Lighting in an Urban Environment with the Consideration of Biodiversity.

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ABSTRACT

This thesis investigates how we can bring adequate and appropriate lighting design into urban green areas to enhance humans' wellbeing and reduce the negative impact of the current relentless lighting on biodiversity. Considering the importance of our connection with nature and the darkness within, searching for a lighting solution for both nocturnal species and humans that reduces the external impacts on the natural habitat. Throughout an extensive literature review, site analysis of JC. Jacobsen Have, including my observations inspired by Pallasmaa along with deductive research approach, a holistic lighting design framework has been created. In the light of this framework, CCT levels, SPD, light intensity are the measurements that have been mainly taken from urban green areas in Copenhagen, for an extensive analysis. The design proposal visualises how can lighting be inviting for people, harmonising with nature and taking the fragile balance between humans and nature into consideration.

READER'S GUIDE

Citations

Citations are made using Hybi11 Amigo Light font and appears at the end of sentences with the author or publisher, the year of release and the page number if relevant.

Example: (Wilson, 1983 p. 139).

Citations are listed in the Bibliography in alphabetical order.

Chapter or section references

References to a specific chapter or section appears in *grey italic*.

Example: As described in Section *3.7. Electric lightings impact on the ecosystem*

Quotes

Quotation marks, written in blue italic identify quotes

Example: *"We find beauty not in the thing itself but in the patterns of shadows, the light and the darkness, that one thing against another creates." - Jun'ichirō Tanizaki.*

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1. Introduction

1.1. General introduction

The last one and a half year have been challenging for humanity, especially for people living in cities. Our life has completely changed from one week to the other in march 2020. The Coronavirus reached Europe in dimensions that not many anticipated. The sudden shift in our daily routine was radical. We were not used to limitations such as having access to certain activities, areas or socialise life. Many things that granted a healthy state of mind have been taken away from us. All of a sudden, we found ourselves in a lockdown, staying home alone for several days. Trying to continue living our life, we adapted to the new norms. After work or studying, we tried to follow our daily routine such as working out, spending time with friends and family etc. but in a new context. As restaurants, bars, libraries, museums, and gyms were not accessible anymore, we rediscovered our urban green areas.
However, many of these urban nature areas became overcrowded, and they could only be used under special rules and restrictions. For instance, such rules included implementing one-way walking routes and a social distancing requirement of keeping at least two meters distance between individuals.
To support recreational activities and other outdoor activities, it became clear that having access to more green areas all year round is necessary. Furthermore, time spent in areas surrounded by nature has a positive impact on mental health and anxiety. (Bewley, 2019)

Everyone could see a stunning starry night sky less than a century ago. However, nowadays, millions of children worldwide will no longer be able to see the Milky

Way. Moreover, the widespread use of electric lighting at night not only distorts our perception of the universe but also has negative consequences for our environment, health, energy consumption and safety.
Furthermore, light pollution affects 88 percent of Europe and nearly half of the United States at night. (Travis Longcore, 2016) The consequences of losing this inspiring natural phenomenon might appear uncertain.

1.2. Personal interest

Since I started my master studies, I got familiar with terms as light pollution or light effects on surrounding nature, etc. Beforehand, I wasn't considering these factors as key elements such as the air, water, and land pollution responsible for many negative changes in our ecosystem.
Over the past year, I gained a more in-depth knowledge of practical lighting design by closely working with municipalities and private clients. I experienced that some entrepreneurial municipalities are considering moving forward to discussions about more "nature-friendly" lighting compared to known conventional solutions. However, as this approach to lighting was only recently considered, we, lighting designers, lack some knowledge about the light effect on biodiversity. The whole practice becomes experimental regarding fixtures allocation, intensity, or light's colour on the spectrum. There is an increasing demand from municipalities to move forward to a more sustainable lighting solution in our urban environment.

1.3. Thesis Structure

Following the thread of my thoughts, I start this paper with my findings of the impact on being in nature, how we perceive darkness and its meaning. Then, my focus is shifting forward to how light affects the surrounding nature, animals and especially bats. After all, I'm looking into how lighting can fulfil basic human needs and create an atmosphere that harmonises with the surrounding nature and has minimal impact.

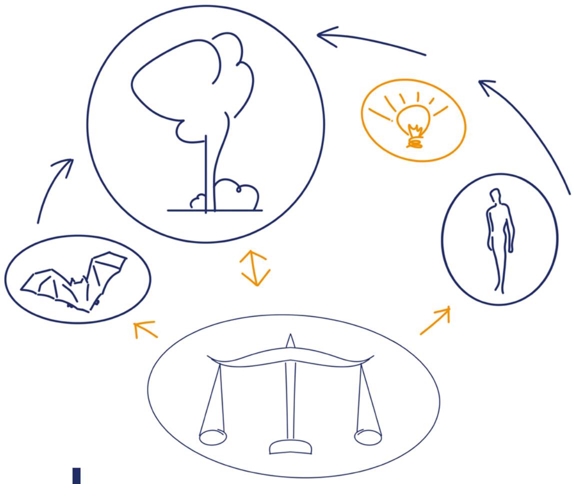


Figure 1
Sketch of mind map
(Personal archive)

1.4. Initial Problem Statement

Based on my previous experience, I conducted an experiment to assess how lighting design guidelines and recommendations could enhance the sense of atmosphere within an inviting space while reducing the negative impacts of lighting on biodiversity. To conduct this study and analyse the experiment results, I used a transdisciplinary approach combining the disciplines of architecture, light engineering, and media technology.
The initial problem statement for my research may be formulated as follows:

How can outdoor lighting meet humans' (biological) need for experiencing nature in urban green areas during dark hours with limited negative impacting biodiversity?

In this context, human (biological) needs means orientation, physical security, relaxation of the body and mind, adjustment of the biological clock, contact with nature and with other living beings, definition of personal territory. (Lam, 1977)
In this thesis, urban green areas are defined as places within cities where plants and animals are both present; furthermore, these places are habitats of some

species. Time spent in green areas would fulfil some of our needs such as recreation or various other outdoor activities.

Biodiversity refers to the variety of life on Earth at all levels, from genes to ecosystems, and can encompass the evolutionary, ecological, and cultural processes that sustain life. (AMNH) Due to resource and time limitations, I narrowed the scope of biodiversity down, and my thesis focuses on bats' presence in urban areas.

Chapter 2

Methodology

2. Methodology

This thesis investigates how to design lighting for natural environments within an urban setting, considering both human and biodiversