrial - directly bound to a place.
Atmospheric - bound to a phenomena in space.

Figure 2
Interpretation of the paper in summary. The 'Value of darkness' image is retrieved from Stone (2018).

Overview of methods

1. Literature review

Published relevant scientific literature. The selected literature has, in most cases, been published recently and represent the state-of-the-art. The wide scope of darkness was narrowed down to a selection of relevant topics. The topics of darkness and lighting aims to provide a base for the understanding from several perspectives: theoretical, physical, emotional, legal and historical, as well as the connection to current discourses. The review brings useful information about possible conflicts and synergies to inform the design.

2. GIS mapping and data analysis

Data with different kinds of information contribute to an understanding of the systems in a city. By overlaying the data (as layers or visualizations) we got a series of maps as a base for observations regarding relations/connections as indicators of conflicts and synergies; where and for whom. The maps are 2D representations of e.g. movement and other processes in 3D space. The relations are materialized in the relevant scale. We conduct spatial analysis of the street network using QGIS plug-in Place Syntax Tool [PST] (Spatial Morphology Group [SMoG]) to highlight global and local movement patterns and activity in the city.

Classification of the layers, sources in [x]:
1. Built environment: Street network, buildings, infrastructure [SMoG]
2. Urban activities: uses, night-time activities, street centrality (pedestrian movement and traffic flows) [SMoG]
3. Habitats: Park areas [SMoG], nature reserves [Naturvårdsverket], habitat patches and dispersal areas for bats (note: data is not complete for Northern Gothenburg, marked in map) [Calluna AB]
4. Lighting: Artificial lighting features (note: data not complete of Southern Gothenburg, marked in map) [Trafikkontoret Göteborg] light pollution [NASA/VIIRS 2021].

3. Over- and review of Gothenburg's development plans

Over- and review of the current development plans, related documentation and ongoing work within the city of Gothenburg. This gives an indication both on the current state and future visions in a top-down approach. It is relevant since this is the frame in which all urban planning and design must be developed, and therefore an interesting reference point for our own findings and discussions. The documentation considered is primarily the vision for Älvstaden and detail plan over Skeppsbron.

4. Design study in Gothenburg

The design study in Gothenburg (chapter 4 - *Designing with darkness)* is a context based research which is a methodology for extracting and applying knowledge within the presented framework.

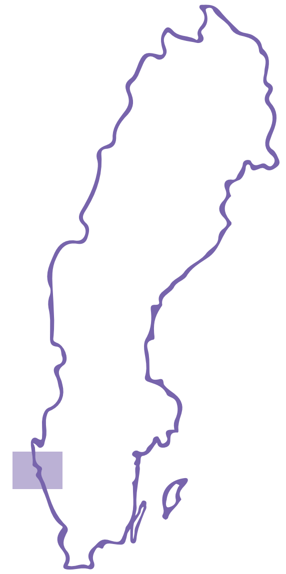
The design study is developed from method 1-3, thus based on scientific literature and analytical and empirical data. Our own observations, reflections and conclusions as well as experiments in physical models contributes to the field architecture.

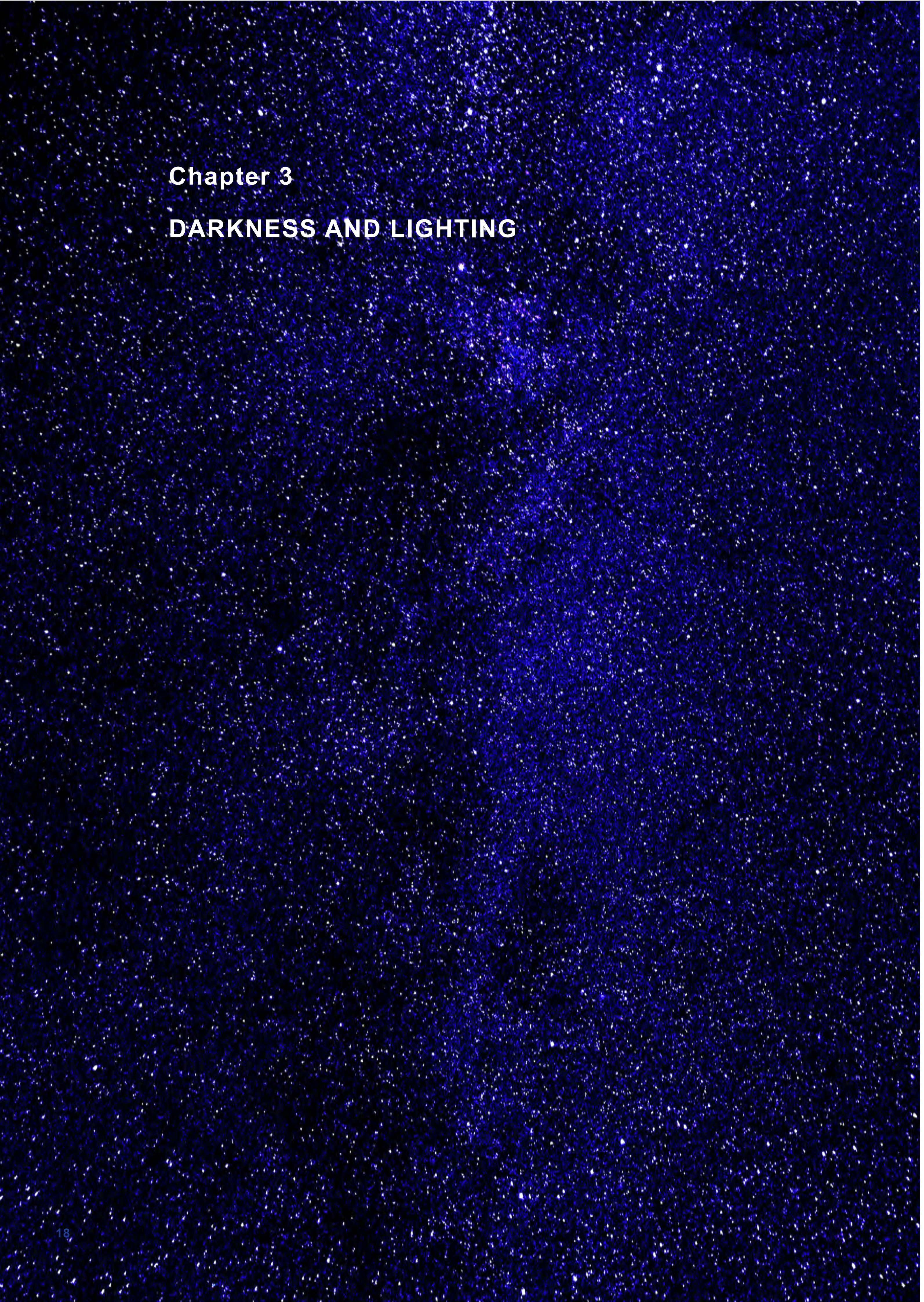
A design study of this kind has not been conducted before from what we know. This emphasizes its relevance and, also, excitement, at the same time as it is challenging as we have to break uncommon ground. By testing parameters in a systematic way, categorizing and grade them, we aim to make clear how and why the specific knowledge was gathered and implemented in the design. Our way of interpreting the information, which in itself is the exploration, is not scientifically approved.

A Swedish context is relevant in relation to the scope of the thesis because of the uneven natural darkness-light ratio over a year. The specific location of Gothenburg is chosen because it is our common ground and place for everyday life. We have a good understanding and personal experience of using it. The large ongoing and future development of the city gives excellent opportunities to propose new urban planning and design ideas.

As a representative species for the ecological, often less prioritized, needs the bat genus will be used. Bats are often used in environmental and ecological assessments as the representative sensitive native species. In Gothenburg, 10 of the 19 bat species in Sweden are occurring (Kindvall, 2021) and they are a very important native species. Bats are possible to map, they are protected by the law and nocturnal, thus sensitive to light and therefore relevant for this thesis.

Location of design study is in Gothenburg, Sweden.





Chapter 3

DARKNESS AND LIGHTING

DARKNESS AND LIGHTING OVERVIEW

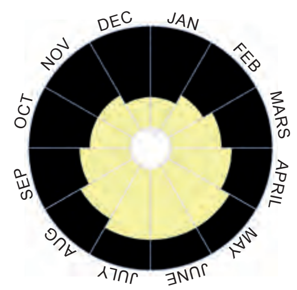
When talking about darkness, one always talks about light too. Light (and darkness) are central in architecture and the built environment. It creates contrasts and shadows which provides depth and shape in spaces (Wänström Lindh, 2018). Mastering light and darkness are essential for a designer.

Darkness and *night* might at first seem synonymous. But, living in a country like Sweden we know that it is not always night when it is dark, rather darkness "is a central feature of the night" (Stone, 2018, p. 611). Therefore, the notion darkness is used in this thesis to describe the condition of the time when there is a lack of daylight from the sun.

Darkness and (natural) light are equally important for almost all living organisms (Gerrish et al., 2009). The balance is vital for processes and cycles among most animal and plant species (Helldin & Jägerbrand, 2020) and fosters well-being and happiness (Stone, 2018). Natural light is not only emitted from the sun, but also from the stars and reflected by the moon. Natural light from stars and moon are central for many species orientation and time perception (Ahlstrand, 2017) and composes the spectacular experience of the starry sky.

For an intangible number of years, the cycle of natural light and darkness directed the rhythm of human life on earth (Garnert, 1993) as well as the life of all other living organisms' (Helldin & Jägerbrand, 2020). At all times, half of the surface on Earth is covered by the night. (Sordello et al., 2022) On a yearly basis, all locations in the world have the same amount of darkness and light. Depending on one's geographic location in relation to the equator, the daily darkness-light ratio (day rhythm) unfolds unevenly based on the closeness to the polar regions. In Gothenburg, the specific darkness quota over 24 hours is, at most, 73% in winter, and at lowest 25% in summer (based on data from Sunrise and Sunset, 2020).

Darkness-light ratio over a year in Gothenburg.



The commonly used terms "diurnal" and "nocturnal" are used to describe a species active phase. This categorization is a human construct. Melbin (1978) makes a connection between the categorization and space and says that a time recognition of a species can "improve our grasp of the ecology of a region /…/ as well as by knowing the spatial dispersion of these or other animals" (p. 5). The description of a species active phase helps us to understand part of their behaviour and spatial needs. It seems like the separation of human and natural systems, as stated by Marcus & Colding (2011), and the separation of humans as diurnal species, as stated by Gaston (n.d), have led to us prioritizing human systems and humans species, thus light above darkness, because that is what we are interested in knowing.

*All species need darkness and (natural) light. No species need artificial light. **

**We might consider the current use of Artificial light at night [ALAN] a necessity for conducting life, but it is only life as we know it.*

HISTORY OF DARKNESS AND LIGHTING

A brief historic overview of Sweden puts darkness and lighting in a time perspective (figure 3 & 4). Highlighting important paradigm shifts, technological development and other relevant aspects gives an idea of the impact of ALAN on social behaviour and space, composed over a very short amount of time compared to human life evolution and the frame of Swedish urban development.

Urban development in Sweden 4000 BCE - 2020 CE

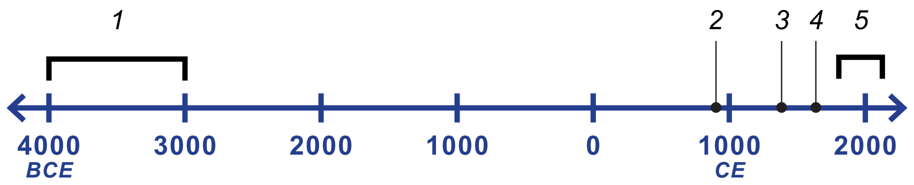


Figure 3
Simplified time line illustrating relevant paradigm shifts.

1. Transition to an agricultural society: A vital paradigm shift in history is when humans settled down (Ekero Eriksson, 2020)

2-4. Formation of cities and urban planning: It took many years before settlements were formed.
2. 900 CE - The start of the formation of city-like villages. (NE, n.d-b)
3. 1300 CE - The notion "city" is established. (Wikipedia, 2021)
4. 1600-1650 - Urban planning is organized. (Wikipedia, 2022b)

Zoom in on urban development in Sweden 1800-2020

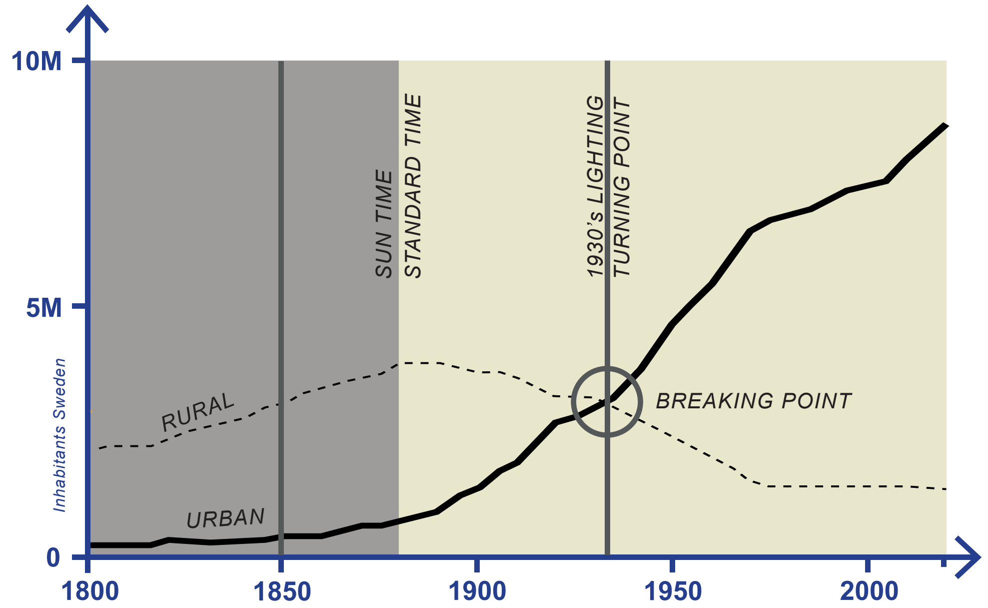


Figure 4
The events in the time line are illustrated facts specified in the text.

The base for this chart is collected from a figure by Statistiska Centralbyrån [SCB] (2015b). The numbers from 2010-2020 are based on statistics from SCB (2021).

5. Transition to an industrial (imbalanced) society

The industrialization around 1850 was the spark to several fundamental events in the history of darkness and lighting. The urbanization trend is one of them, at first slow in the early 1800's with 10% of the inhabitants living in urban areas to increase rapidly the following centuries (SCB, 2015a) and is now [2020] at 88% (SCB, 2021). The new rational era required a rational framework, and one important step was changing the *sun-time* to a *standard time* [1879] which made time transform from being a physical factor to becoming a social construct. This was only possible when "there was enough light to break the natural division of time in light and darkness" (own translation, Garnert, 1993, p. 220). The 1900's was the century when we altered the day rhythm (and darkness was eradicated) enabled by the electrification of society and the low energy prices, which, by gradually increased use of artificial light, led to a changed view on time and space (Garnert, 1993).

The 1930's was a turning point in the history of artificial light, as it was widely adopted in society. Campaigns from architects and light companies presented the idea of "light in the service of man" and modernism, which was a mark for the wonder and delight of future of cities (figure 5). Later, from the 1950's forward, when cars were implemented large scale in public space, the focus of lighting shifted from lighting pedestrian spaces to lighting the streets (Garnert, 2016). This is still often the case, and lighting questions are generally handled by traffic departments.

In the 1970's the phenomena of light pollution were noted for the first time. Since then, lighting has increased both in use and attention, for example emphasized through the new profession branch of *lighting designers*.

Transition to a balanced society?

When we saw the big time line, we understood that our "need" of ALAN is a recent construct and how human behaviour, expectations and preconceptions can change over a generation. Even though artificial light use increase globally (Helldin & Jägerbrand, 2020) new perspectives on darkness grows stronger. Maybe we are just now, in a historic darkness and lighting shift to balance the imbalance and re-introduce darkness?

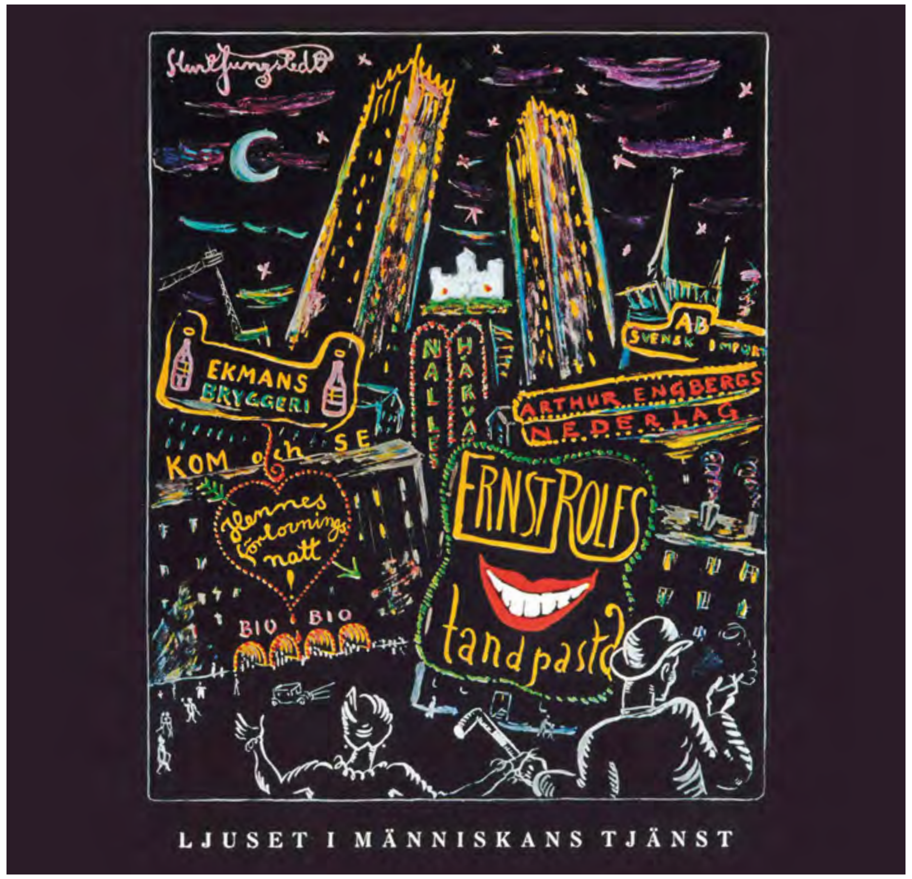


Figure 5
"Light in the service of man" by Kurt Jungstedt for the magazine "Revyn 1928".

ARTIFICIAL LIGHTING IN URBAN AREAS

Artificial light is present in all spaces - public and private, new and old. The campaign of "light in the service of man" is a good description of the "need" of ALAN. ALAN sure is a service for humans, creating visibility that enables social, spatial and characteristic qualities after dark. Artificially lit areas increase 2-6% annually, which is a doubling in 20 years (Helldin & Jägerbrand, 2020). In parallel there is a process called light inflation which is that light levels increase in both new and existing areas over time (Jägerbrand & Bouroussis, 2021).

Light emitters in urban areas

Artificial light in urban areas is generated by all individual light sources and lit/lighting elements (figure 6). The sources are located on both private and public property and could be lit constantly or dynamically.

Public property light: signs, landmarks, decoration (greenery lighting, Christmas, art installations), street light, path light (fixtures, bollards, diodes etc).
Private property light: facade lighting (including landmark buildings), light from resident units, decorations, light from stores, signs, cars and other vehicles (dynamic).

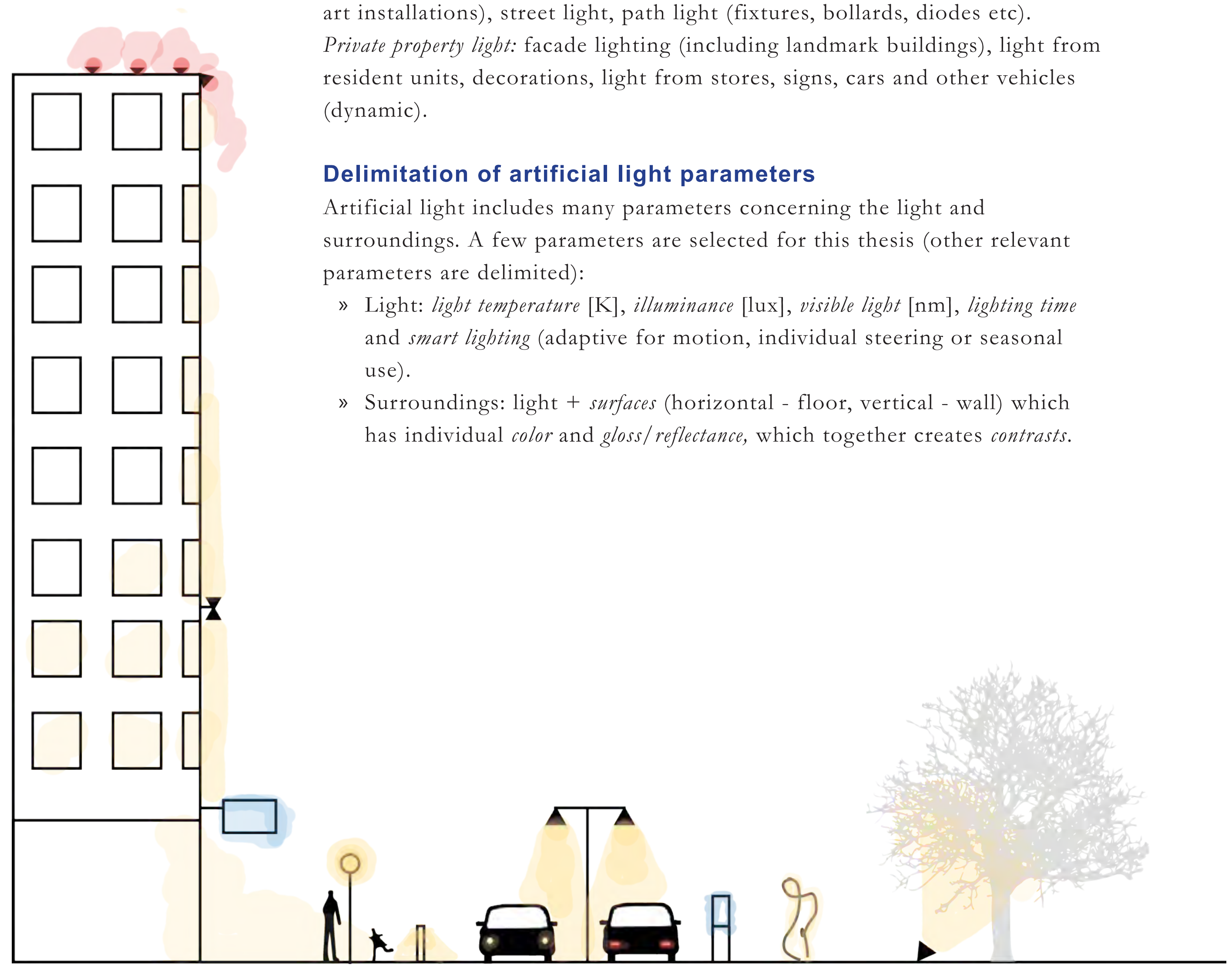
Delimitation of artificial light parameters

Artificial light includes many parameters concerning the light and surroundings. A few parameters are selected for this thesis (other relevant parameters are delimited):

- » Light: *light temperature* [K], *illuminance* [lux], *visible light* [nm], *lighting time* and *smart lighting* (adaptive for motion, individual steering or seasonal use).
- » Surroundings: light + *surfaces* (horizontal - floor, vertical - wall) which has individual *color* and *gloss/reflectance,* which together creates *contrasts*.

Figure 6

Illustration of elements that contributes to emitting light in the city.



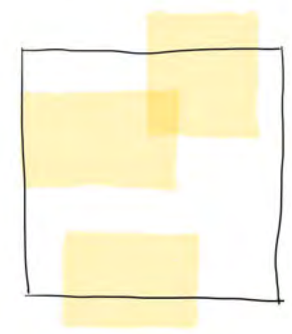
Designing with artificial lighting (in darkness) in public space

Light and darkness, thus contrasts and shadows, generating shape and depth are core in the field of architecture (Wänström Lindh, 2018). Which practitioner is doing the lighting design seems to differ a bit depending on project, scale and purpose of the project and could be light designers, architects, planners, light engineers, traffic engineers or electrician consultants. Depending on individual background, education and approach the contributions of these of course differs.

Traditional lighting research has been focused on reaching "even (horizontal) light". Even light distribution is required for central vision, and uneven light distribution is required peripheral vision (see p. 24) - a field in which few studies has been conducted. Lighting standards are based on parameters of the central vision (Wänström Lindh, 2018) and indicate the minimum amount of lighting required in public space. However, the maximum amount of lighting is not regulated.

Visual perception of space is a complex combination of many physical and relational parameters. Experiences of light is hard to predict, and not all experiences are measurable. The visual perception of a space consists of both physical space and intangible light space (figure 7). The spaces are defined by boundaries and different light environments. They are connected in sequences (Wänström Lindh, 2018). Physical and intangible space both contribute to distinct and interesting experience of a space (Wänström Lindh, 2018).

Figure 7



■ *Physical space boundary*

■ *Light space*

Strategy for site-specific lighting environments

White Architects and Nacka Kommun have developed *Strategies for public lighting in Nacka* (own translation, Nacka Kommun, 2017) in order to achieve socially, ecologically and economically sustainable public light environments. They propose a site-specific lighting environment to meet the basic needs of artificial lighting in the planning and creation public space. Accoriding to Nacka Kommun (2017) site-specific lighting environments are a summary of:

- » *Spatial lighting* – the spatial conditions of the city and landscape such as scale, topography, views, boundaries, directions, open ground and landmarks.
- » *Social lighting* – the social need for light (see p. 32-33).
- » *Characteristic lighting* – the character of the place, preserves and develops architectural, cultural and natural values.
- » *Biological lighting* – the need for darkness during the night, minimizing the risk of disturbances to human health and well-being and living conditions for other species.

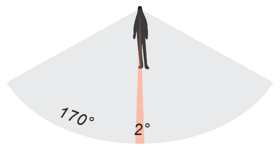
This strategy will be implemented in the design study.

VISION

Human vision

Humans' visual capacity is good in daylight. The retina has a high ratio of *cone cells* (high color sensitivity, high light dependency) and a low ratio of *rod cells* (high light sensitivity, low color and detail sensitivity). (Helldin et al., 2020) The visual perception of space is based on *central vision* and *peripheral vision*. Central vision provides *visual acuity* (see details in even light), and peripheral vision makes us perceive and orientate in space, mainly through fields of contrasts and vertical surfaces. In darkness, the capacity of the cone cells reduce vision (Wänström Lindh, 2018). However, the sensitivity of the cells can compensate for light level changes and thus adapt vision to a darker setting (Wikipedia, 2022a). The rod cells' light sensitivity attract the eyes to the most contrasting point. The peripheral vision is reduced and makes space decrease in size and change in shape (Wänström Lindh, 2018).

Central vision (2°) and peripheral vision (170°).



Nocturnal species vision

Nocturnal species have a high ratio of rod cells and low ratio of cone cells (less color sensitivity and visual acuity, high light sensitivity (Helldin et al., 2020). ALAN has therefore fundamental impact on nocturnal species, for example leading to disturbance for movement and hunting, increase risks of predation through exposure (Helldin & Jägerbrand, 2020), habitat fragmentation (Victorsson & Håstad, 2020), alters species composition in systems and ecological processes (Helldin & Jägerbrand, 2020) and creates vacuum effects (see p. 31)(Jägerbrand & Bouroussis, 2021). Below is a table of light spectra impacts on different species. In general, blue spectra lighting, e.g., emitted by LED, is the main disturbance for most nocturnal species and should be avoided (Spoelstra, 2020).

Chart based on Jakobi et al., (2011), Morita & Tokura (1998) and Millon (2021)

Species / Wave-lenght (λ)	Bats	Human	Fish	Insects	Birds
UV (λ<380 nm)	X	-	X	X	✓
Violet (380-420 nm)	X	X	X	X	✓
Blue (420-490 nm)	X	X	X	X	✓
Green (490-575 nm)	X	X	?	?	✓
Yellow (575-585 nm)	✓	✓	X	✓	X
Orange (585-650 nm)	✓	✓	X	?	X
Red (650-770 nm)	✓	✓	X	?	X

Legend

- X Species is attracted to the light / is negatively affected.
- ✓ Species is not affected by the light.
- ? Impact by light not yet known.
- \- Species avoids the light / is negatively affected.

LIGHTING (DARKNESS) LEGISLATION

Sweden

Sweden does not have any darkness or lighting policies on a national level. Instead, is it up to each municipality to create one based on few laws and recommendations of minimum light level in urban spaces.

The Planning and Building Act [Plan- och bygglag] has a few legal restrictions for lighting. It says that the placement and design of lighting fixtures must not be done in a way that brings a negative effect on the groundwater, its surrounding or in any way cause harm to people's health and safety or in any other way cause any inconvenience (Plan- och bygglag, SFS 2010:900, chapter 2, §9). Further it states that the light fixture should be appropriate for its purpose, have a good shape-color and be accessible and useful for people with reduced movement- and orientation ability (Plan- och bygglag, SFS 2010:900, chapter 8, §3).

A traffic issue?
On a governmental level question related to lighting falls under "infrastructure" and is handled by the Transport Administration with a focus on traffic and pedestrian safety. Gothenburg's lighting documentation is filed under infrastructure matters.

Gothenburg

Gothenburg has a light policy which is called *Stadens Ljus*. It is part of the city's environment policy aiming to promote a cohesive design and strengthen the character of the city while creating safe and accessible environments. The light solutions should also be sustainable and energy efficient and choices be based on quality and economic analyses. Examples given to reduce light pollution is lowering the light intensity, install well directed light and deciding places where light is not at all needed (Göteborgs Stad, 2015).

Economy and energy seem to be the two important factors when considering lighting in the city.

International policies

France

In the beginning of 2019, a new law came to force in France addressing the protection of night-time darkness through controlling emissions of light in outdoor spaces. This sets out national regulations and provide guidance that limit illumination levels, restricting the use of blue light and reducing emissions directed towards the sky. The guidelines also add outdoor lighting curfews and prohibition of sky beams (type of lighting). The law is a first step to establish regulations that will prevent, limit, and reduce light pollution which will bring positive effects to people, ecosystems and reduce energy waste (Barentine, 2019).

Law and not recommendations. A stronger statement!

Australia

The Australian government has developed a national light pollution guideline for wildlife. The guidelines are set out to provide theoretical, technical, and practical information that is required to assess if the artificial light will be likely to influence wildlife. The guidelines also provide tools to minimize and mitigate pollution, e.g. best practice lighting design (Commonwealth of Australia, 2020).

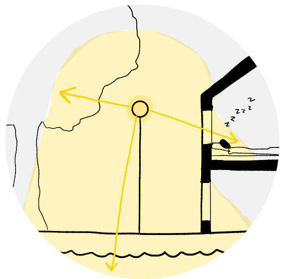
LIGHT POLLUTION

Inappropriate or excessive use of artificial light at night is called *light pollution* (IDA, n.d-a). Light pollution is described as an anthropogenic pressure on the environment (Challéat et al., 2021). Light pollution has gained significant academic and public attention in recent years based on the recognition of several serious consequences (Stone, 2018) on wildlife, human health, safety, energy and heritage (IDA, n.d-a). The "pollutant" of light pollution is quite unique compared to several other environmental issues since it could be eliminated by switching off the light (see figure 8 for a thought experiment in Gothenburg). With that said, it does not mean that light pollution is less important than other pollutants (Stone, 2018) and its effects could still be irreversible.

The four components of light pollution

1. Skyglow

Skyglow is "brightening of the dark sky over inhabited areas" (IDA, n.d-a).
Consequences for humans: constant light levels, a gray haze that obstructs the connection to the starry sky, less night vision adaptation.
Consequences for ecology: e.g. risk of obstructed mitigation, vacuum effect (see p. 31), disturbance in physiological processes and rhythms.

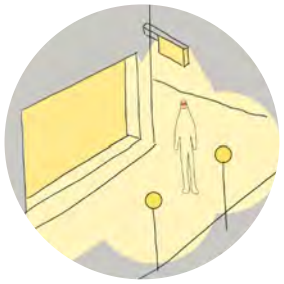


2. Light trespass

Light trespass is when "light falls where it is not intended or needed" (IDA, n.d-a). Different wave-length trespass has different impact.
Consequences for humans: sleep deprivations because blue light increase melatonin levels and make us alert.
Consequences for ecology: trespass in water affects species conditions, blue light reach deepest (Helldin et al., 2020).
Consequences for bats: trespass in important corridors or nests jeopardizes survival conditions.

3. Glare

Glare is "excessive light that causes visual discomfort" (IDA, n.d-a), Glare can appear from e.g. light intensity, direction, placement or reflection.
Consequences for humans: "visual impairment glare" or "discomfort glare" (Wänström Lindh, 2018) can make us temporary blind - the light generates darkness.
Consequences for bats: temporary blindness which could make the animal a simple prey or being hit by a vehicle (Helldin et al., 2020).



4. Clutter

Clutter is "bright, confusing and excessive groupings of light sources" (IDA, n.d-a). Clutter contributes to the other components of light pollution.
Consequences for humans: can create confusing patterns which has a negative impact on space perception, orientation etc. (Wänström Lindh, 2018).

Figure 8

UNDERSTANDING DARKNESS

Physical and emotional darkness

Darkness is a word with multiple embedded perceptions. *What do you think about?* We thought about this:

NEGATIVE — POSITIVE

Associations connected to darkness

Obstacle, Ghosts, Unknown, Northern Lights, Depression, Danger, Death, Bats, Winter, Quiet, Nightmares, Cold, Protection, Night, Sleep, Milky Way

Feelings connected to darkness

Absence, Loneliness, Endlessness, Calmness, Fear, Hidden, Tension, Power, Unsafe, Anxiety, Shyness, Relief

In a dictionary, the noun darkness has several definitions. They are *the state or quality of being dark, absence or deficiency of light, wickedness or evil, obscurity; concealment, lack of knowledge or enlightenment, lack of sight; blindness* (Dictionary, n.d.).

Our own preconceptions about darkness turned out to be about associations and feelings. Some associations have a physical action or experience connected to darkness, such as sleep, Milky Way, cold or nightmares, while others are connected to feelings in relation to darkness. The conclusion of our own preconceptions is that many associations often have their opposite relation in light, that darkness often has a negative connotation and that darkness entails limitations rather than assets. The definitions of darkness in a dictionary indicates a "lacking" dimension embedded within the word.

The way people understand and perceive darkness is interesting to bring up for a reflection, since it puts emphasis on the individuality of the matter and therefore also the complexity to discuss it in general. One man's fear could be another man's relief at the same time, at the same place (figure 9). The similarities between our own initial associations and the definitions might however indicate common ground. It is likely that the apparent negative association of darkness unconsciously affects how we design for a dark setting (if we consider it at all). Either way, we have banished darkness, maybe to avoid a large collective unwanted experience, without really knowing why. "In sum, we have inherited a narrative that champions the expansion of artificial night-time illumination" (Stone, 2018, p. 612).

Figure 9

BATS

Bats are a nocturnal species that is adapted to a life in darkness, a lifestyle that is traced back to the first fossil bats over 55 million years ago (Eklöf & Rydell, 2020). The dark landscape acts as their hunting ground and gives a protection from birds of prey (Bat Conservation Trust, n.d). In the last 30 years artificial light has been spread across our built environments disrupting the darkness-light balance and interfering with the native way of life.

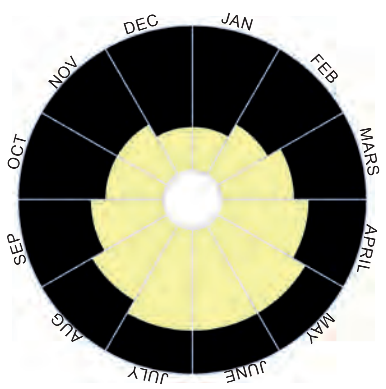
Moving between summer nest and winter hibernation

Bats have an important ecological role, acting as pollinators and keeping the insect population level consuming up to a thousand insects per hour (Naturvårdsverket, 2022b). The access to insects is key for the bats and controls their activities during the year and where they decide to nest. When the supply is low during the winter periods the bats enter hibernation (BatLife Sweden, n.d). The length of this period differs among species from two to eight months between September and April (BatLife Sweden, n.d; Naturvårdsverket, 2022b). In spring the females return to their nests, the same place year after year, to raise their pups. After this period the breeding takes place (BatLife Sweden, n.d). Bats seek out nests in natural cavities, like those in old trees (Naturvårdsverket, 2022b) but also find shelter in old buildings, attics and churches (Eklöf & Rydell, 2020).

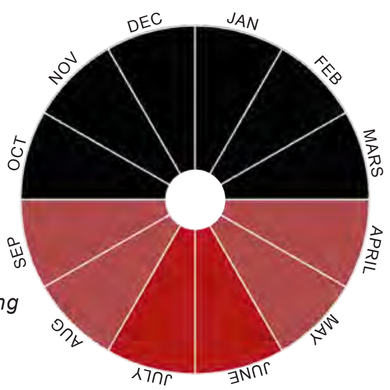
Artificial lighting can influence multiple bat behaviours including hunting, commuting, roosting, breeding, and hibernation. The light can have direct impact on foraging grounds making them unsuitable, and an indirect impact from light infiltration into commuting routes like hedges and watercourses separating the foraging ground from the nests (Stone et al., 2015). As façade lighting on churches becomes the norm bat colonies are forced to seek out other nesting sites (Eklöf & Rydell, 2020).

Bats hibernation overlaps the darkest period of the year, when humans need more artificial light.

Yearly darkness-light ratio in Sweden

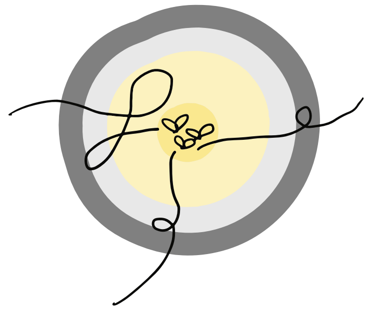


Bat activity over a year



Artificial lighting also attracts insects, a phenomenon called *vacuum effect* (figure 10) (Bat Conservation Trust, n.d). Some opportunistic bats benefit from the insects gathering by the light and dive down towards the light to catch prey before returning to the relative dark space above the light fixtures (Eklöf & Rydell, 2020). For other slow flying and more light sensitive bats, this brings negative consequences because of the lower insect supply (Bat Conservation Trust, n.d). The bats naturally seek the dark spaces and keep in the shadows of the tree crowns. Sometimes they wait for the darkness to arrive before leaving the shadows, a wait that can lead to starvation in the ever glowing city lights (Eklöf & Rydell, 2020).

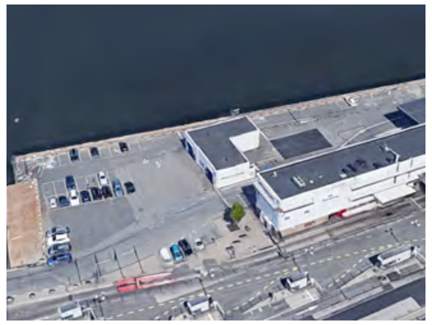
Figure 10
Vacuum effect is when a single light or a whole city like a vacuum attracts species. Insects can be attracted up to 0,5 km distance (Helldin et al., 2020)



Out of the 19 bat species existing in Sweden 12 are red-listed (Naturvårdsverket, 2022a). However, all species have strong legal protection in the Species Protective Ordinance. The ordinance states that it is prohibited to deliberately capture or kill animals, deliberately disturb animals, especially during breeding, rearing, hibernation and migration and deliberately destroy breeding sites or nesting places (Artskyddsförordningen, SFS 2007:845, §4). This prohibition includes and applies to all the life stages of the bat. The legislation provides protection for species and the environment against various damage and harmful impact, like those caused by artificial light (Jägerbrand & Bouroussis, 2021).

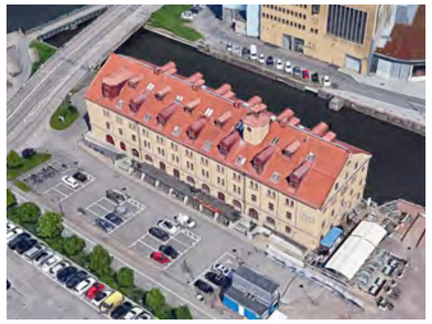
Nest at small pier

Nest at Stena terminal building



Nest in old trees on cliff

Nest at Lagerhuset



Example of existing nesting sites in built and natural structures in Gothenburg

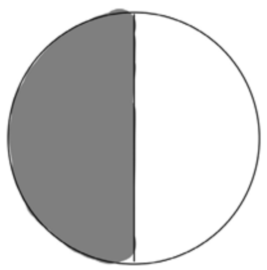
Map data ©2022 Google.

SAFE PUBLIC SPACES

Artificial light has a central role when designing safe public spaces. "Safe" spaces includes both security (prevent accidents/assault) and perceived safety (the individual inner assurance that accidents/assault will not happen). Perceived safety is mostly about visibility, seeing and be seen, but not exposed (Wänström Lindh, 2018). Perceived safety is a very complex field since it is connected to a personal experience. Many aspects, e.g. gender, age, abilities, feeling of power imbalance and previous experiences or thoughts have an impact on the perception of the space. Sometimes it seems like there is a common conception that more light equals safer space, but too much light might as well have the opposite effect. Perceived safety can be supported by artificial light, *social lighting*, and other design aspects.

What is usually not highlighted in the discussion about designing safe public spaces is the security for other than human users, in this case nocturnal animals as bats. Acknowledging the need of safe public space by artificial lighting *and* other parameters could make bats secure and humans feel safe and be secure at the same time in line with the duality of this thesis.

Contrasts



Security:
Contrasts

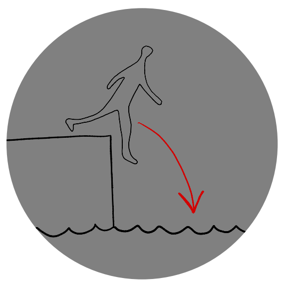
"Contrast" is a difference in lightness (from light or color) and appears in the combination of lightness and darkness and therefore also has a border. When different spaces can be perceived though their contrasts the overall spatial perception increases which has positive effects on security. Lighting design is about designing contrasts, not only adding light (Wänström Lindh, 2018).

Glare

Glare

Humans: *Too high differences in light intensity can cause glare and be blinding - this is how light can create darkness. Glare can e.g. come from badly shielded fixtures, too strong lighting/spotlights, sudden light exposure or surfaces (Wänström Lindh, 2018; IDA, n.d-b).*
Bats: *sudden light exposure can be blinding and create dizziness, until recovered bats risk being a prey or hit by a vehicle (Helldin et al., 2020).*

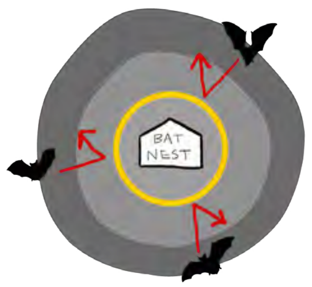
Detecting obstacles



Detecting obstacles

Humans: *detecting actual obstacles such as objects, elevations, holes, glass, edges and drop heights are important to prevent accidents. Detection of obstacles are possible even at very low illuminance (2-3 lux) (Jägerbrand & Bouroussis, 2021). Different kinds of contrasts, light intensity and placement of fixture can be actively implemented.*
Bats: *Bats seem to not have issues with detecting obstacles (buildings or objects) in order to avoid collision as e.g. birds. However, increased or altered lighting close to bat nests can be such a big obstacle that they abandon it.*

Light barriers



Light barriers

Bats: *Observations indicates that bats always use the least lit route to minimize light exposure and use trees as stop-overs for protection. There is also indication that bats can wait for light to be turned off. If the light then is static, the wait could be in vain and the bat and pups rather starves to death than entering the dangerous light (Eklöf & Rydell, 2020). Light barriers therefore have a risk of cutting off important movement patterns and reduce dispersal areas with catastrophic effects.*

Perceived safety:
Orientation

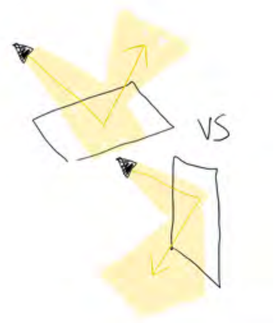
In darkness, the public space changes shape (Wänström Lindh, 2018) and the ability to orientate changes even though the spatial composition remains the same. Orientation is mainly provided from perceptions in the peripheral vision (low visual acuity). Low acuity does not improve with more even lighting but improves with high contrasts. Orientation can be supported by visual guidance from e.g. patterns, lighting, surfaces/paving or supporting elements that indicates a direction. Sightlines could also support orientation, and so can landmark accentuation in the sightlines. Landmarks can be a common orientation support and connect perception of a space and the orientation to daytime (Wänström Lindh, 2018).

Orientation

Vertical surfaces

In recent lighting design, there has been an emphasis on lighting vertical surfaces instead of the traditional horizontal lighting. Vertical lighting accentuates space definition which eases visual space perception (estimate distances, objects etc.) thereby increasing perceived safety. Only horizontal lighting makes a place, but adding vertical lighting makes a space. Vertical surfaces also give the space a visual boundary (Wänström Lindh, 2018).

Vertical surfaces

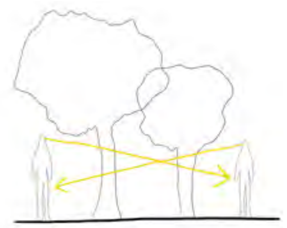


To see and be seen without being exposed

To see and be seen without being exposed could be achieved in several ways. One example is lighting the surroundings of a path instead of the path. Lighting from shop windows or entrances are other examples that can contribute to the perceived safety through the feeling of being seen. This was first presented by Jane Jacobs and are often referred to as "eyes on the street". The possibility to see faces and perceive others' intentions is one important contributor to perceived safety. Soft light from a lower height and side angle gives natural facial expressions.

Men and women are not experiencing unsafety in the same way. Women are, statistically, more afraid than men, but the rate of exposure to violence is, paradoxal, higher among men (Wänström Lindh, 2018). Our own reflections are, firstly, that we seem to be more afraid of the people and potential danger hiding in the dark than the dark itself, and the fear of darkness to a large degree is inherited. For the both of us, with a background from rural areas but now living in a city, the city context provides higher perceived safety than the rural context. This is probably because of higher flows of people which generates a feeling of being seen.

To see and be seen

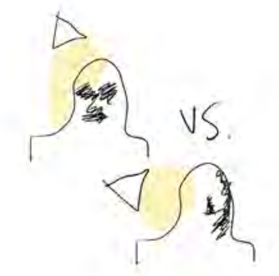


Detect potential danger

The environment considered to contribute to the highest perceived safety is the one with possibilities to overview the space at the same time as it is not too open and provides refuge. It could be a bit contradicting to provide openness and enclosure at the same time and this must be elaborated to find a good balance, stressing the need of contrasts and vertical surfaces for space definition and avoiding exposure.

Vegetation is often pointed out to contribute to perceived unsafety because it can hinder visibility (Wänström Lindh, 2018). Vegetation is therefore often removed in public space, which on the other hand also removes a space defining vertical element. The other measure is to light it, which is commonly implemented in public space also for creating atmospheres, landmarks etc. It is usual that old trees are lit. We are however strongly hesitant to the appropriability of vegetation lighting from an ecological point of view being aware of the known and potential risks artificial light has on many species. For bats, old trees are the main nesting place, and if not obstructing an existing nest, vegetation light might hinder the establishment of a new nest.

Detect potential danger



Signal values

A factor that is often discussed in relation to perceived safety is about maintaining public space - if the space is taken care of it appears safer (Wänström Lindh, 2018).

LITERATURE REVIEW SUMMARY

Main conclusions:

- » The physical space and perceived light space could be complemented with the term *darkness space*.
- » Excessive light must always be avoided for social and ecological users.
- » Poorly designed space or components in space have negative effects on light pollution.
- » Darkness planning & design are as important as lighting planning & design (it has the same origin and should not be separated). After all, we are dealing with 50% of the time which is a huge potential!

Social-ecological synergies:
Urban darkness

Meet the need of darkness for human and bats in urban areas. → *Where, how and how much?*

Darkness design

Active design choices for re-introducing darkness could have a positive impact on humans at the same time as it does not cause disturbance for bats. → *How can darkness be re-introduced?*

Rhythms

In a year, the most important phase for bats is when the human need of artificial light is the lowest. In a day, the most important phase for bats is when the human public activity is the lowest (but also then ALAN is needed). → *How can a dynamic approach be implemented in the scales?*

Time

Managing time is a design tool with big potential to adapt to both human and bat needs in public space. → *What existing possibilities does technology offer?*

Red light

Light on the red wave-length spectra does not interfere with human or bat well-being. → *How is red light experienced, more than unusual?*

Social-ecological conflicts:
Darkness-light imbalance

The created imbalance in darkness-light rhythm could have effects of such scale we cannot grasp it, which makes the need of re-balance urgent. → *Explore how we can balance through design.*

Development of building projects

Development in urban areas could seriously harm bats, but development is also a crucial process. → *Acknowledge risks. Identify what areas/connections are important, where they are located, how they can be protected or established.*

Safety measures

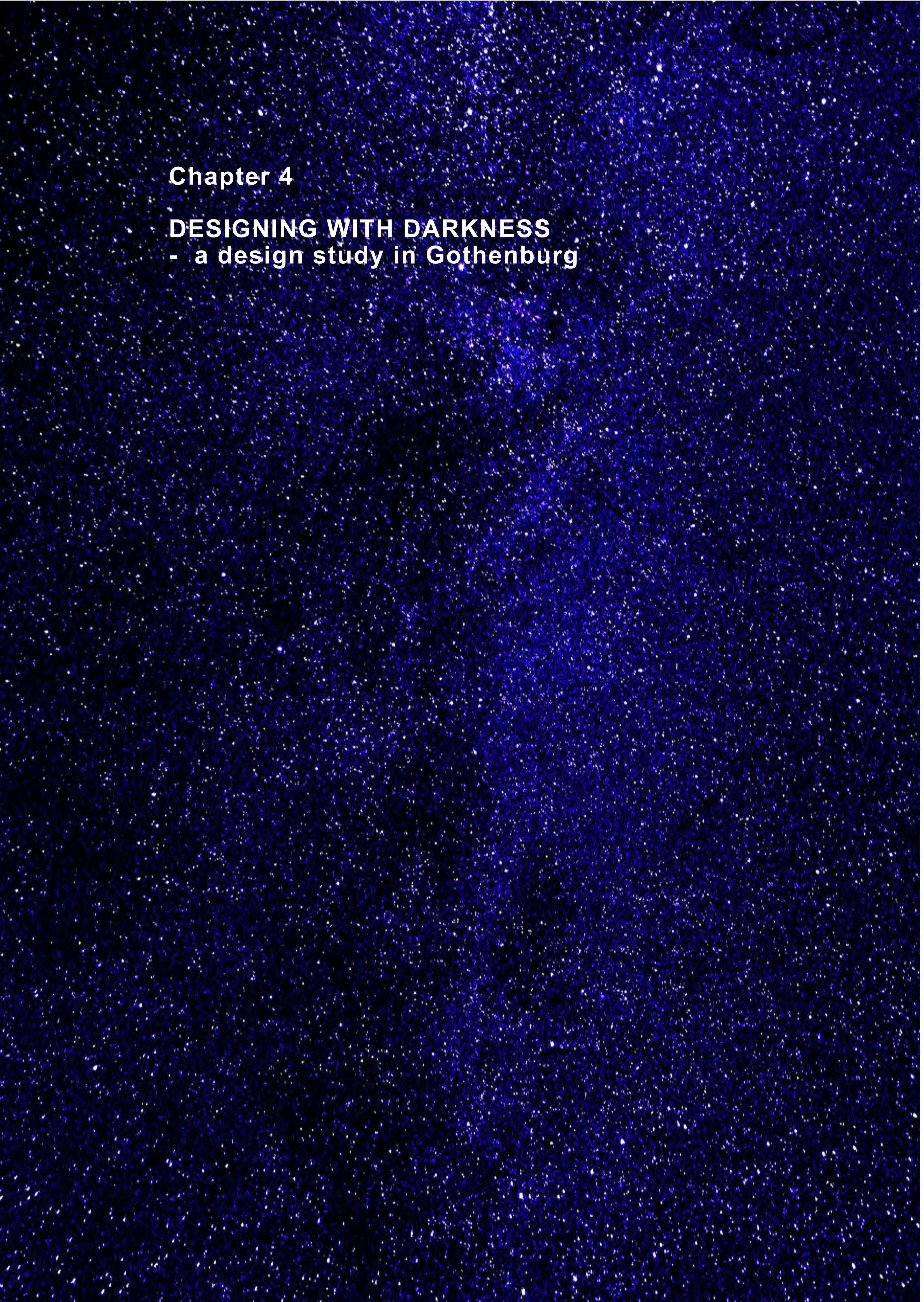
Public spaces need light to be and be perceived as safe, but too much light harms the nocturnal animals, e.g. bats. → *Find balance!*

Blue light

Light on the blue wave-length spectra interferes with humans (well-being disturbance) and bats. If LED is implemented (common, profitable) there are measures to filter the undesirable.) → *Pay specific attention!*

Reflections:

- » The lit components on private properties may be difficult to impact, but the components on public space are not!
- » All contributions to reducing light pollution are positive. Darkness can be reached only if all places get darker, which could also result in some spaces appearing lighter due to enhanced darkness vision
- » Humans have survived for thousands of years without artificial light. Our behaviour is obviously easy to adapt to a new situation. Therefore, a re-programming of behaviour could reconnect us to the system we are (supposed) to be in for the good of all species.
- » All parameters of light (amount, placement, technical properties) contribute to the entirety. There are many technical aspects to consider, our limitation of these could therefore have big impact on the outcome.
- » It is unrealistic to say that every space in an urban area should be dark. Therefore, it is important to prioritize where measures have the biggest impact are the most urgent. However, many spaces can be darker.
- » Because of the inherited negative associations of darkness all the design of a dark space may be experienced in a negative way by individuals.
- » Depending on interpretation the existing laws should be enough to restrict light pollution. But is it really followed? We do not know but it does not seem that way. The laws protecting bats are clear (forbidden to disturb deliberately) and with the proven knowledge of negative impact of ALAN should be strong enough.
- » If a national authority would establish a framework for a darkness-lighting policy, there would be a better base for the individual municipalities to complement the frame with their specific conditions.
- » Light inflation could be avoided if there is a maximum level of approved light (like France). The phenomena of light inflation may indicate that a maintenance and/or development aspect is important to consider beyond the planning phase.
- » Maximum lighting-curfews, like France, could be an efficient and common way of dealing with the issue. However, the difficulties of measuring all aspects of the light in its context may complicate the procedure.



Chapter 4

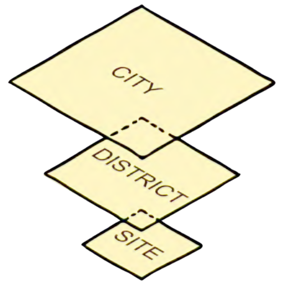
DESIGNING WITH DARKNESS
- a design study in Gothenburg

BACKGROUND OF THE STUDY

Outline of design study

This chapter presents a design study of the main findings within the theoretical and methodological framework of Social-Ecological Urbanism. The perspective will be shifted from mitigation light pollution to focus on the vales of darkness in order to re-introduce darkness to our urban areas.

Three representative scales.



The design study is a process of extracting knowledge through the key literature findings, observations, reflections and experiments which in some sense make the outcome of this thesis "research based design". The study is represented in city, district and site scale. Potential synergies and conflicts between humans and bats are acknowledged on all scales. Bats are representative species because they are native, nocturnal and sensitive.

The aim of the design study is to re-introduce (promote, protect and preserve) darkness and it is inherent values as a mean to shift perspective and try to balance the current imbalance through design. The aim of the dark ecological network (city & district) is to identify, protect and create important connections which enables movement for bats in Gothenburg's urban areas. The aim of the public space design (site) is to reduce light pollution and enable movement for humans and bats using light, darkness, contrasts and shadows.

Outcomes of design study

City

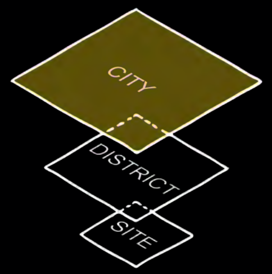
- » Observations of parameters connected to skyglow in the city of Gothenburg.
- » A strategy for a dark ecological network providing a backbone for bat (and nocturnal species) movement in the connection of city and surrounding areas.
- » Overview and reflections regarding the future development plans in Gothenburg and potential conflicts.

District

- » Refinement of the dark ecological network acknowledging significant and complementary corridors for a robust and resilient system.
- » Inventory of parameters in the dark corridors.
- » Recommendations for planning and design.

Site

- » Experiments with light and surfaces in physical model.
- » Explorations of darkness design in a physical model of a selected public space.



LIGHT POLLUTION IN GOTHENBURG

Skyglow map

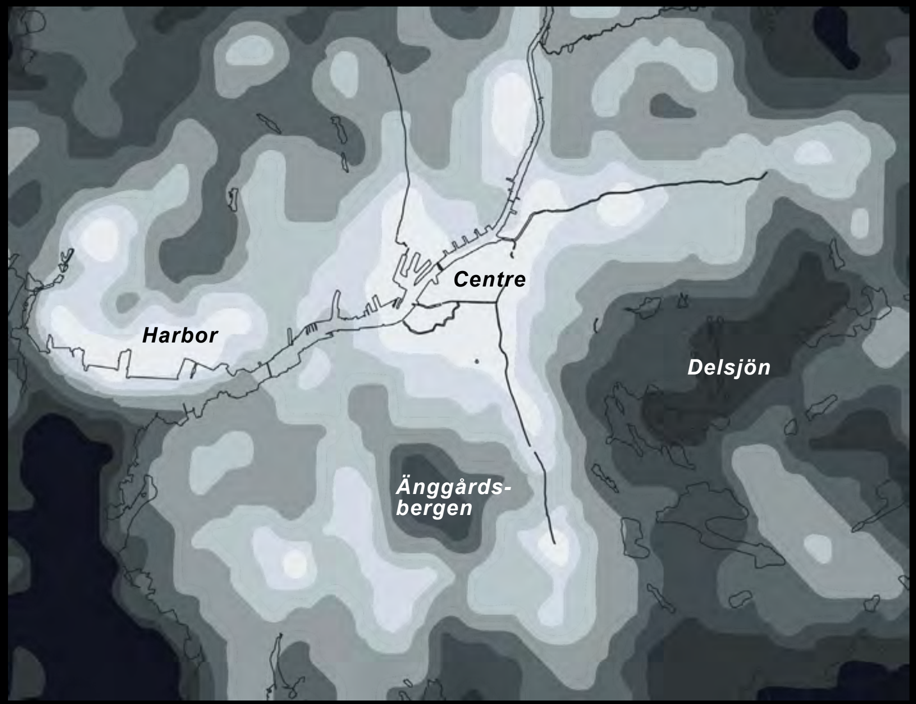


Figure 11
Skyglow illustration over Gothenburg. The illustration is based on VIIRS 2021 images, measuring visible light seen from space.

It seems like the reflective property of water adds to the skyglow despite having no lighting fixtures itself.

VIIRS ©2022 Microsoft Corporation, ©2022 TomTom, Jurij Stare.

The original images are in appendix.

High - low skyglow

Light pollution is a given in all major urban areas worldwide and Gothenburg is no exception. Figure 11 shows the skyglow over Gothenburg where the brighter colors represent a higher pollution level. The brightest parts occur in the city centre, along highways (also figure 16) and the water. The darkest parts are found by the bigger nature areas.

As already described in detail in chapter three, the skyglow does not only obstruct the starry sky but create spatial barriers for nocturnal animals (Challéat et al., 2021) and confuse species that orientate using the night sky (Sordello et al,. 2022). It also creates vacuum effects (Jägerbrand & Bouroussis, 2021).

Light pollution overlays

To understand *which* factors contribute to the skyglow in Gothenburg and *where* the skyglow illustration has been overlaid with selected data to find connections between them. The main findings will be presented in the following pages along with some conclusions and reflections.

Bat dispersal area

CONNECTION ——●—————— ***NO CONNECTION***

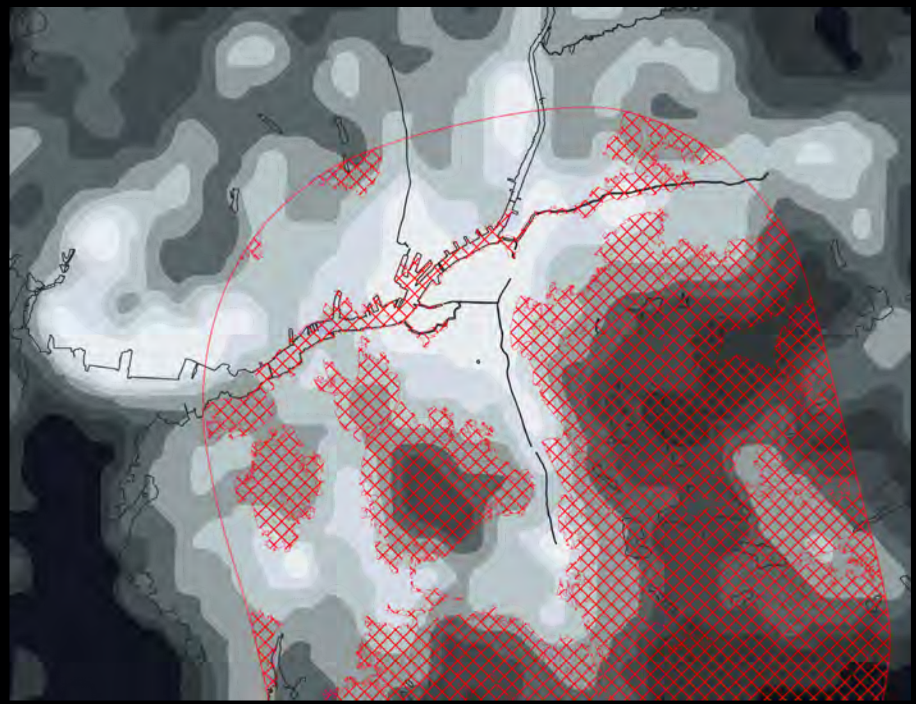


Figure 12

Bat dispersal area

This map shows a strong connection between dark areas and bat dispersal with an exception over the river. Bats' need of water for hydration and hunting and this seems to override the fact that the water is very light polluted. It highlights the rivers' importance for bats.

Data from Calluna AB. Area outside red outline indicates data boundary.

Artificial surfaces

CONNECTION ——●—————— ***NO CONNECTION***

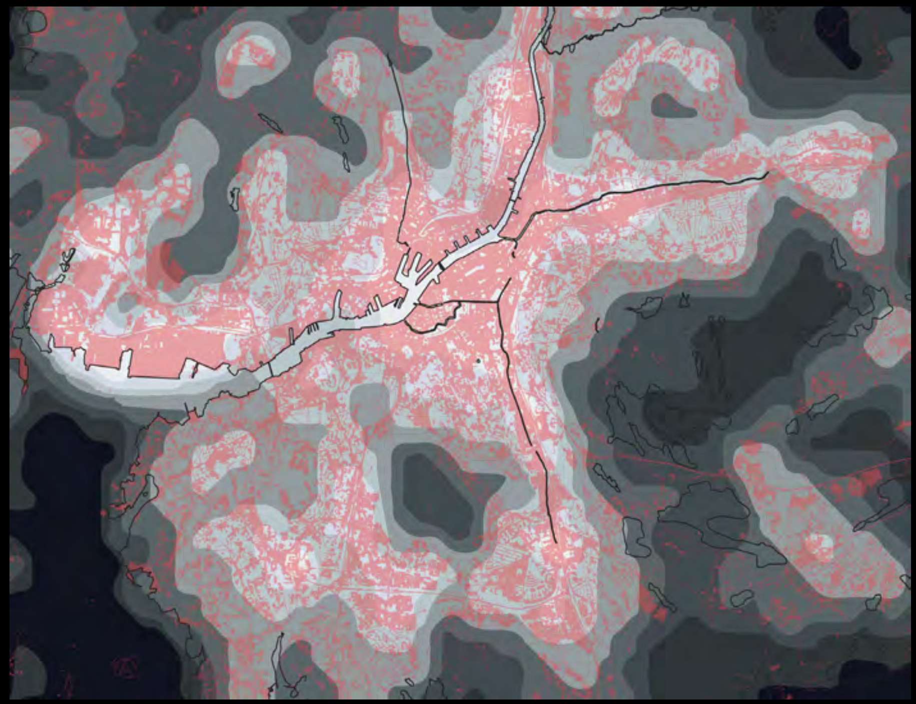


Figure 13

Artificial surfaces

This map shows a strong connection between artificial surfaces and skyglow. This can be caused by the surfaces' reflective properties, as well as being an indication of where land is heavily built. Artificial surfaces close to the water can direct light to the reflective water surface spreading the light even more.

The definition of "artificial surfaces" = road or railway [53] & artificial open and vegetation-free surfaces (not buildings) [52] (Naturvårdsverket, 2020).

Residential units

CONNECTION ——●—— NO CONNECTION

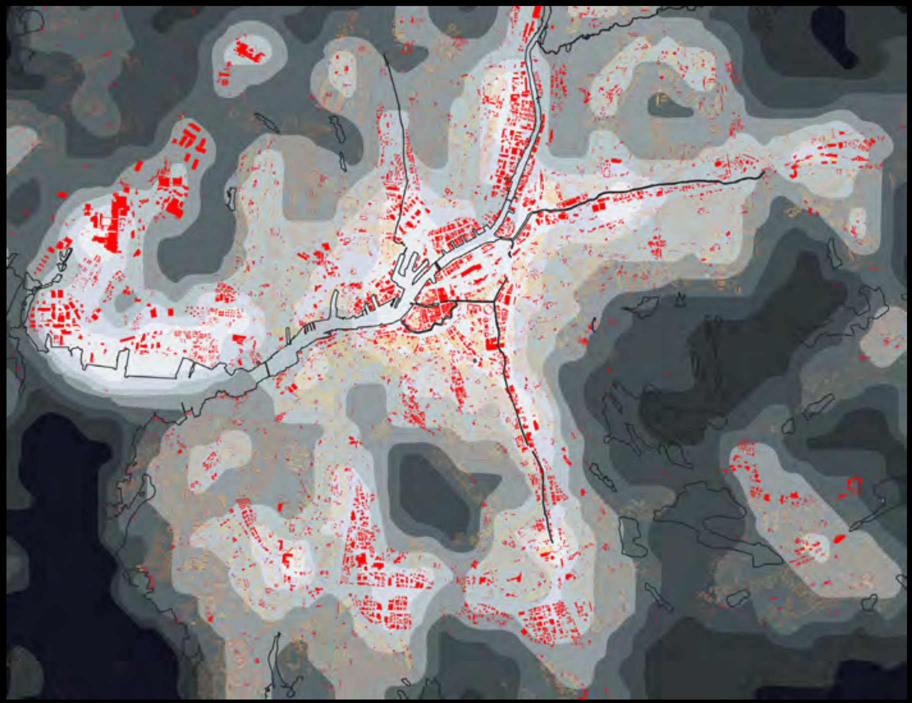


Figure 14

Non residential units

Residential units

Since the preconception was that residential areas would correspond to a high light pollution the result is unexpected. This overlay rather show that the non- residential units have a connection to high skyglow. Non-residential could be commercial, offices or public buildings and these tend to be lit later at night, make use of signs and facade lights.

Data from SMoG.

Population

CONNECTION ——●—— NO CONNECTION

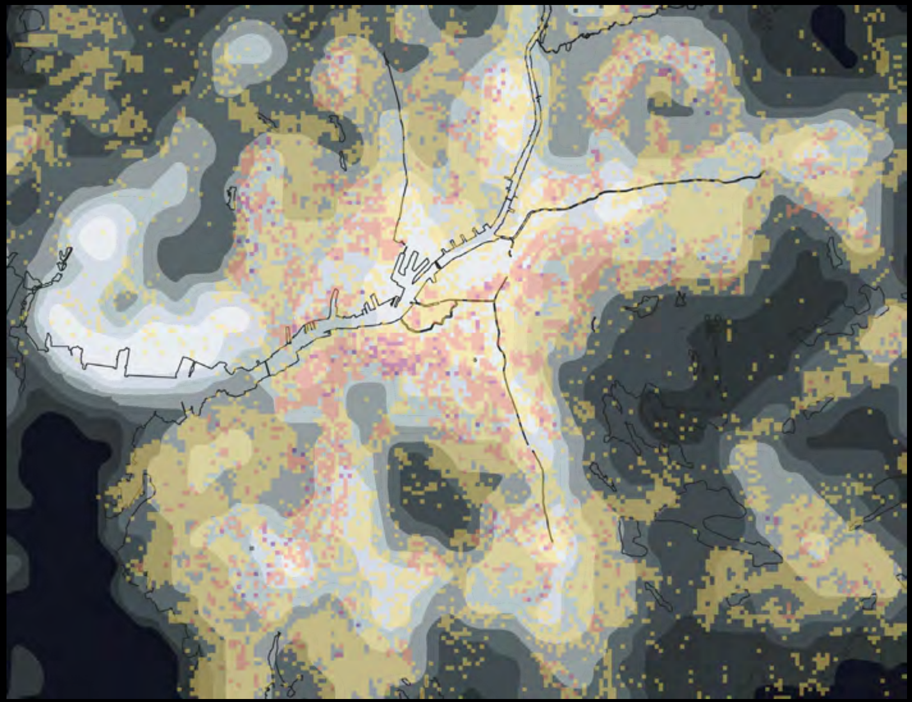


Figure 15

High - low resident concentration

This map shows some connection, but the assumption was that a high residential density should influence the light pollution more. Window and garden light seem to have little effect on this scale. The brightness of the harbor area is very striking in this image along with other big industrial areas by the water.

Data from SMoG.

Motorized network

CONNECTION ——●—— NO CONNECTION

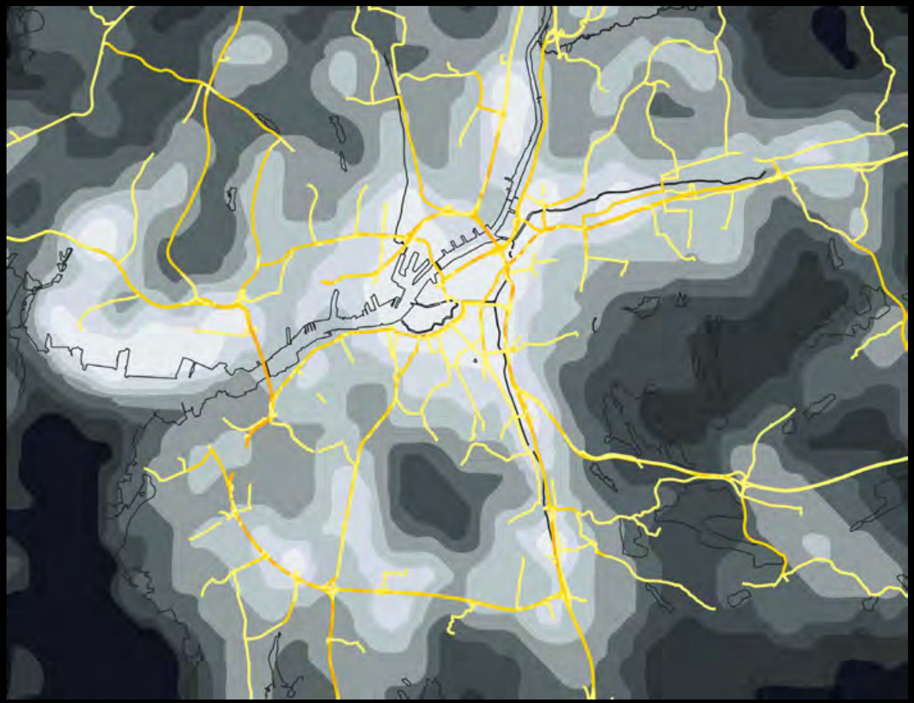


Figure 16

Highest - lower "through movement"

This map shows medium connection. Bigger roads tend to have a lot of light due to safety reasons and the vehicles themselves. The infrastructure also indicates where other built structures exist and are made up with artificial surfaces. Even if the connection is not that strong, infrastructure can act as a barrier between darker areas.

Data from SMoG.

Summary synergies and conflicts

Synergies:

- » Bat dispersal areas are located mainly within the natural areas which are darker.
- » Resident units and population concentration are not the worst contributors to light pollution which could be positive for coexistence.

Conflicts:

- » A high level of light pollution can affect ecological systems even outside the city as excessive light spreads far.
- » The water (Göta Älv), which is crucial for bats, is very light polluted.
- » The reflective property of water adds to the light pollution. Its central location in the city makes it exposed to many light fixtures.
- » The risk of light infiltration into the larger natural areas.
- » Large infrastructure could act as barriers and fragment all other movement.

DARK ECOLOGICAL NETWORK

The dark ecological network is a concept for strengthening the protection and preserving the benefits of darkness. The concept builds on mapping out the dark landscape with potential dark cores (significant and complementary) including a buffer zone, stop-over sites and dark corridors between them (figure 17). The mapping also shows disconnections, habitat fragmentation and light barriers (Challéat et al., 2021).

The multiscale of the network enables an understanding on different levels while capturing the effect of ALAN from the footprint of a single light to the skyglow generated by a city as a whole (Challéat et al., 2021). This gives an overview on different scales of what needs to be preserved, protected or added in regards of darkness for the network to connect and thereby enable movement for nocturnal species.

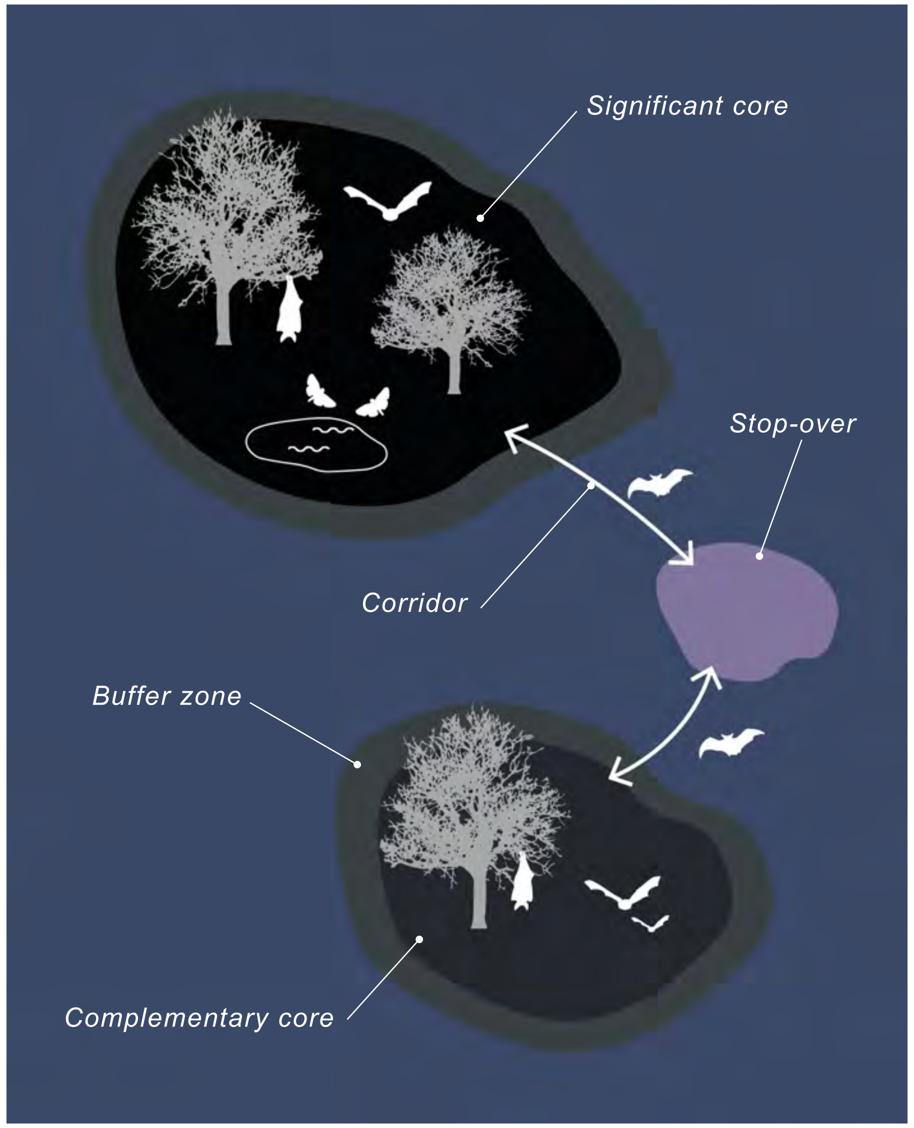


Figure 17
Illustration of the concept.

Dark ecological network structural components

The components composing the dark ecological network are based on Challéat et al. (2021), which areas in Gothenburg they represent are our interpretation. The core components are based on public areas. Public areas were used for the cores because they can be regulated by authorities or the municipality.

How the structural component will be represented in the strategies.

Significant core

The core areas of darkness. The core has (or could have) a high level of darkness and cover big areas. We used nature reserves and large water mass.

Complementary core

A large area of darkness, holds a complementary function to the significant cores. We used bigger parks.

Dark buffer zone

Area surrounding the cores, aims to create a protective buffer between the dark core and light environment.

Dark stop-over site

Smaller patches of (potential) darkness between core areas. We used smaller public parks, but there should be potential to also use green roofs or small vegetated areas as stop-overs.

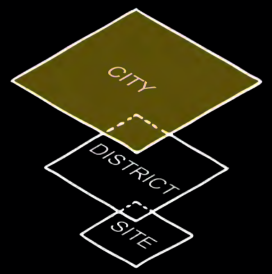
Dark corridor

A dark connector that enables movement between core areas, thus crucial for bat movement. The dark corridors link all the other components. They could be dark or have lighting adapted to not disturb bats, i.e light in red spectra.

We have added one class to the dark corridor:

Dynamic

A time dependent corridor, could be a part of infrastructure where streetlight is turned off at specific times of the day or turned off when there is no movement; i.e. smart lighting.



CITY SCALE

Main strategy for dark ecological network on city scale

The strategy map for the city scale dark ecological network is the backbone of the system and includes the main cores and corridors (figure 18).

The significant dark cores are made up by nature reserves, larger green areas serve as complementary cores. The water serves as both a dark core (sea) and creates an important main corridor (Göta Älv and streams). Water is prioritized because the results of our research show its importance to bats.

Around these main components the buffer zone protects the dark areas from light infiltrations. Light should be restricted within the buffer zone. The buffer zones are of special interest for this project since they are in the interface of dark and light, nature and built. The width of the buffer zone is dependent on how much space is needed to achieve dark conditions. The buffer zone is illustrated with a generic width in the map.

Main dark corridors link the main cores and create the dark ecological network. They are planned where there is a short distance or physical potential to be connected.

Conflicting aspects in relation to strategy

Adding layers of municipal artificial light in public space and existing bat nests on top of the strategy map illustrate the conflicts between the dark ecological network and artificial light on a city scale (figure 19).

The light along infrastructure create light barriers for the main corridors. The light clusters have a high concentration along the water and within the buffer zone which leads to light infiltration into the dark areas, where many of the bat nests are located. Managing these conflicts is the challenge to achieving the strategy of the dark ecological network. Measures are needed to protect and preserve the dark cores from excessive light with help from the buffer zone. The fact that many bat nest lies within the buffer zone emphasizes the need to protect darker condition. To be able to establish the dark corridors there is a need to bridge the light barriers created by infrastructure, both from the light fixtures along the street and the vehicles on it. Recommendations and strategies on how to achieve this are presented on p. 56-57.

Buffer zones

Buffer zones are especially interesting for this study since it is in the interface of dark and light

Figure 18

Strategy map with dark ecological network-components.

- *Significant dark core/corridor*
- *Complementary dark core*
- *Dark buffer zone*
- *Main dark corridors*

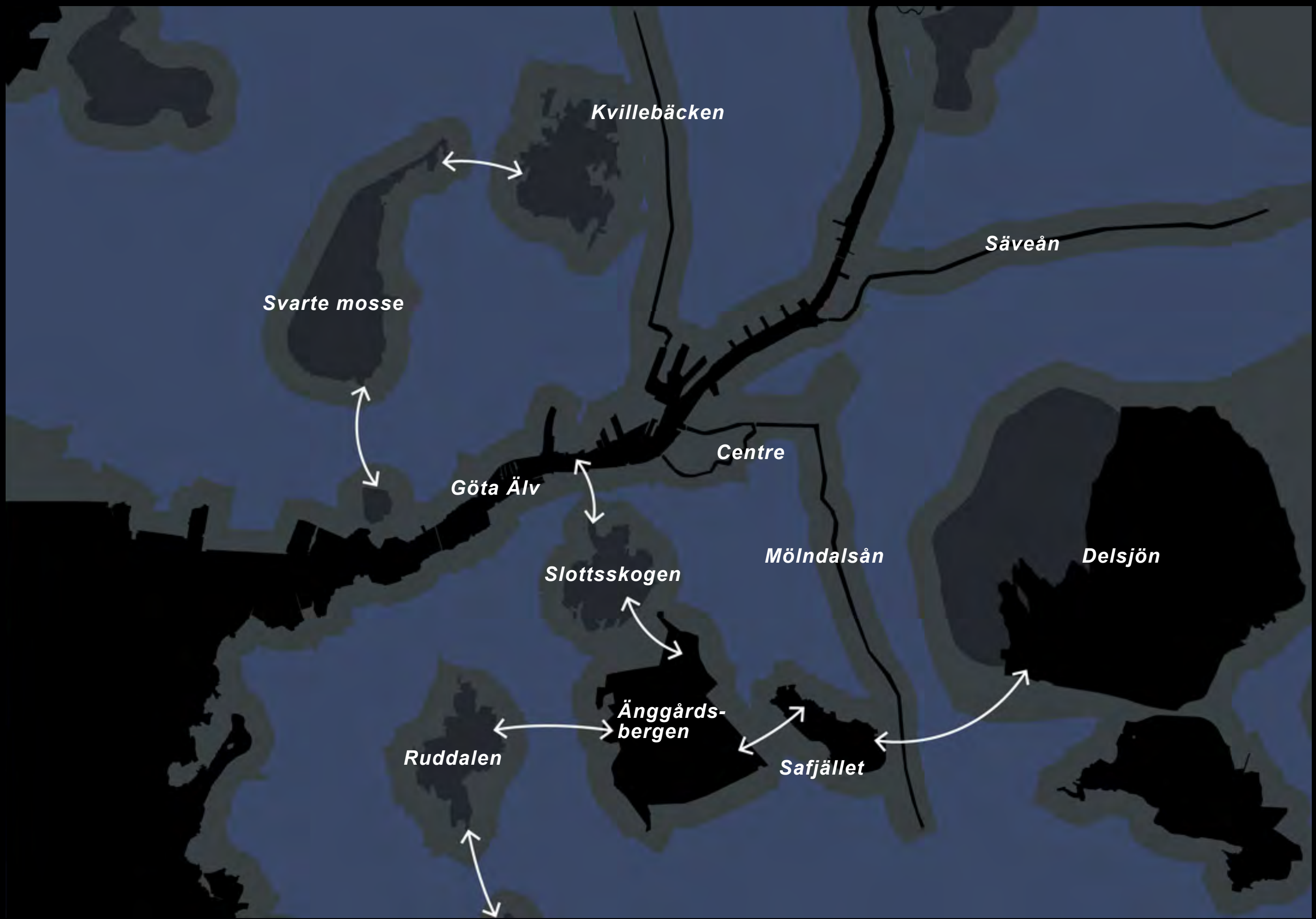
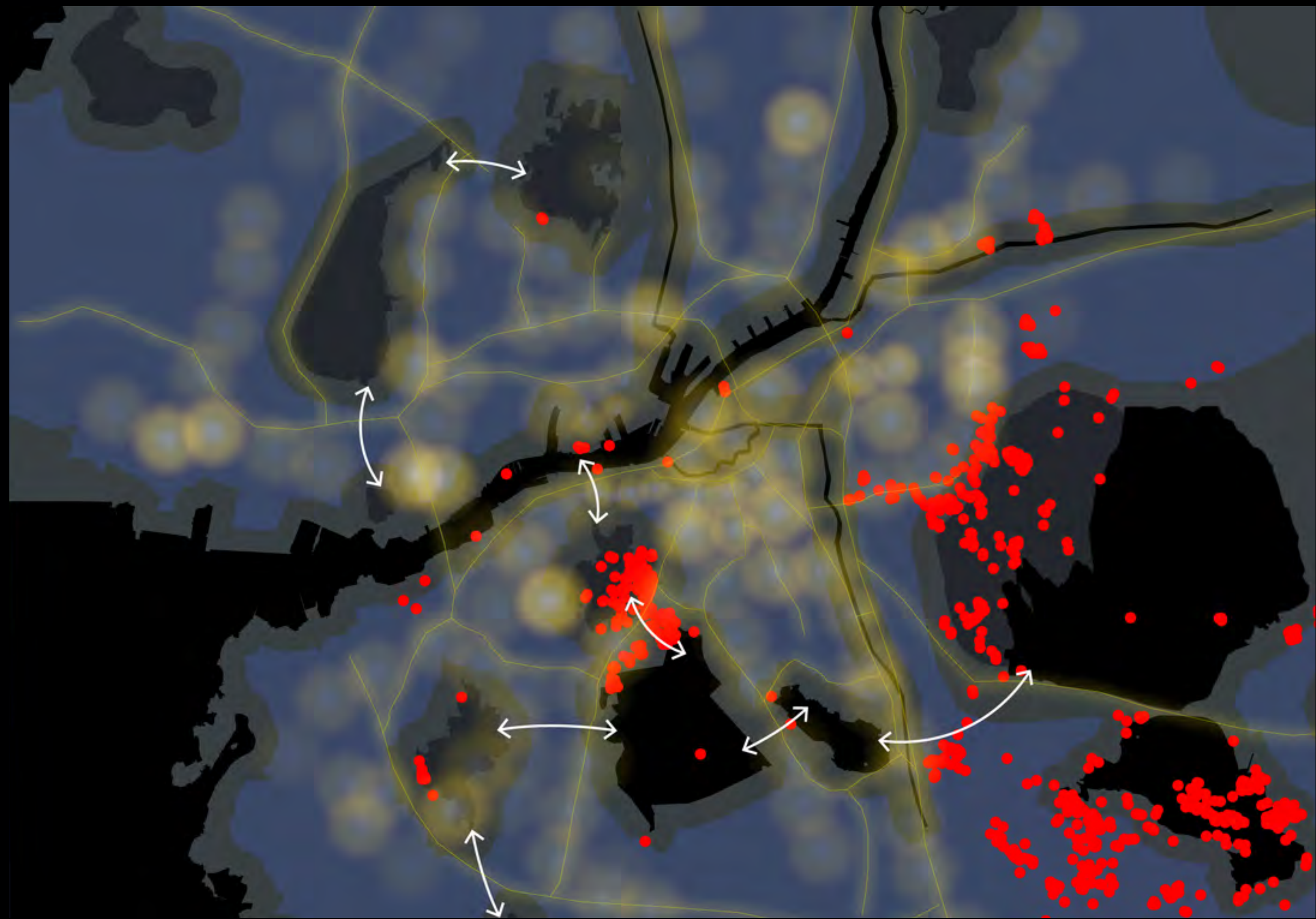


Figure 19

Strategy map overlaid with existing bat nests and illustrations of artificial light clusters and light along main infrastructure. Light is based on data over municipal lighting fixtures in Gothenburg.

- *Artificial light cluster*
- *Artificial light along main streets*
- *Bat nests*



Building development plans

Gothenburg city is expanding. In the large development project Älvstaden, Gothenburg city is aiming to double in size within the central areas and largely so along the waterfront (Göteborg Stad, 2022). Previous industrial areas, large infrastructure and parking lots are removed or moved to make room for new housing and workplaces and by that improve Gothenburgs' connection to the water. Land extensions into Göta Älv are part of the plan.

With more residential units along the water there could be a positive impact on light pollution since the analysis shows that residential units are not as strongly connected to skyglow as non-residential units. The transformation of land use and probably also ratio of artificial surfaces/greenery may contribute to reducing skyglow as indicated by the analysis. New land use may contribute to increased perceived safety in the whole area.

The planned land expansion by Masthuggskajen and Skeppsbron and the general plan to build close to Göta Älv risk increasing light trespass onto the water. Especially the high-rise buildings, envisioned to become "landmarks", with whole façades or top parts of the building lit could create *vertical light barriers* by the building and its reflection. These might disturb flight paths for bats to, from and along the water.

Making the water accessible for humans could arise conflicting interests with bats as the important dark corridor will have an attractive walking path within its buffer zone. This could bring more light close to the sensitive water corridor. Since water acts as a large mirror it could reflect and spread the trespassed light onto the sky and brighten the conditions in the corridor.

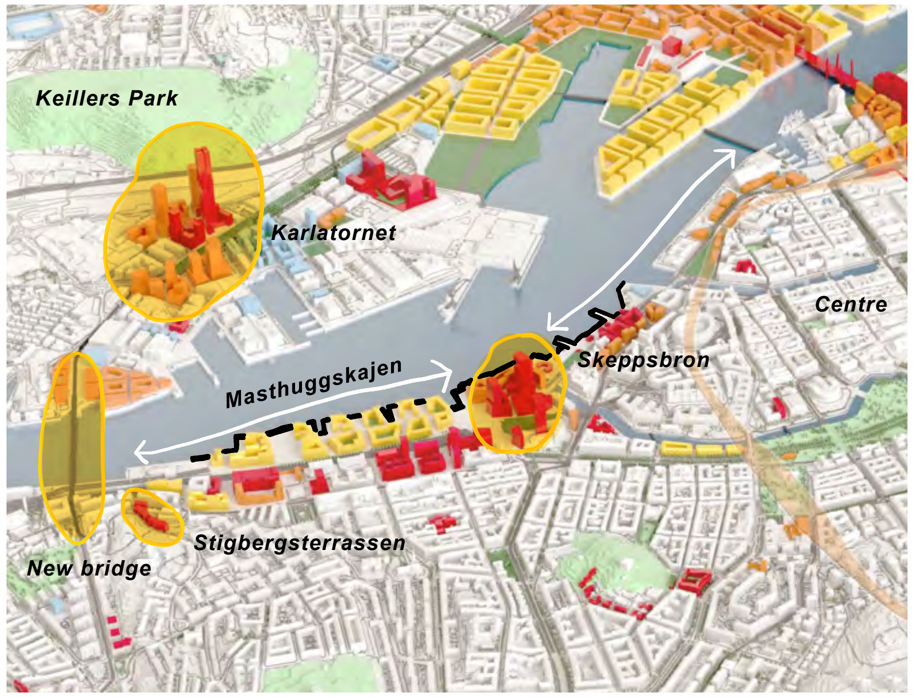
Image from Älvstranden Utveckling (2020) with our annotations.

Approx. year of development completion.

- *Existing buildings*
- *Finished by 2012*
- *2025*
- *2035*
- *2035 - 2050*
- *New infrastructure*

Annotations

- *Land extension, attractive river-walk*
- *High risk development*



Potential conflicts in the plans

Tall buildings

Tall buildings create vertical barriers for bats. Usually high glass ratio on the facade, especially on office buildings, make it shine like a lantern around the clock. Office buildings tend to be lit more compared to residential units. See figure 22 for Gothenburg example.

Bridges

Bridges enable crossings over water barriers for humans. New bridges could pose an issue if decorated with a lot of light. Lit undersides are directing light towards the water with no real purpose other than the aesthetics of it. This spreads light and could disturb bats movement on water.

New buildings in corridors

New buildings along dark (in daytime often green) corridors could break or disturb important movement patterns for bats. Light may infiltrate the green areas when buildings are placed close.

One example from the development plans is the new buildings by Masthuggskyrkan - Stigbergsterrassen - which interferes with one of the main connectors in the proposed dark ecological network.

Land extensions

The new land extensions into Göta Älv may have consequences on bat movement along the water. The river width is reduced, probably with light cast further in the water. Important connections between the river and e.g. the canal could also be obstructed because their way is elongated and potentially more lit.

Gothenburg by night (March 26, 2022)

Figure 20

Skyglow over Masthuggskyrkan.

The photo is taken from Skansen Kronan, Gothenburg.

Figure 22

Water reflections in Göta Älv from the upcoming skyline at Hisingen.

Skylines are a feature in many big cities which seem to be a role model for Gothenburg too. Lit skylines at night could be attractive tourist features. However, the trend globally seems to be the opposite - offering tourists the rare darkness experience.

The photo is taken from Masthuggskajen, Gothenburg.

Figure 21

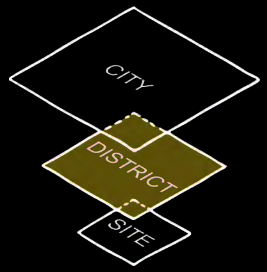
Lit street level from entrances, signs, commercial windows and street light by Skanstorget.

The photo is taken from Skansen Kronan, Gothenburg.

Figure 23

Water reflections in the canal, Feskekörka and the other buildings are mirrored in the water. The brightness in facade color is a parameter.

The photo is taken from Pusterviksgatan, Gothenburg.



DISTRICT SCALE

The district scale focuses around Göta Älv and the central parts of Gothenburg. On this scale a finer component to the dark ecological network is added, the *stop-over sites*.

In our interpretation these stop-over sites are natural areas pointed out to be of "specific interest" according to the city of Gothenburg. When integrating the stop-over sites into the dark ecological network potential for a resilient system with multiple connections is forming.

The map (figure 24) illustrates the finer corridor structure connecting the larger scale network to the stop-overs. These are placed over dispersal areas to ensure that the bat nests are a part of the network to enable movement for the bats between dark areas and their nests.

Figure 24

District strategy map

- *Significant dark core/corridor*
- *Complementary dark core*
- *Dark buffer zone*
- *Main dark corridors*
- *Complementary corridors*
- *Stop-over sites*
- *Bat nests*
- *Bat dispersal area*

Conflicting aspects in relation to strategy

Lighting fixtures

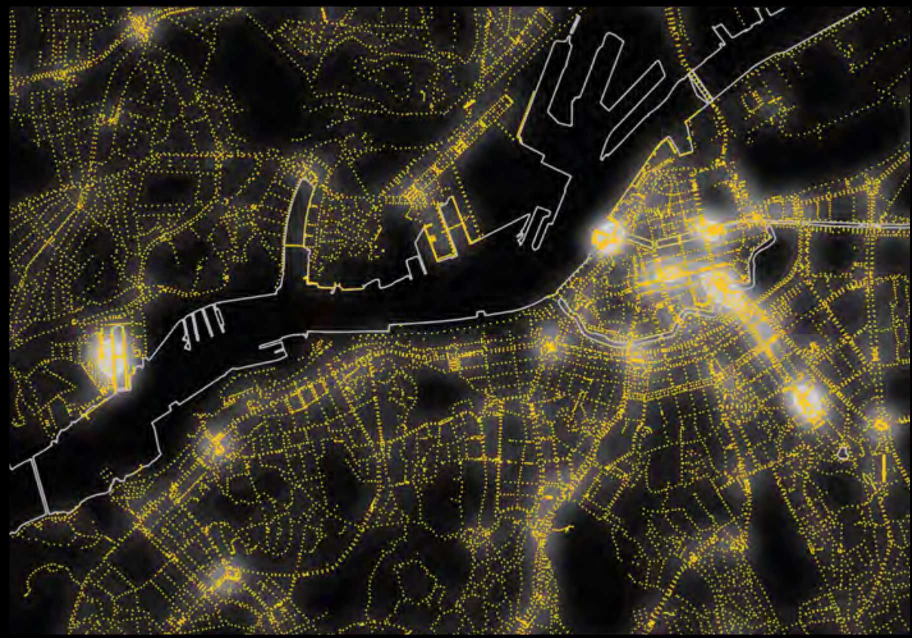


Figure 25

Municipal light fixtures and light clusters in public space. The light follows the streets network creating light barriers for bats while the dark patches create darkness barriers for humans.

Note: dark patches in the map could also be private property, therefore might not be dark in reality.

Data from Göteborg Stad.

- *Artificial light fixtures*
- *Highest - Lowest concentration of light clusters*

Through movement

Figure 26

The map shows street centrality from high to low for the motorized (vehicles) and non-motorized network (pedestrians, bicycles). It is a proxy for expected traffic and pedestrian flows, where high centrality creates conditions for high flows. There is no high through movement along the riverside.

- *Highest - Lower main streets [NB] in motorized network (global scale 15K)*
- *Highest - Lowest main streets [NB] for pedestrians in non-motorized network (local scale 5K)*
- *Green public areas*

Alternative corridors within the dark ecological network on district scale

On p. 54-55 there is a map illustrating alternative dark corridors with an inventory of conditions (figure 27) based on the strategy map (figure 24). All corridors either connect a bat dispersal area to a water corridor, or run along the water. To understand the conflicts and potentials for establishing the alternative corridors some aspects were selected and these elements are based on categories.

The evaluation generates a score for each corridor. If a corridor contains an element in the category it scores 1 point. If the corridor partly contains an element it scores 0.5 points. If the corridor does not contain any element is scores 0 points. The total score indicates which corridors have the need for intervention and the greatest potential for further development within the frame of the thesis.

The categories have been selected to show potential for development and implementation of corridors and do not aim to show where it is easiest but rather where conflicts exist and therefore have a need of design interventions.

The categories have three themes:

Natural potentials

Natural elements/features found along/crossing the corridor. Indicates existing structures which are beneficial to base a corridor on. This is the base for ecology *in* cities.

Potential for new addition

Where there is a potential for design interventions and to add something to the public space.

Human factors

Where a corridor collides with human activity, movement or infrastructure, i.e. human conflicts.

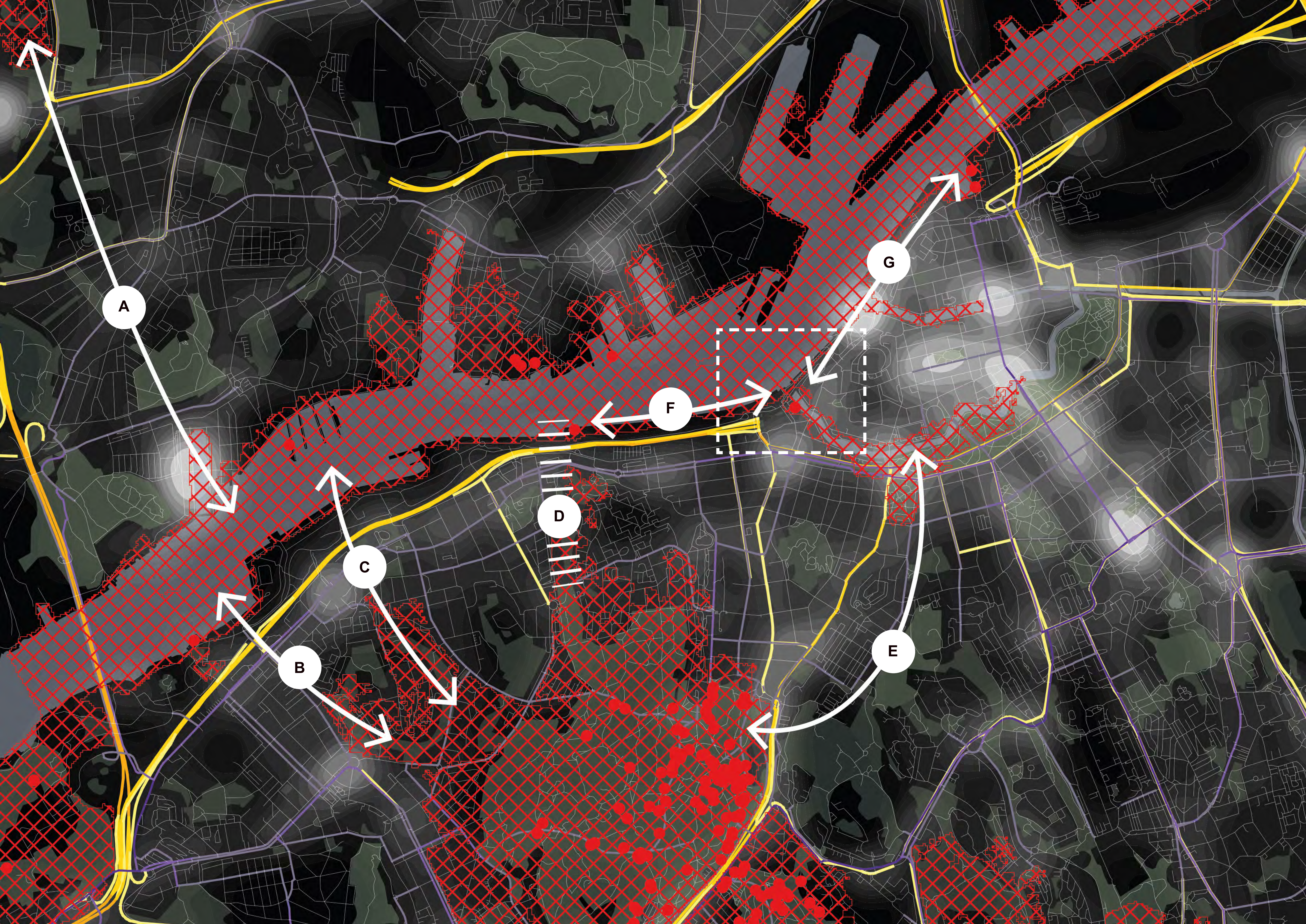
Inventory chart (figure 27)

1 p
0.5 p
0 p

Corridor:	A	B	C	D	E	F	G	
Within water dark buffer zone	0	0	0	0	0	1	1	*Natural potentials*
Crossing overall green structures	1	1	1	1	1	1	0	
Crossing public parks / green areas	1	0	0	1	1	1	0	
Crossing "natural areas of interest"	1	0	0	0	1	0	0	
Crossing bat nest	0	0	0	1	0	1	1	
Crossing open area (potential design intervention)	0	1	1	1	1	1	1	*Potential for new additions, possibility for design implementations*
Crossing public place (square)	0	0	0	0	1	1	1	
Crossing planned new development	0	0	0	0.5	0.5	1	1	
Crossing large scale infrastructure	0	1	1	1	1	0	0	*Human factors (movement)*
Night time activity (people presence at dark hours)	0	0	0	0	0	0.5	0.5	
Running parallel to high people flows	0	1	1	1	0.5	1	1	
Crossing high people flows	1	1	1	1	1	0	0	
Points:	4	5	5	8.5	8.5	8.5	6.5	

Corridor comments:

A: Mostly through residential villa areas, i.e. private property.
B, C: Almost identical.
D: Design implementation in buffer area between parallel to and in water connection.
E: Connect the canal with Slottsskogen (dark complementary core).
F, G: East west connection - river-walk. Tie together nests. Protect water buffer. Green structure based on future plans for the area.


A
B
C
D
E
F
G

RECOMMENDATIONS ON CITY & DISTRICT SCALE

Based on the city and district scale findings we pose a summary of recommendations in relation to planning or design.

Dark ecological corridors

The dark ecological corridors must be continuous and light barriers need to be bridged. Crucial corridors should be permanent while complementary corridors can have a dynamic solution.

In the intersection of a crucial (backbone) corridor and a large scale infrastructure e.g. highway it could be necessary to make a physical construction so darkness becomes permanent.

Priorities

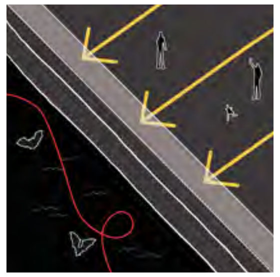
Priorities are an important tool to use in planning. Measures should be implemented firstly where they have the biggest positive impact. Implementing also the alternatives gives resilience in a system. Prioritizing the most influential parameters goes for all scales.

Time

Another important tool to use both in planning and design is time management. The use of time or motion controlled lighting, "smart lighting", can reduce light to only when it is needed. This is positive for both environment and economy.

Development plans

The dark ecological network must be acknowledged in the development of the city on all scales. Projects on varying kind (buildings, places, land use change, bridges, infrastructure etc.) can strongly affect movement patterns for both humans and bats. It is in the development plans that ecology in cities could be protected and strengthened since it is not only relevant for outer urban or natural areas.



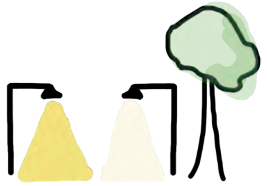
Water

Light can reach water from a distance, e.g. by high rise buildings. Water is attractive for humans and crucial for bats. Water is very reflective and spreads light. Light trespass should therefore be hindered for the sake of bats and other species.

Artificial & non-artificial surfaces

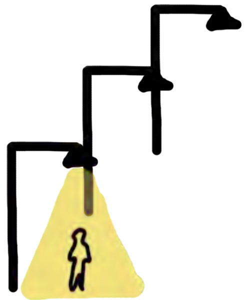
Analysis indicates that specific attention should be paid to surface color and surface gloss when aiming to reduce skyglow. The image shows the different colors of asphalt (artificial) surfaces. Asphalt is not only dark and absorbing (as one might think), the brightness in color between different types differs.

Replacing artificial surfaces with non-artificial surfaces in sensitive areas have an absorbing function.



Lighting restrictions

It could be reasonable to have light restrictions within and close to sensitive areas (dark cores or buffer zones). In these areas there should be a minimal level of light, only to ensure visual perception and perceived safety.

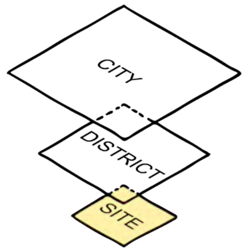


Lighting strategy

Lighting strategies should be applied from large scale planning to detailed design. Considering the overall situation and connecting places have implications on all scales. A rule for lighting strategies to remember is "right light at right place at right time". This could include lighting curfews as an effective mean in the most sensitive areas.

Building design + public space design

Optimal results of lighting and darkness design could be reached when a building and connecting surrounding spaces are designed with a common idea and should be developed at the same time. Features of a building such as dark/green roof, dark facade color or openings have an impact on light spread on a bigger scale than the building itself and is especially interesting if it is placed in sensitive areas.



SITE SCALE

The site scale public space is located in a buffer zone where the corridors F and G intersect with the water corridors Göta Älv and the canal which show large need and potential for intervention. The whole area is about to be completely transformed with new land use and extended land (see fixture p. 60). The chosen site is called Skeppsbron, it has a detail plan but the actual land is not yet built. The rather general plan is considered to be positive since it gives freedom for explorations, but it also requires that we make some assumptions of unknown parameters (stated on p. 60).

Frame and process of design

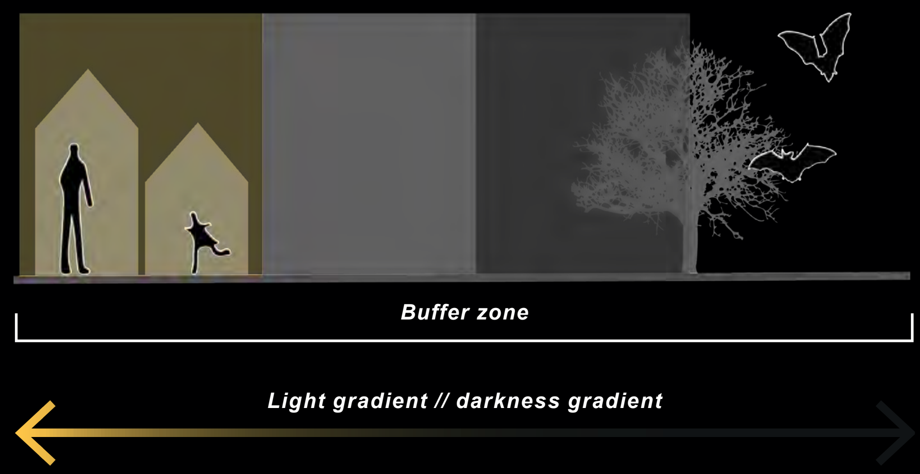
Physical models and *light lab facilities* were used as the main tool to develop, visualize and present the public space design. It is a proper tool to experiment with and to understand darkness, light and visual perception of space. The relevance of the tool is further strengthened by the fact that visual perception is difficult to measure and visualize digitally. Explorations through physical models has inherent restraints of dual character. Modelling with convenient materials enables direct outcome and thereby an iterative process. The materials and light sources at hand sets a limitation in terms of precision of material texture and -gloss as well as light source color, amount, intensity etc. Therefore, the materials and light sources should be understood as simplified representations of selected properties. The restraints were reviewed and we concluded that the intended outcome would be reached.

Two kinds of model explorations were conducted; one about surfaces (see p. 62-65) and one of the site with the public space design (see p. 70). The site model started as 1:50 cut-outs as physical 3D test beds intended to be used for digital implementation. However, the fruitful outcome of working with physical models led to a full size site model. The 1:50 scale enables a certain detailing, but is also comes with an inherent limitation of detailing which we found reasonable for the intentions of the public space design; exploring darkness, light, shadows and contrasts.

The design was developed by the previously gained knowledge and through conclusions of the two conducted experiments which then led us to create a catalog implemented on and derived through the site model. The catalog consists of chosen parameters and designed objects. The parameters are connected to space perception in darkness, crucial for enabling movement in public space for humans while creating suitable conditions for bats.

Strategies

Located in the buffer zone, there is a need to achieve a gradient of light/darkness over the public space so that the dark corridors (Göta Älv and the canal) can be dark while having a light path for humans, i.e. a darkness stragety.



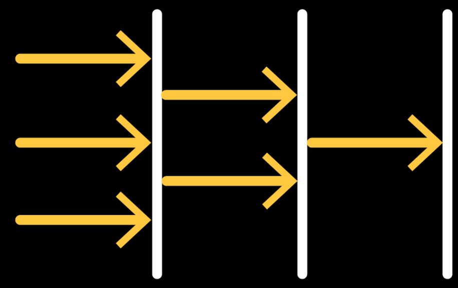
The main strategy to achieve the gradient, get a smooth transition between dark and light and mitigating light pollution is to reflect light and filter light. This is conducted by *designed objects* in combination with artificial light.

The lighting strategy follows three steps:

- Use given/existing light from buildings
- Add light where it is needed (enable movement)
- Adapt light when it is needed (technology)

Reflect light

Filter light



The site is located by the new river-front of Gothenburg. The main spatial features are the pier boundaries, bridges and building. The building is rather undefined in the plans by the city. The known factors is the maximum footprint, the height < 12 m and function as a public building. Our own assumptions about the building is that it will be approx. 50 % open towards the canal and have the entrance to the North.

New artificial land extensions

Bat dispersal

Ferry

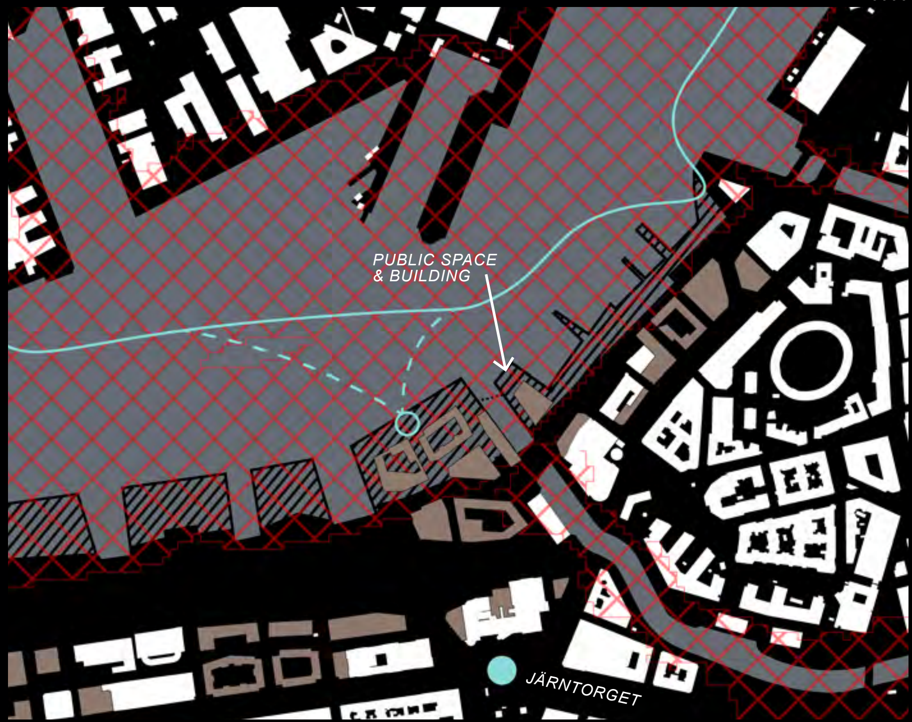
Attraction points

New buildings

Site analysis

Context and site

1:10000



There will be no natural flow of through-movement since the site is by the river. However there will be an attractive river-walk generating flows. Bridges over the canal on both sides of the building give rise to concentrated flows and are important for crossing the water barrier (humans). The North bridge is only for pedestrians and the South also for cars.

River-walk

Bat flow & nest

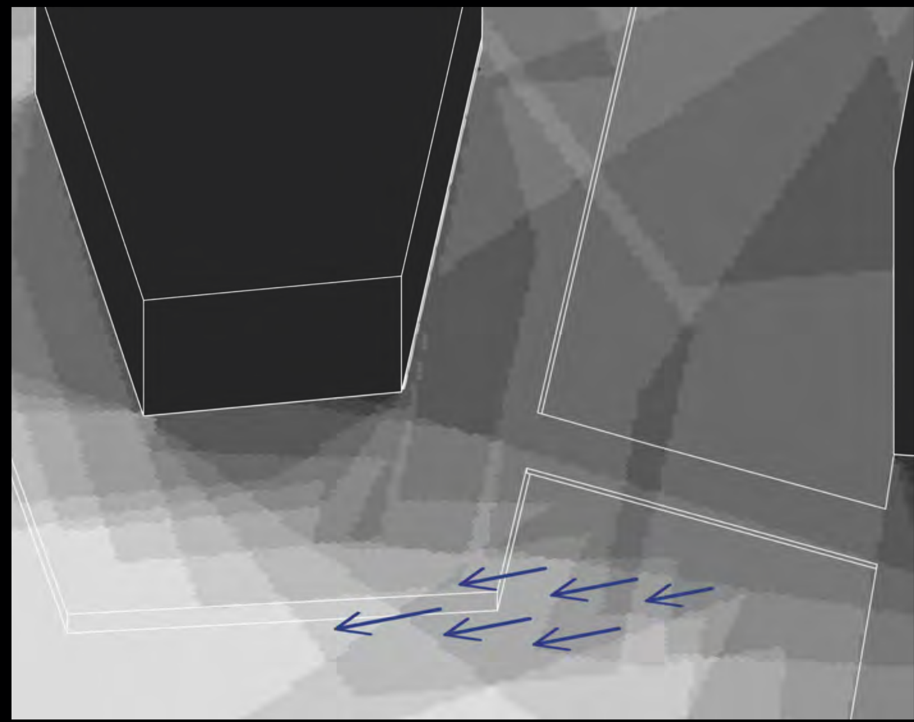
Sight lines

Car movement

Site access - movement and sightlines

1:2500

Sun, shadows & wind conditions



The illustration shows analysis of relevant site conditions for day use of the public space.

Because of the (upcoming) tall surrounding buildings there is limited sun hours. The most sunny corner is considered to be important for daytime use.

The site could, at times, be a windswept location. The most common winds are from SW (Molander, 2015), which should partly be shielded by the upcoming buildings.

Wind direction

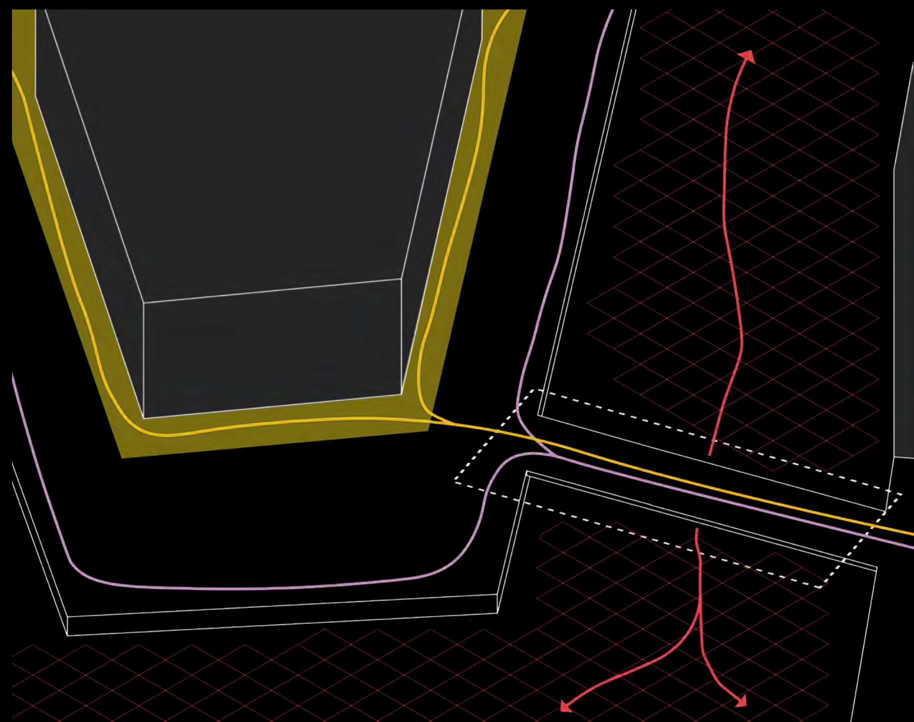
Hours of sunlight March 21st:

9 h

6 h

3 h

Flows - synergies & conflicts



The bat flows are in the inlet and canal and must be protected from light trespass. The inlet corner is suitable for greenery. The human flows could be divided in 2 alternatives, one by the river (optional access in darkness) and one by the building (required 24/7 access in darkness). There is a conflict by the bridge which at the same time could be a lit crossing for humans and barrier for bats. In this proposal the South bridge is considered to provide a constantly lit crossing and the pedestrian bridge is prioritized for bats.

24/7 lit path

Bat flow

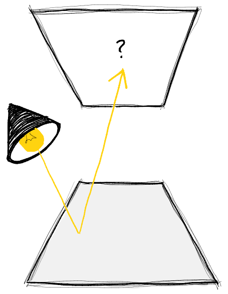
24/7 human flow

Optional human flow

Conflicting area

Experiment 1

Figure 28



Horizontal surface

The goal of the experiment was to understand how different ground surfaces reflect light upwards and contribute to skyglow observed in previous light pollution mapping. It also gives an understanding of how different colors are perceived when lit in a dark surrounding.

For the experiment a single light source was used and directed in a downwards angel towards a horizontal surface (figure 28). Different materials were tested as the horizontal surface (all with a similar texture). Then, a reflective transparent surface was placed on top of the other surfaces as a test to illustrate the effect of water on the ground. It could also represent a high gloss finish on a surface. The experiment was conducted with four different light settings in a blue, white, yellow and red light spectra.

Light lab setup of experiment.

Conclusion:

- » The light temperature, red, blue, yellow or white, have little impact on the reflection. Therefore the light temperature can be decided based on other factors like human well-being and ecology.
- » Dark surfaces reflect less light compared to bright surfaces.
- » The reflected light clearly shows the color of the ground surface in "the roof", it is little affected by the light temperature.
- » Red light makes all reflected light red too and reduces/removes the perception of surface color.
- » Risk of glare effects increase when the ground surface is reflective.
- » Gloss on surfaces increase reflection compared to the non-water test and the result is constant for all surfaces.
- » Gray and wood surfaces were considered very similar in the results and was therefore merged in further tests.

High gloss surface

White

Gray

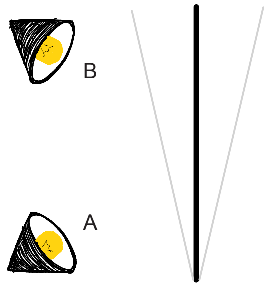
Wood

Black

Reflective

Experiment 2

Figure 29



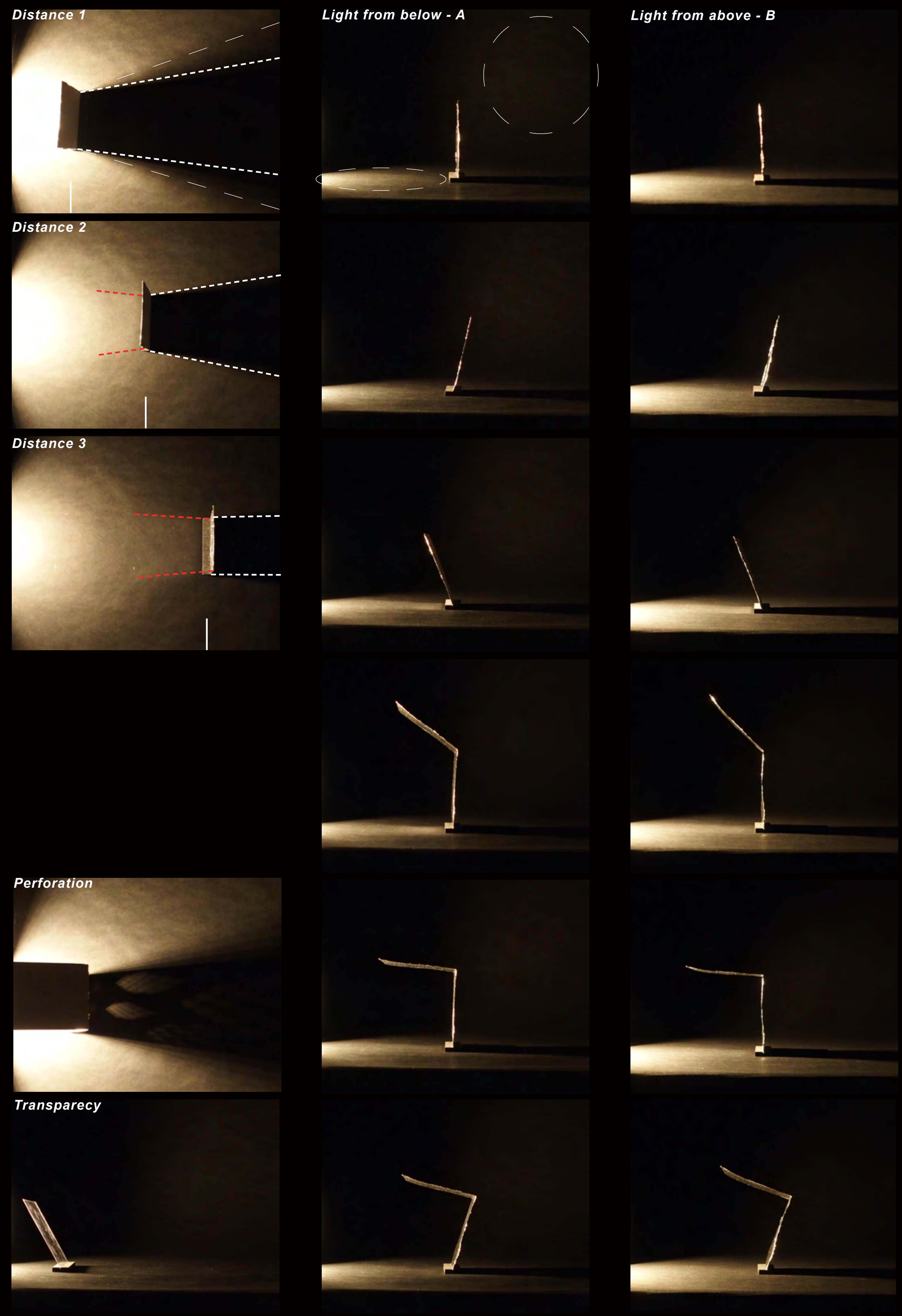
Light lab setup of experiment. The reflections from the screens were reflected on the wall.

The goal of the experiment was to understand how different angels of a light source lit on a vertical surface affect the reflection and shadows created in the surrounding.

For the experiment a single light source where used which emitted a warm light. The source was directed towards a vertical surface of varying material (figure 29). The vertical surface was either a straight screen or a screen with an angle ("roof"). All screens were then tested in a straight or angled position and placed at three different distances from the light source. In the first test the light was coming from a lower point directed in a upwards angle and in the second test from a high point directed down.

Conclusion:

- A shorter distance between the light source and the screen increase reflection.
- A shorter distance between the light source and the screen cast longer shadows behind the screen.
- A shorter distance between the light source and the screen direct more light to the sides.
- The distance between the light source and the screen is also affecting the intensity of reflection.
- A roofed screen reflects more light back towards the ground. The effect gets stronger when the light is coming from above and directed downwards.
- A transparent surface both reflects and lets light through. Transparent materials allow for daytime visual connection between the two sides, during the night it depends on the light level of the two sides.
- Light from above have less excessive light directed up which leads to a brighter ground.
- A small solid material by the ground is effective to prevent light flow on the ground.



CATALOG

Surfaces

Surface + light source.

The 5 chosen representation surfaces (white, gray, black, transparent, reflective) comes from the previous experiments.

The scale bar indicates the level of absorption to reflection and is based on the experiments in relation to the four other surfaces.

A set of materials are proposed for each representation surface. For example a black surface could be dark wood, dark color, dark asphalt or soil. The gloss values (reflection) varies between the materials which is not considered in the scale bar.

White

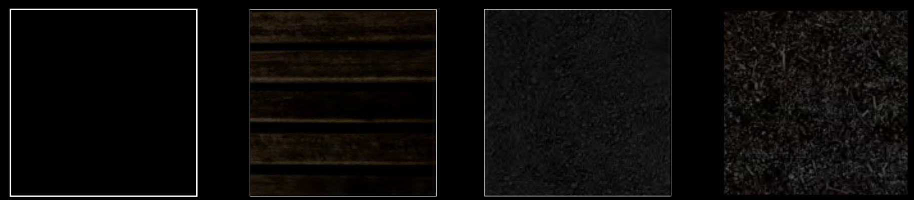
ABSORPTION — REFLECTION

Gray

ABSORPTION — REFLECTION

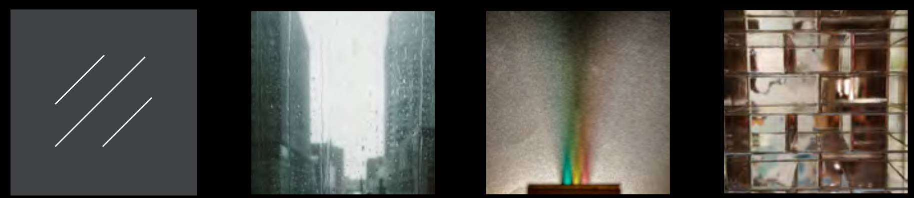
Black

ABSORPTION — REFLECTION



Transparent

ABSORPTION — REFLECTION



Reflective

ABSORPTION — REFLECTION

Spatial perception

Surface combinations.

The surfaces together creates different spatial perceptions, here represented in 5 principles.

Each spatial perception principle is complemented with real examples found in the built environment.

Sharp boundary - contrast

Gradient boundary

Pattern

Direction

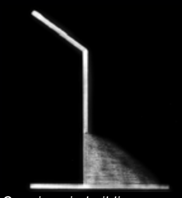
Height difference

Artificial light

Artificial light notions from p. 23.

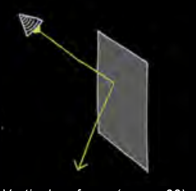
To understand the shape and scale of a space.

Spatial lighting

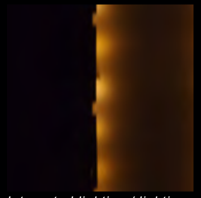


Openings in buildings

Bollards with shielded light.



Vertical surfaces (see p. 33)



Integrated lighting / lighting in a spatial boundary

Create conditions for social interaction safety in a space.

Social lighting

Lantern with soft glow

Light provided mainly for facial recognition

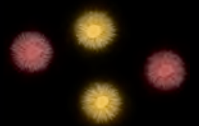
Entrances, signs and shop windows lights the public space

Motion sensors activates light by human movement

Light that is special to a place.

Characteristic lighting

Diodes in the paving with minimal light emitted



Red and warm light could indicate that a certain area belongs to humans / bats

Lit objects

Create conditions that enables the ecological aspect of a place.

Biological lighting

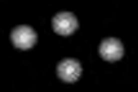
Red lit path in Mölndal,Gothenburg

Reduced light in sensitive ecological phases

Create an experience.

Light typology

Continuous even light on main paths



Point light in surroundings for main orientation

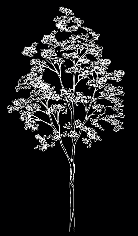
Rhythm or hierarchy

Vegetation objects

European oak [Quercus robur L.]

Since vegetation is an important object in public space both for humans and bats and due to the site conditions it is crucial that the chosen vegetation endures wind. The species are chosen from a master thesis about vegetation called "Växter vid havet" (Vegetation by the sea) by Blixt (2007).

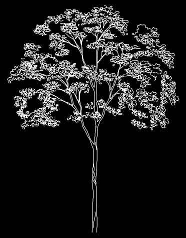
Silver Birch [Betula Pendula]



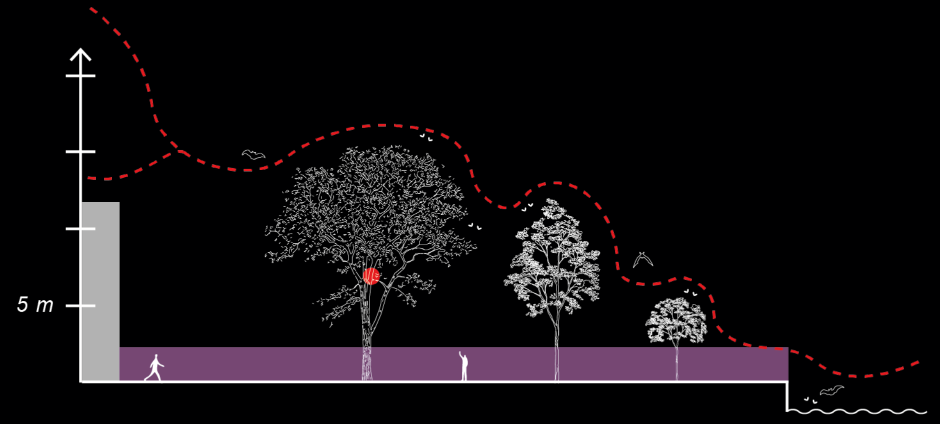
All trees are deciduous which means the branches are bare from October ~ April, approximately the time when bats hibernate.

The choice of vegetation is based on an assumption that enough soil is provided when the new land is extended.

Rowan [Sorbus spp.]



Spatial requirements in relation to vegetation for humans & bats



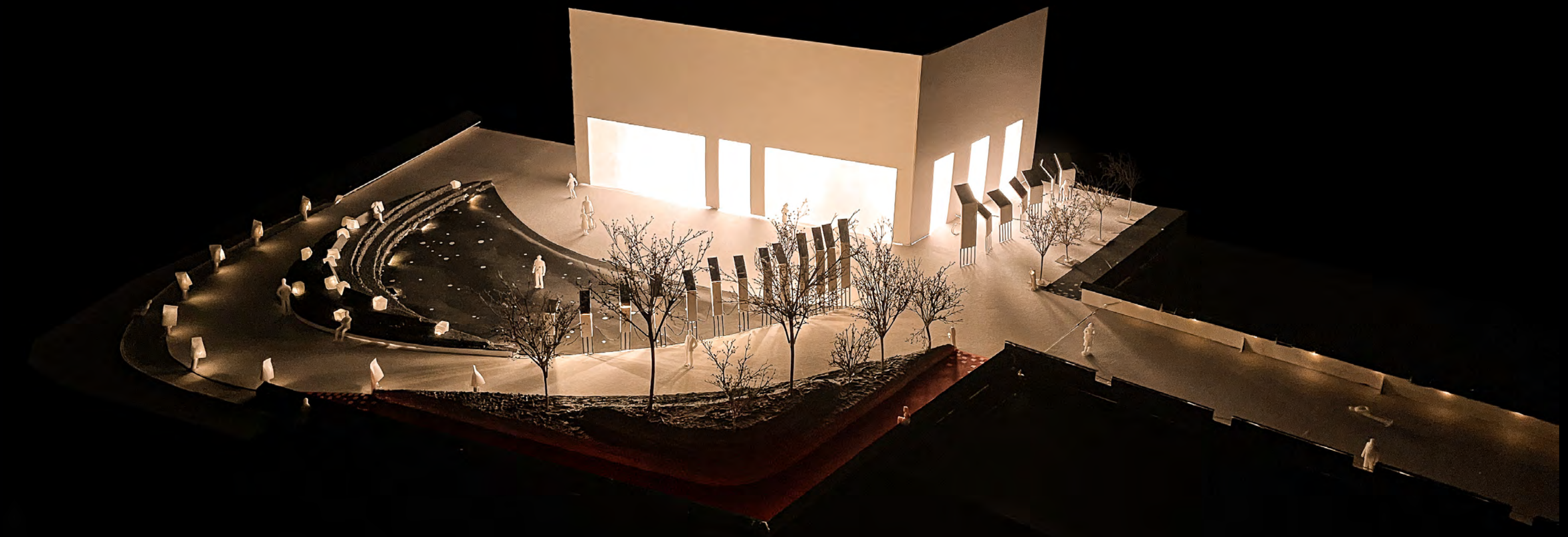
Vegetation with crowns enables human visibility underneath leading to overview of the space, thus increase perceived safety while creating safe space for bats.

Section scale 1:50. Note: bats and insects are not made to scale.

The trees are placed in a table which indicates average height.

- Human overview
- Bat spatial requirements
- Public building height

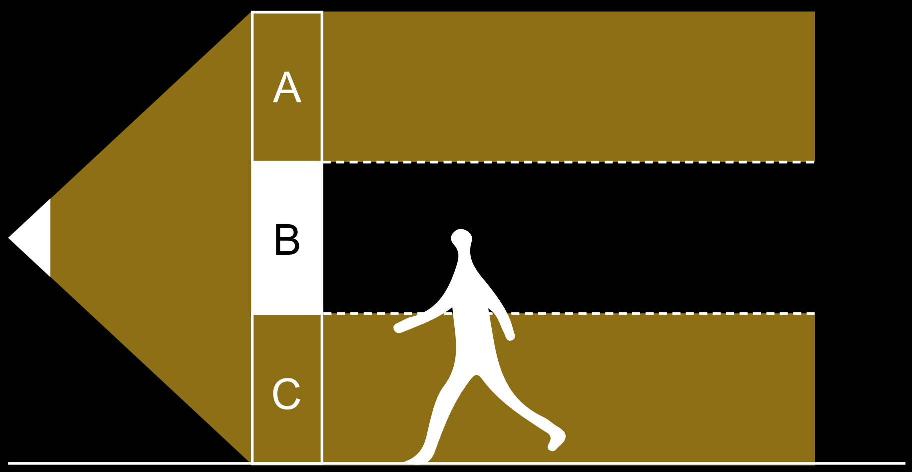
Overview of the public space



Concept for object design

Based on the experiments and the catalog, a set of designed objects was developed for filtering and reflecting light and supporting movement.

Each design object filters light in a zone called A, B or C which indicate a height in which light trespass is blocked.

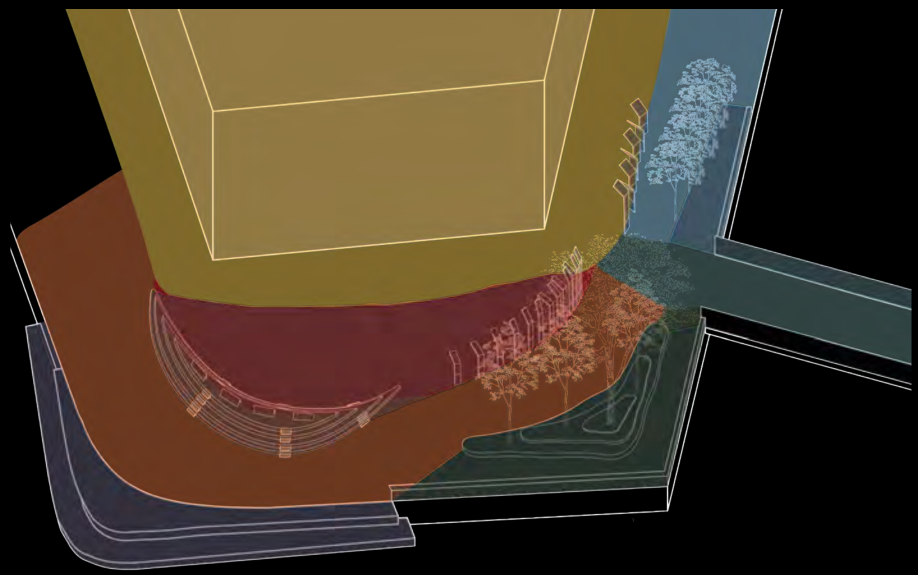


Darkness and light spaces

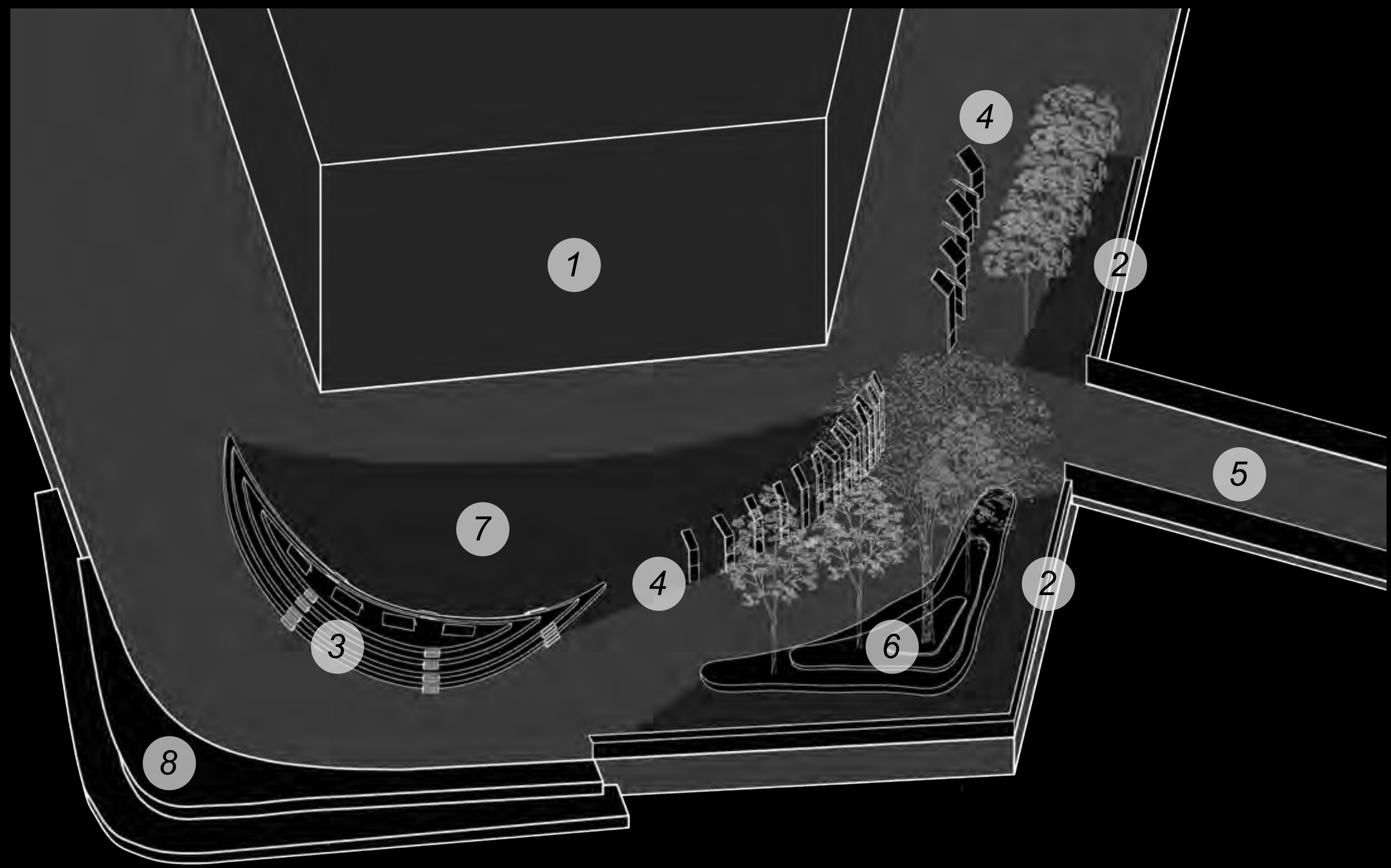
With light and darkness we can direct movement and design light spaces which do not have to correspond to the physical space. To this theory we have added the term darkness space.

Each light and darkness space has their own light conditions, in the image it is illustrated as a color.

In this public space there are seven light/darkness spaces.



Object implementation diagram



Components in public space:

1. (Public building)

2. Bench

3. Seating area

4. Screen installation

5. Bridge

6. Green wedge

7. Square

8. Deck

The main features on the site, except the building, is the square in front of it, the deck area which enables a water connection, the pedestrian bridge and a green wedge.

Their boundaries are defined by, and, together with the designed objects. The design objects are the bench, the seating area and the screen installation.

A row of trees along the canal together with the green wedge make a continuous green addition.

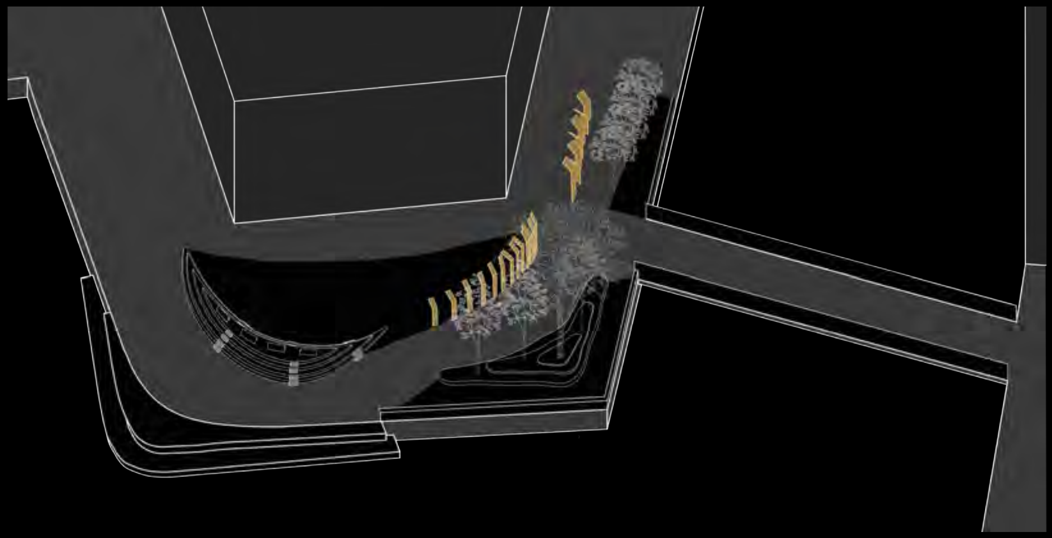
DESIGNED OBJECTS

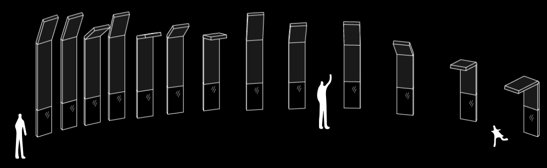
The screen installation

The screen installation is a large scale object which is space defining, place creating and a landmark. It blocks light in zone A and B.

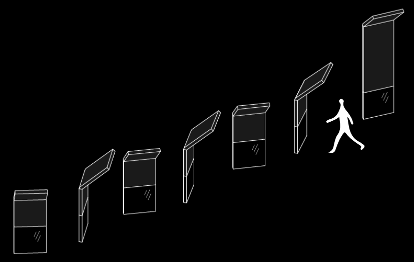
The screens provides lit vertical surfaces for increased perceived safety and creates interesting shadows in the paving.

The installation consists of 2 variants. The one by the building needs to filter light on a short distance. It makes use of the existing light and reflect and direct the light towards the less lit parts (figure 30 & 31). The second variant is a continuation, but the purpose is filtering and space definition. Since it is further away from the building it does not reflect as much light and has an integrated fixture that can be lit if needed. The height decrease and the space between the screens increase as they get further away from the building.





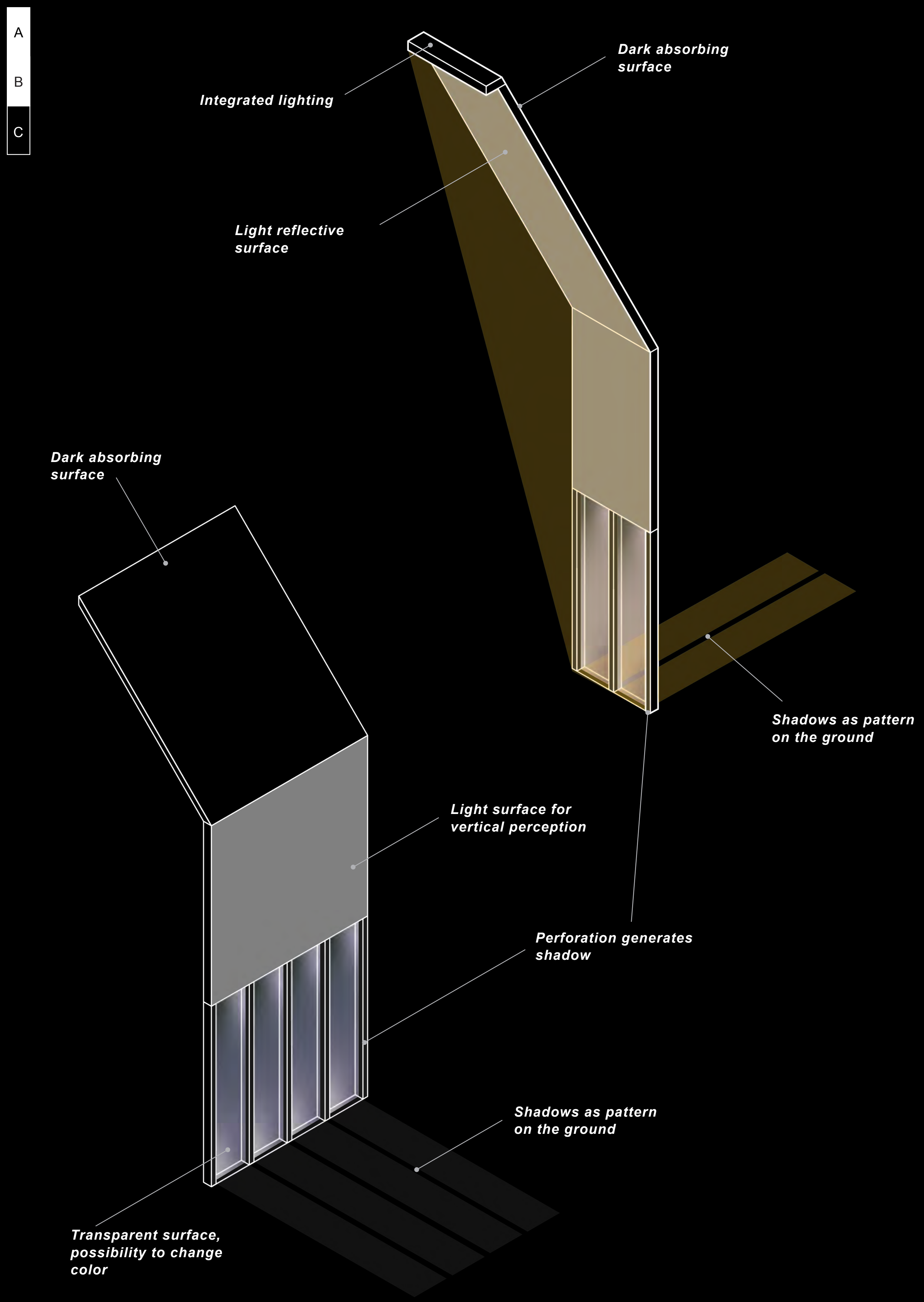
2. spatial perception + reflection + absorption



1. filtering + reflection + absorption

Figure 30

Figure 31



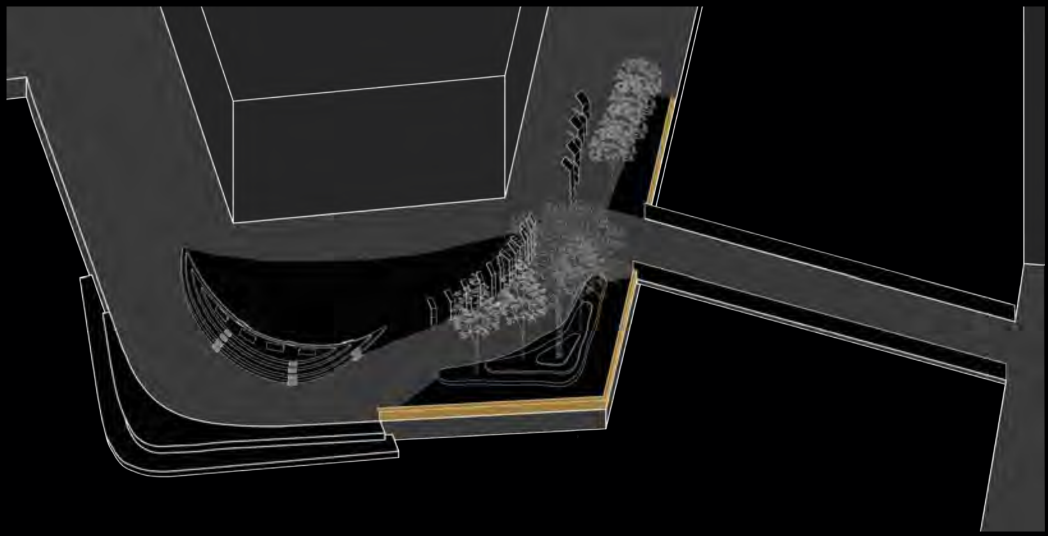
The bench

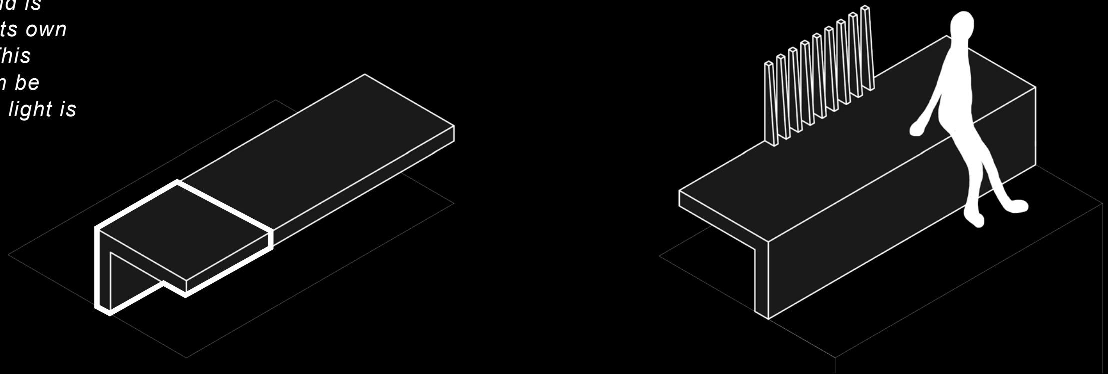
The bench is made of a solid material effectively blocking ground light flows. This object is implemented in the boundary between land and water to prevent falling accidents.

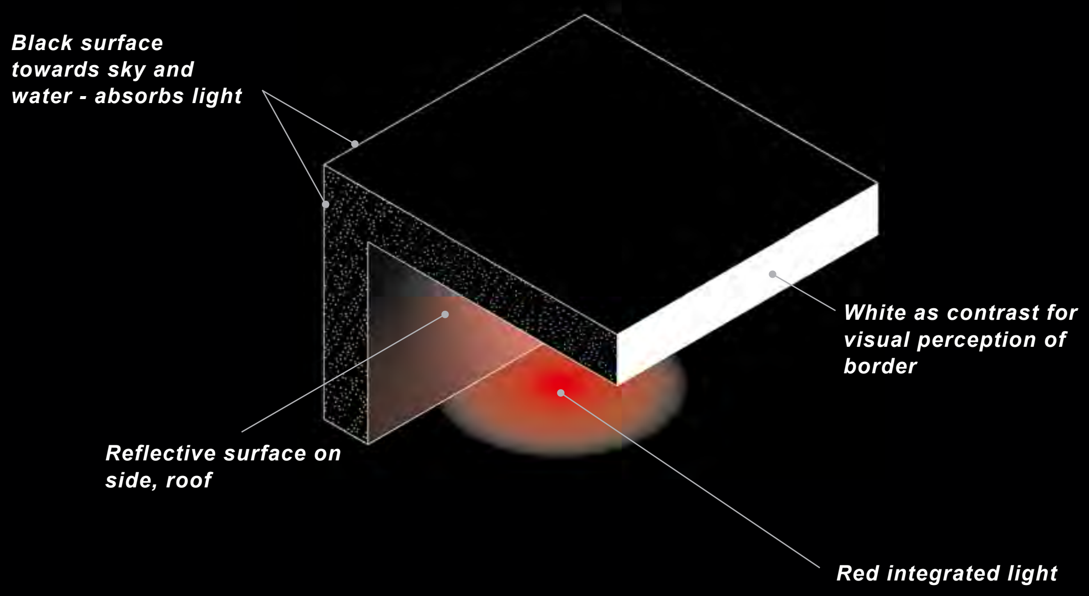
An offset placement from the pier edge enables possibilities to sit on the outside of the bench.

There are two variants of the bench. The first has an integrated red light underneath and the second an integrated backrest.

The surface towards the water is dark, absorbing light. The surfaces towards the ground is bright, reflecting its own integrated light. This way, less light can be used as the given light is optimized.







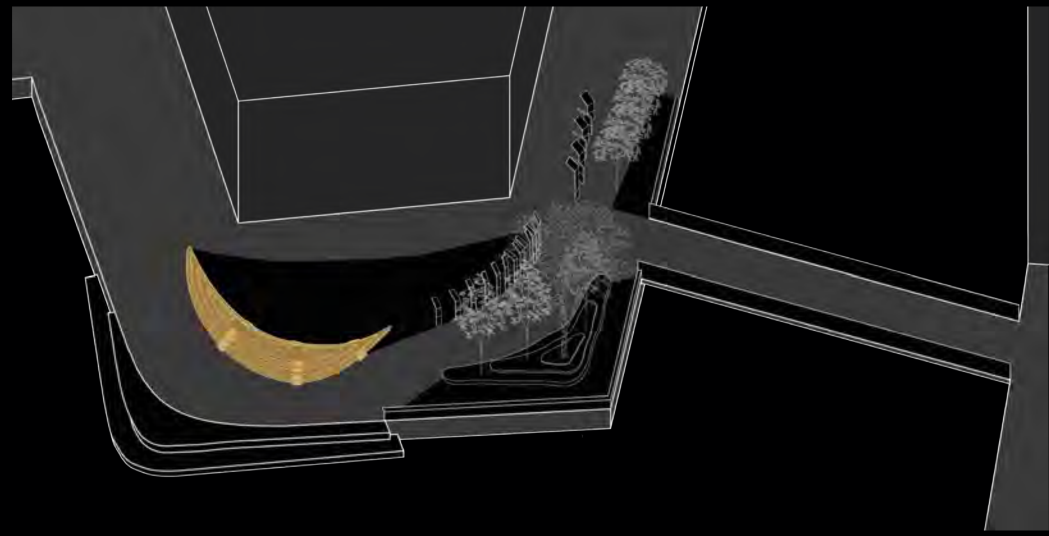
The seating area

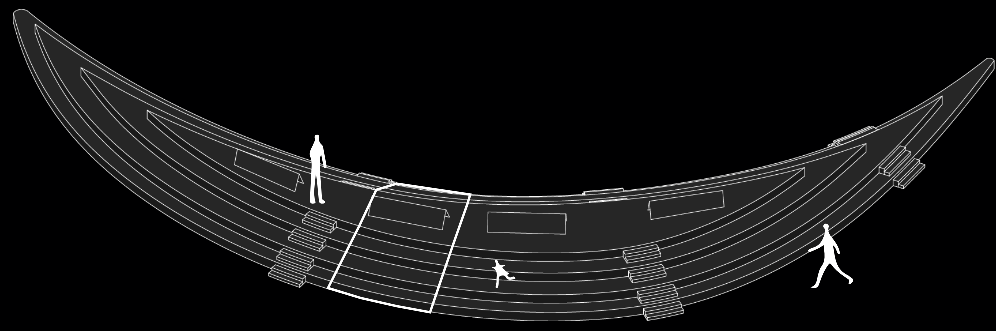
The seating area is a large scale furniture object with height difference as a spatial perception feature. It blocks light and frames the square in front of the building. The design offers seating both towards the square and the river.

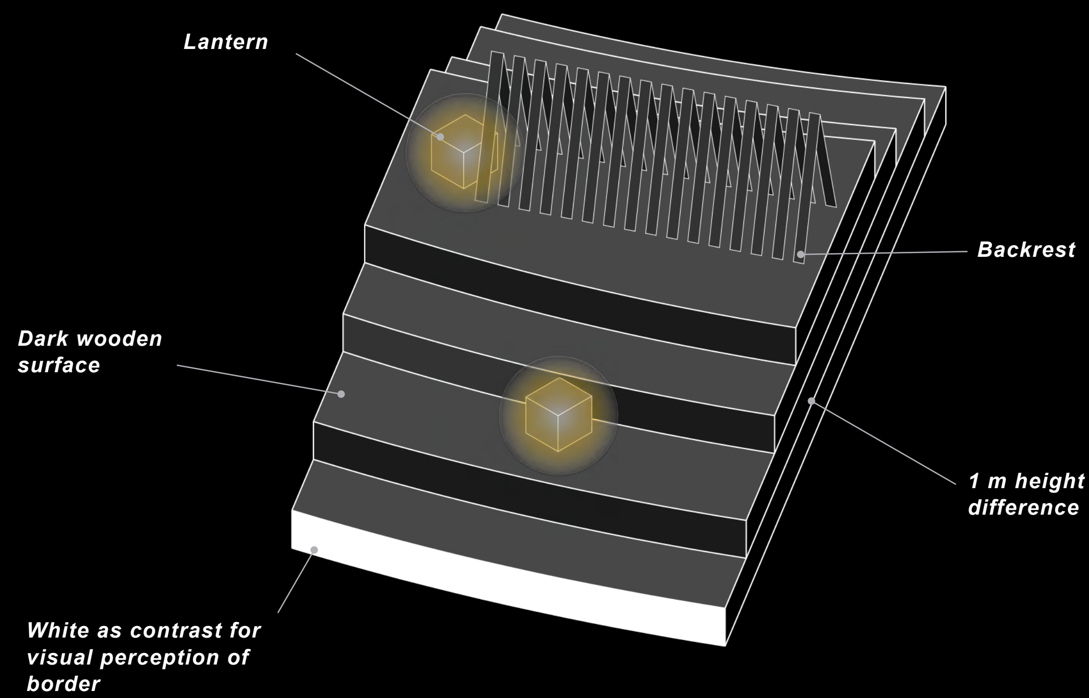
A soft social light from lanterns which provides a soft light so people using the seating area can see faces.

The first step has a light contrasting surface which indicates direction and height difference.

The main light block is in zone C, but the backrests filters some light in B too.





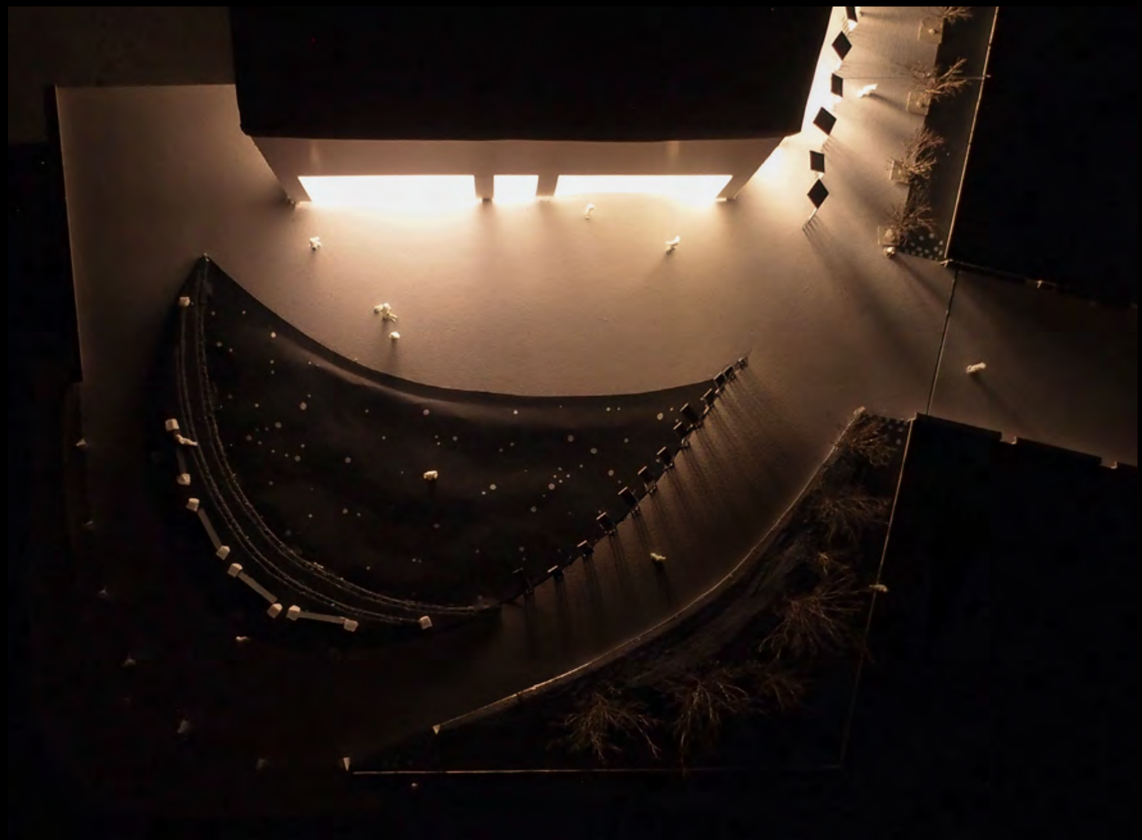


Use given light:

The light from the building is the "given light". It is the main light source for the 24/7 accessible lit path closest to the building. It also flows over the open surfaces at the square where it is absorbed by the dark color and filtered through the screens creating shadows.

The light that reaches the dark wedge makes the contrasting boundary appear.

The seating towards the square are lit by the light flow.



Add light where needed:

The "added light" enables movement.

Light diodes with motion sensors at the square and the deck are activated when the border is crossed. On the square it is an attraction and on the deck it is a safety measure.

Here is also bollards, the lanterns, the bridge rhythm and the green wedge light.

The images on this page illustrate the power of directing flows and space by the use of light and darkness.

Use light when needed - April - September:

In the summer, the bats require darkness and the need for social light among humans decrease because there is natural light longer.

Letting the corner of the inlet be dark alters the boundaries of the physical space and the light space which does not intersect.

The bridge light is turned red to avoid disturbance on the bat corridor. The faintest light required for humans to feel safe is used.

Use light when needed - October - March:

In the winter when bats are hibernating the need for social light among humans increase.

In the winter, red light enables possibilities to also use the green wedge, but it still indicates that it is prioritized for other species and has other function.

The image also shows the integrated light from the screens.

View from Göta Älv.

The square:
The open square area is in direct connection to the building entrance and lit route.

The border between the square and the path is distinct with a contrasting color. The dark surface absorbs ground light flows from the building.

The square has a pattern alluding to the starry sky and should generate a thought of looking up too. The “stars” are highly reflective metal bricks capturing the light from the surroundings and diodes. When entering the square a motion sensor activates a small twinkle from star constellations.

Deck:
The wooded deck makes the water accessible and is inviting to sit on for view of the river.

Bridge:
The bridge is easily over-viewed from surrounding space and buildings. The railing has integrated lighting.

Green wedge:
The green wedge is a space which becomes part of the bat corridor. The surfaces are dark to absorb light. The surfaces and height difference blend together. The entrance to the dark wedge is articulated with a surface gradient.

The dark wedge is prioritized for bats.

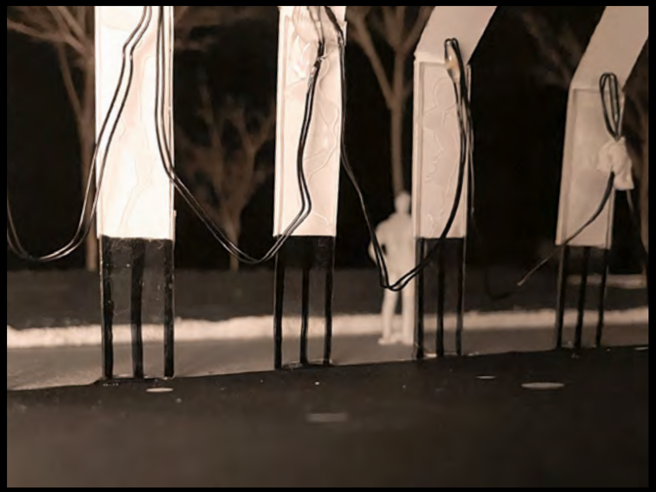
Canal-walk:
The short distance between building and canal requires concentrated measures for hindering light trespass. Zones A, B & C are blocked by the objects and a row of trees.

This filtration has implications for building views. However, the corridor is considered to be of such importance that the view is secondary.

The facade towards the canal should have restrictions in facade lighting on the second floor. Note: the second floor is not taken into considerations in these explorations.

Social light - increased perceived safety for seeing faces. The seating area before and after lanterns.

Objects enables transparency to identify people on the other side which increases safety.



The images shows boundaries of contrast created by the objects and surface materials.

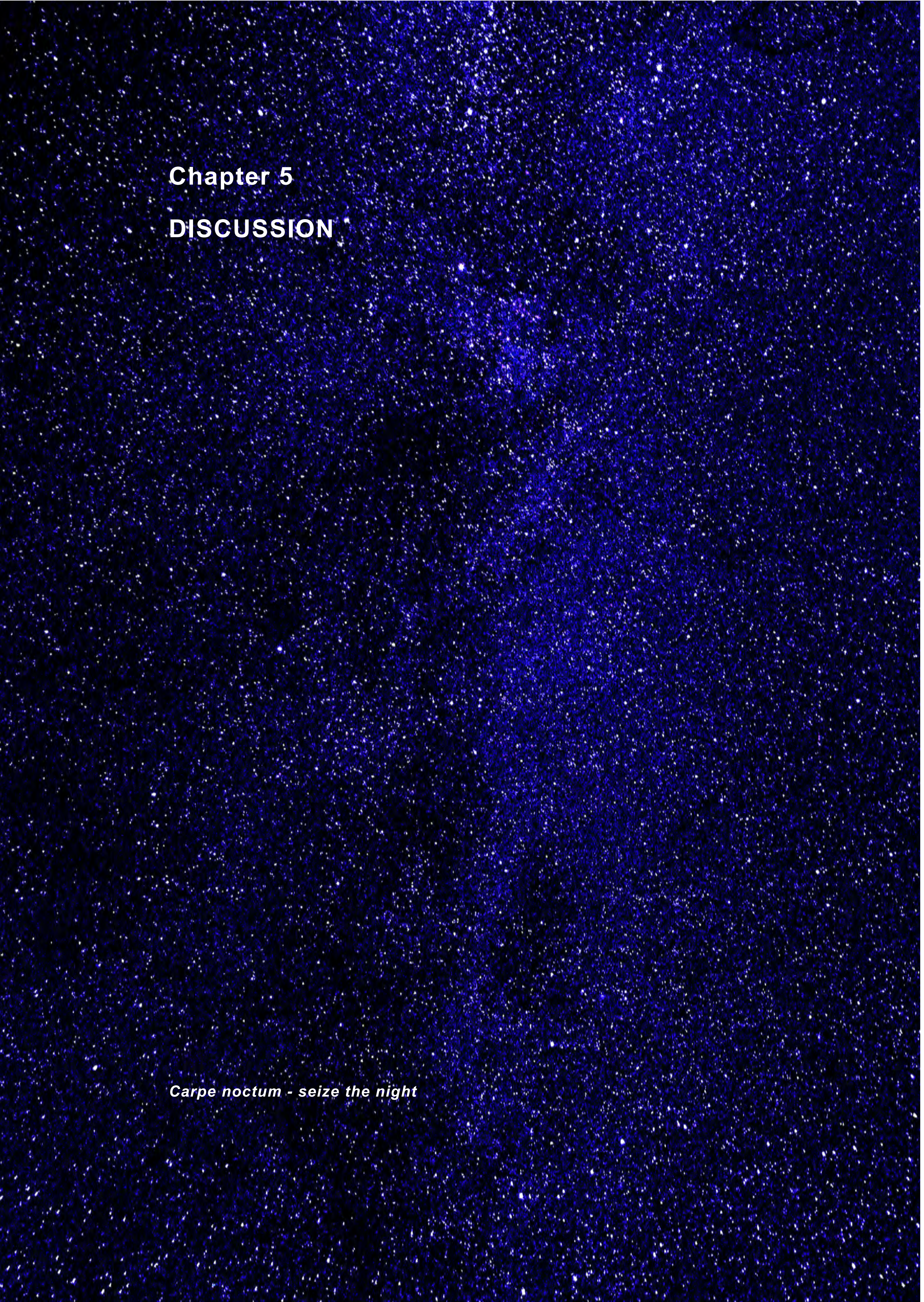
The screen creates a height extension of the space and shadows mimicking paving details.

Seating area, dark wedge and bench have a contrasting edge which indicates the spaces.

The image shows visual directions created from the sharp contrasting boundary of the square, the screens and the rhythm of the bridge lighting.

The image shows the view from the seating area towards Göta Älv and Hisingen skyline.

The bollards marks the curved direction.



Chapter 5

DISCUSSION

Carpe noctum - seize the night

Conclusion

The importance of darkness can no longer be overlooked. The arguments for protecting, preserving and promoting darkness are supported from several perspectives. We strongly believe that the work of designers must stretch outside the traditional frame of architecture and always acknowledge the coexistence of different species in the spaces created. It is important that architects understand how to create synergies, mitigate conflicts and avoid creating conflicts in design and planning projects. To do so, one must know how to find the knowledge. If the knowledge yet not seem to exist, as in our case, one needs to extract it then prioritize its importance. This thesis demonstrates not a refined design proposal but rather a methodology of knowledge extraction through research based design. This is our contribution to the current knowledge. The moral contributions are about acknowledging the values of darkness as more than a backdrop, taking a stand for a neglected perspective from which we hope to raise thoughts on human behaviour as well as architectural possibilities and responsibilities.

Summary

This thesis has been developed seeking answer to the research question *"How can a darkness perspective affect the design of public space in Gothenburg, balancing the social and ecological interests and users?"*. We have answered the question by:

1. Exploring in a broad sense and summarize what a "darkness perspective" can be and which topics are related to it: the duality of darkness-lighting, values of darkness, emotional perception of darkness.
2. Connecting the findings to the field of architecture and use of space: artificial light in urban areas, light pollution in urban areas, relation between darkness-lighting imbalance and history derived from urban space, conditions for safe public spaces, national and international legislation.
3. Who are "social and ecological users": humans and bats as a nocturnal and native species in Gothenburg and commonly used as a representative species.
4. Exploring and summarizing which interests are key when having a darkness perspective on social and ecological users: conditions to move in a safe way (all other interests were delimited).
5. Exploring Gothenburg from three scales to showcase synergies and conflicts emerging from the social and ecological systems in a context.
6. Propose strategies and public space design where interests and needs are balanced. The act of "balance" implies an imbalance and acknowledges the importance of other than human species.

Key reflections and conclusions related to each chapter have been presented throughout the booklet. These are some main reflections about the topic:

- Light at system level is derived from each individual lighting fixture.
- Light distribution and pollution are not only about the light source, but also the surrounding surfaces, which is interesting further work.
- Darkness is a natural part of our rhythm and should be preserved,

protected and promoted in urban areas because of its inherent values and importance for all living species.

» From several perspectives we found that systems and topics tend to be separated. It might be because it is easier to understand complex things separated or because of bias. In general, separation of systems seem to risk reducing the parameters to topics and not system components. In the beginning we tried to separate darkness from light and delimit light, only to realize it is impossible.

» Humans' bias seem to always override everything in our way even though we are dependent on functional ecological systems to survive. One of those obvious things from the process is humans' "right to space". We stated early "*All species need darkness and (natural) light. No species need artificial light*.*" At the end of the day humans do not really need artificial light. We "need" it to use space the way we have created them but the "need" is a superior human-bias-way of seeing it.

» The experience of dark space may be mainly connected to the fact that darkness entails an individual experience connected to inherited, experienced or perceived aspects, or abilities, gender etc. Design can only provide a set of conditions enabling safe use of spaces, but not guarantee a positive experience of it.

Methodology & process

The authors "out and about in different topics".

The theoretical and methodological framework of Social-Ecological Urbanism, dark ecology and the value of darkness composed the frame of the thesis. The approaches at times led us to paths away from the field of architecture; unknown territory which might or might not be relevant. It was a time-consuming but interesting phase since we found aspects we would not find within the traditional frame of architecture. The thesis has the emphasis in the field of architecture but acknowledges, for example, dark ecology as an important perspective, even though it is not our expertise. In a real project there would probably be experts contributing with the important parameters, for example an ecologist (we did talk once to an ecologist to have a transdisciplinary perspective).

The research question, social-ecological framework, multiscalar approach and the context of Gothenburg were the base parameters of the process. We knew that we wanted to reach the detail level of a public space design, but the outcome and way to get there could not be predicted in advance. The progress of the process was about finding something interesting and explore it further. The main sources of error in the work were deciding which findings are main and risk of making incorrect observations.

In the more general scales city and district, we had originally intended to design and reshape the corridors proposed in the backbone and inventory, and in the site scale to propose a design of a public place. Due to the time frame, we chose to let the corridors be covered by a series of more general design recommendations, while the public space was designed site-specifically. The site scale exposed some additional difficulties and sources of error. Primarily it was about lack of knowledge in the subject of "light" - something for us completely new that turned out to be very large. The fact that we knew so little about light and the lack of the topic throughout the education, even though it is fundamental in architecture, is remarkable. However, the fact that there is a separate education in lighting design indicates that it is a large topic. This thesis has begun to fill a knowledge gap for ourselves.

The design could have been strengthened by some development of the technical specification of figures used in practice, but for us the figures does not tell us anything about the experience of space. Capturing an experience as we saw it in reality through photography proved to be difficult. It would have been interesting to develop the day perspective to understand how light/darkness can create a flexible useful space, but it was not in the scope of the thesis.

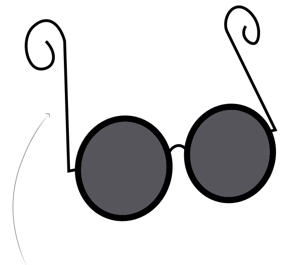
The experiments on the site model are detached from the actual context in terms of surrounding lighting. It is very difficult in a physical or digital model to capture the effect of the surrounding light, even though it is an important parameter. The fact that the site does not yet exist adds to this. It would have been beneficial to bring forth an image for comparison between the site scale design and what the design is likely to become without the darkness perspective.

Despite this it would have been a good exercise to add the site to its context to better understand how the surrounding effect the space and how the site is perceived from outer areas. By taking this step the design interventions on site scale could be viewed from a broader perspective and fill a gap between district and site scale. This gap has been brought up orally during seminars and would be a positive complement to the work.

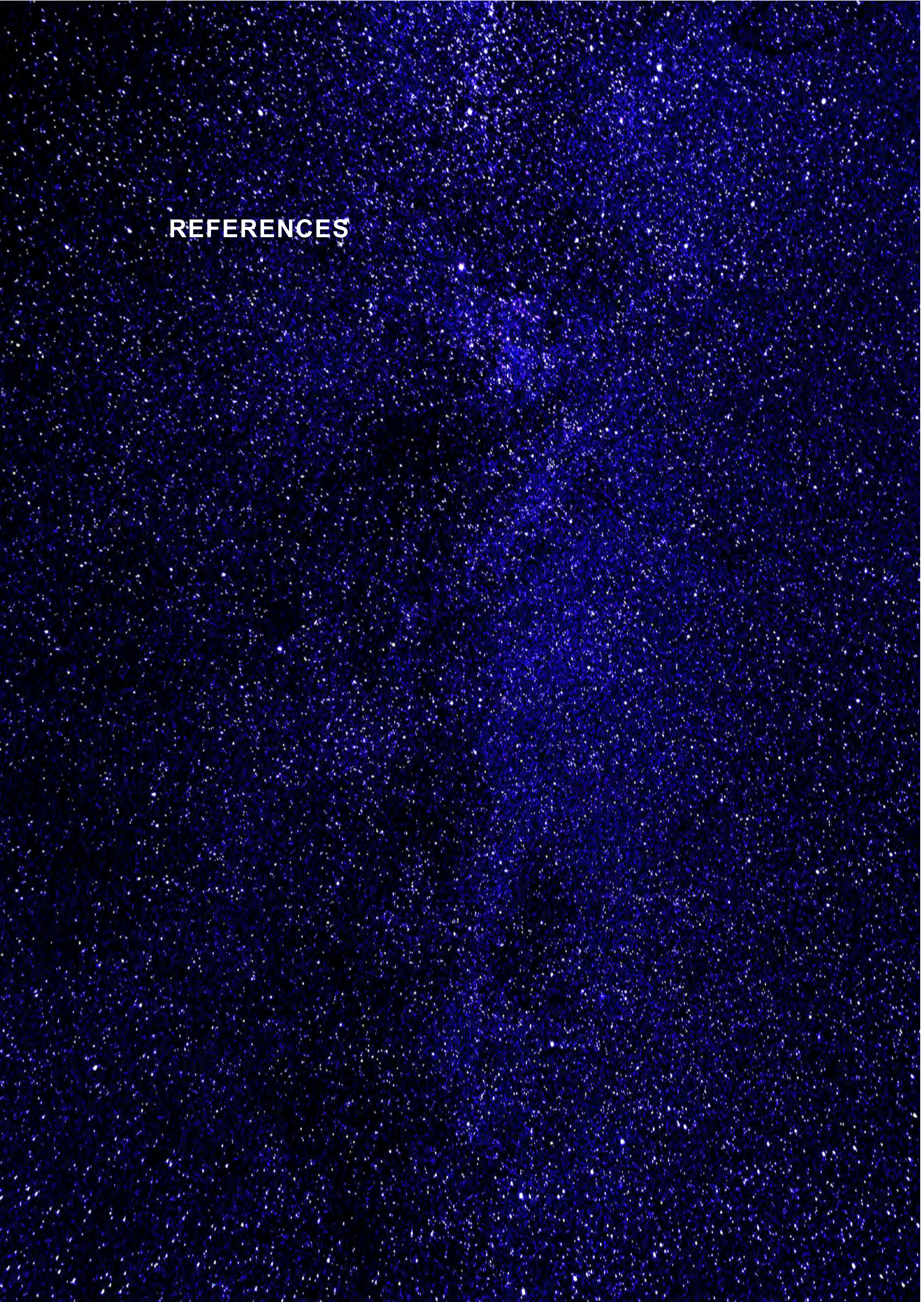
Our perception of Gothenburg at night has changed a lot during this thesis as we have started to notice our own findings and the knowledge retrieved. At Earth Hour we had hopes of being able to see the skyglow over Gothenburg disappear. However, we could not see any change except Ullevi and Liseberg's ferris wheel being switched off. The city of Gothenburg has a big influence on this matter and should do more, Earth Hour or not.

Final thoughts

This has been a very rewarding process for us and feels like a start of something. At first, we did not understand how big the subject was and, in the end, it feels like we only scratched the surface and that there are still lots left to learn. The things we have started to notice in our own surroundings cannot be un-seen. We believe and hope that in our upcoming working lives we have the chance to re-introduce the darkness that was designed out of the urban areas.



Finally, we can say that the thesis opened the nocturnal world after dark.



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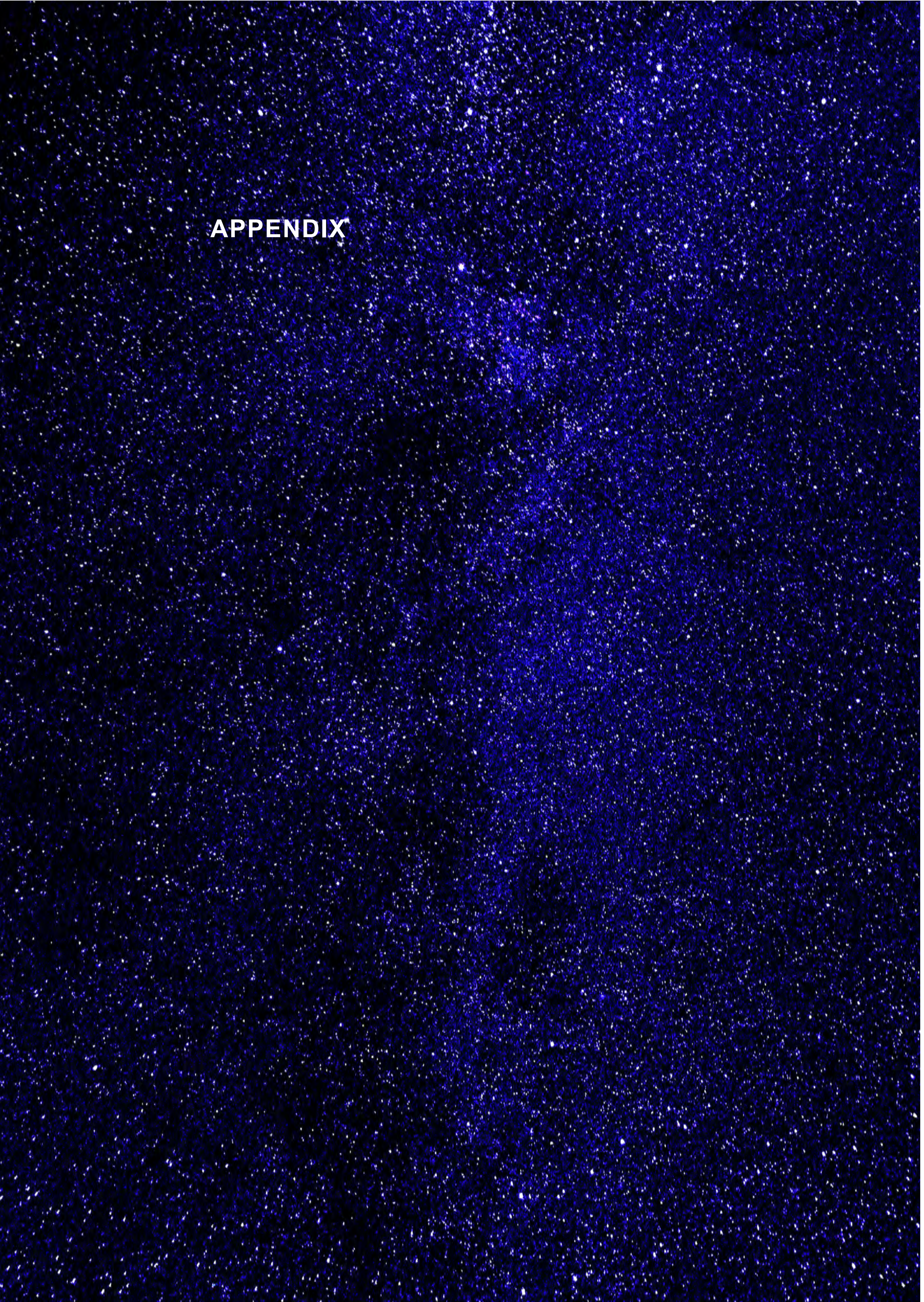


APPENDIX

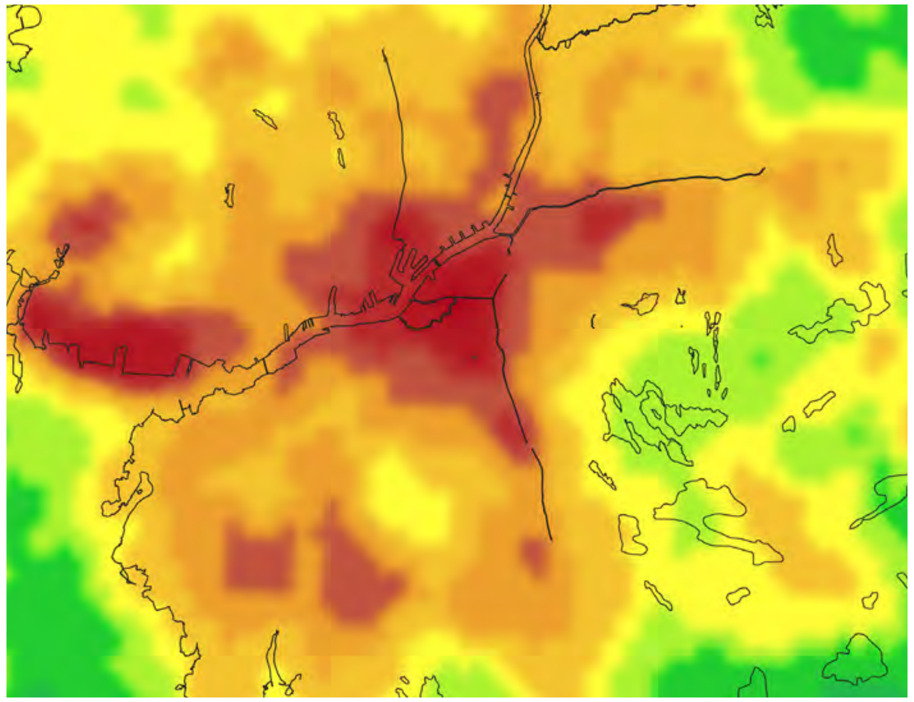
Exhibition

Thesis at display on the physical exhibition at Chalmers school of Architecture May 30th - June 7th 2022.

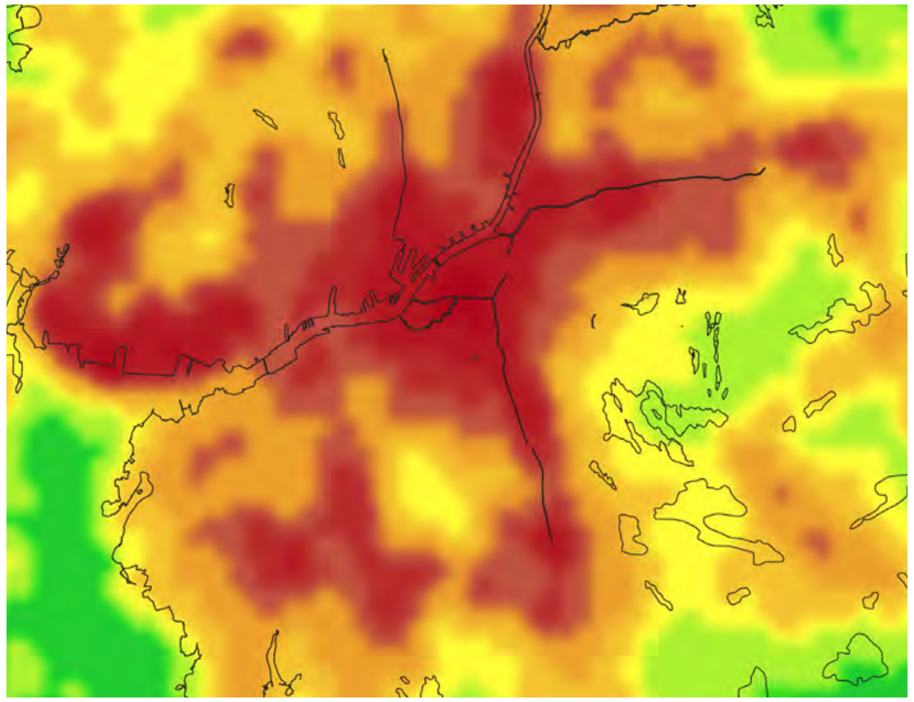
Light pollution map base

2012

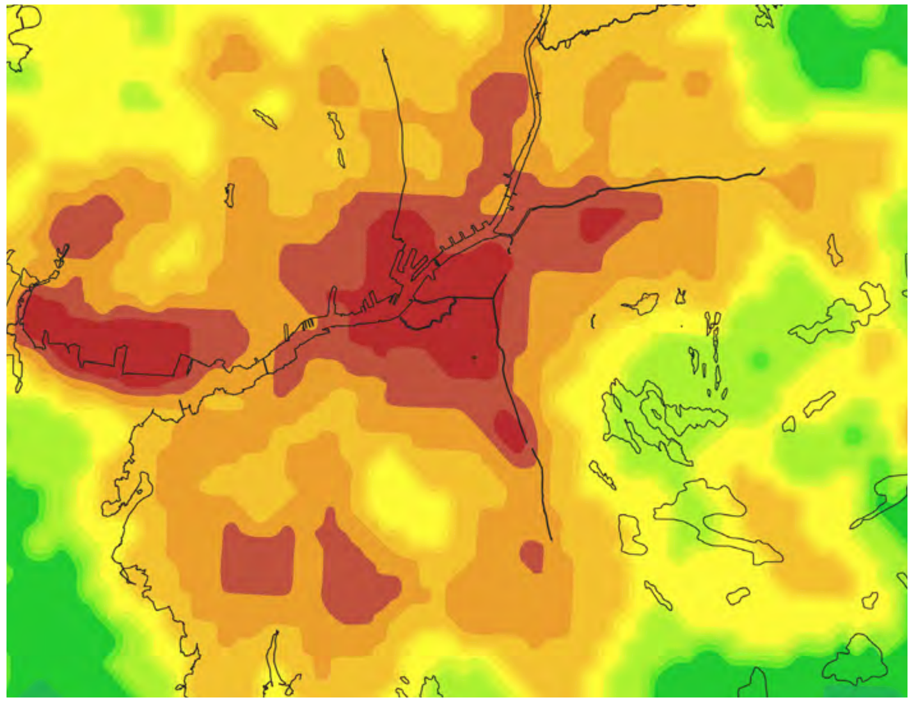
Light pollution map from website.

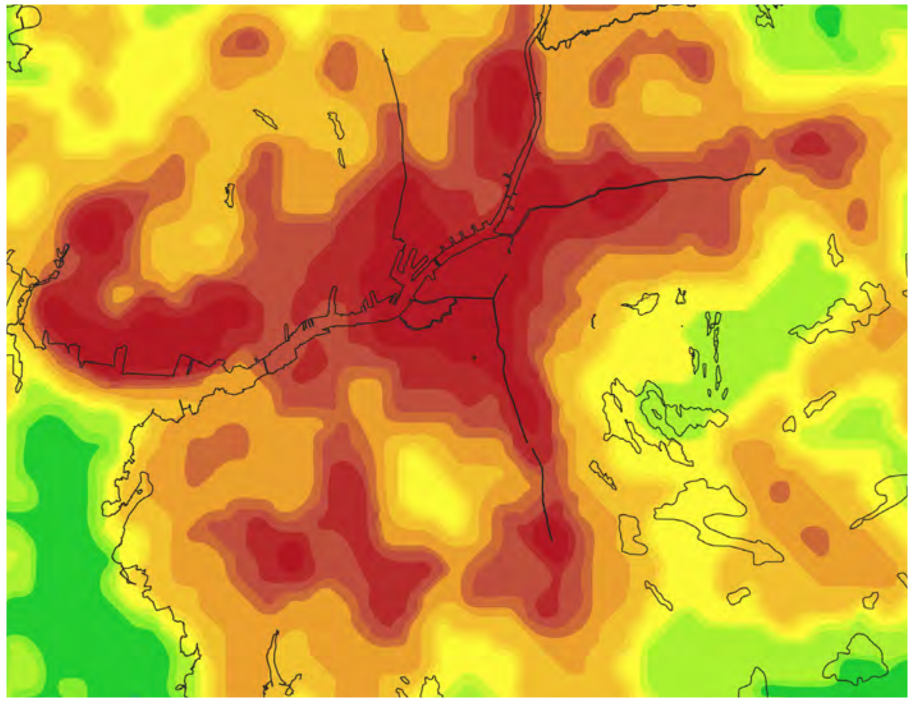


2021 (data used in thesis)



Vectorization of map in Illustrator using the tool "image trace".

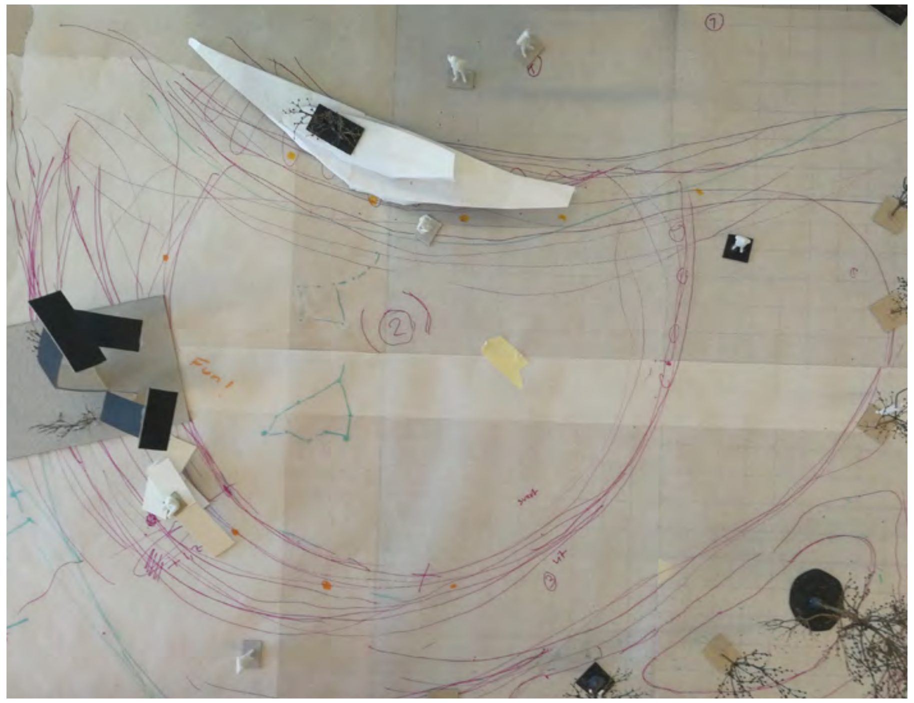




If the 2012 and 2021 data are compared, it is clear that the light pollution has increased.

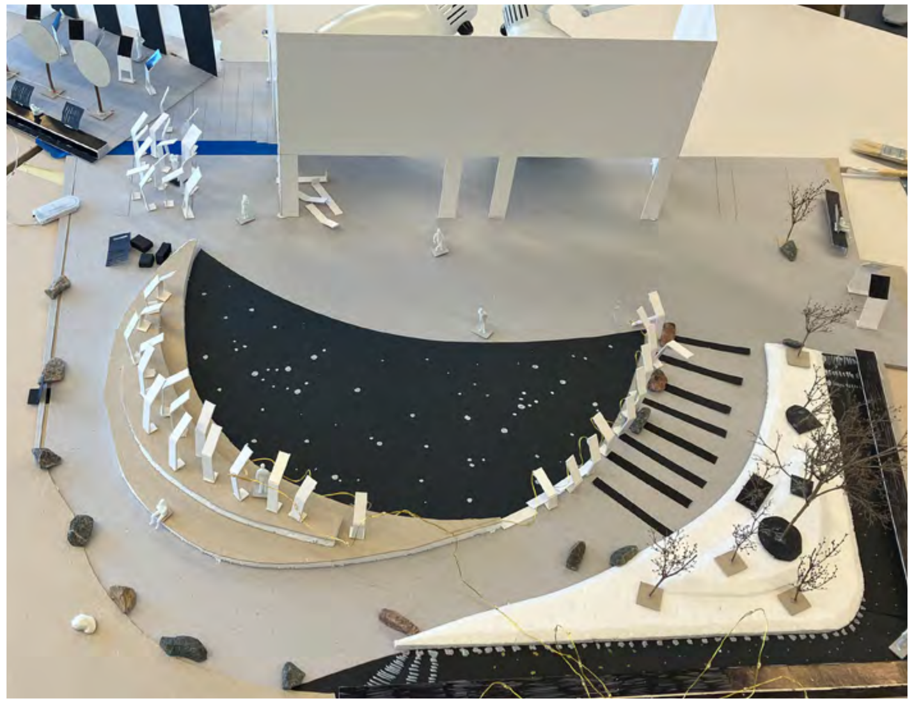
Site scale process selection

Sketch from site scale before model making. Trying out placement of objects.



Process photo of the model. The screens are placed on the seating area and in a cluster by the side of the building. These were later removed.

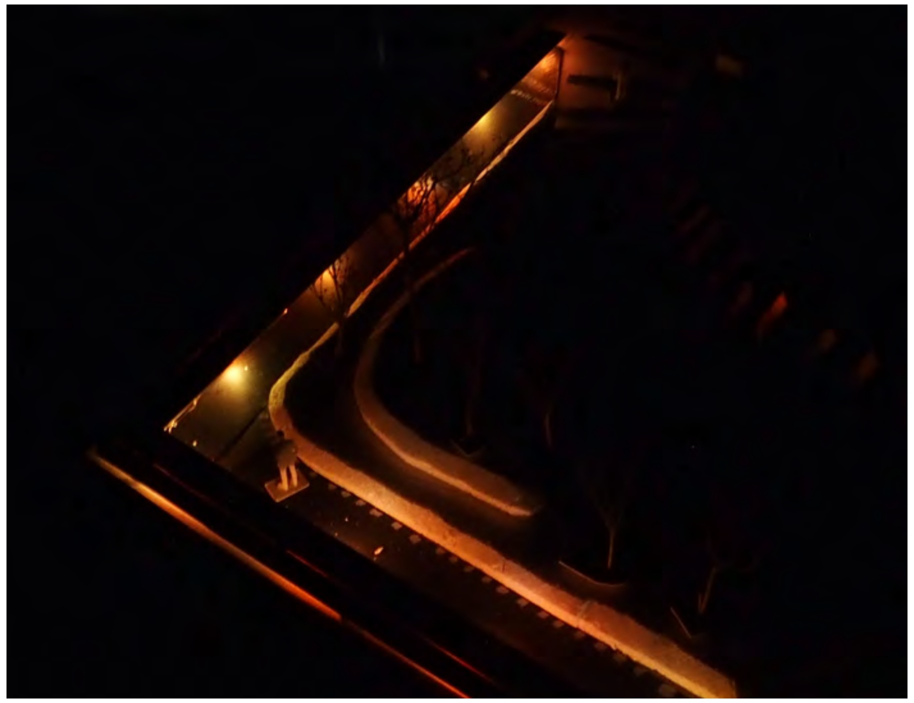
Stones indicate the placement of artificial light and dark stripes on the ground mimicking the shadows during daytime.



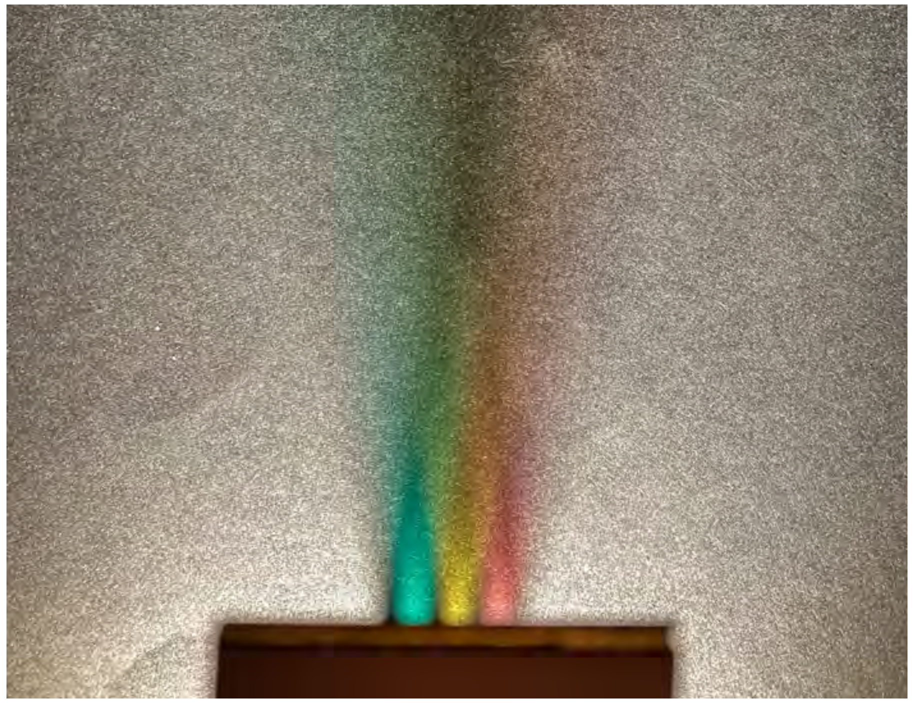
View from the side of the building looking towards the water. Smaller versions of the screen with different surface materials were tested.

View from the bridge. Objects are placed in the middle to create two lanes. The end of the bridge is marked with an arc.

Photo of the dark corner with only the red light on.



Experiment with colorful glass in the bottom of the screen.



An early version of the screens. Lower and without the transparent bottom part.

The trees on the green wedge can be seen in the background.

View from the bridge with the arc at the end. The light from the building is the only one that is on.

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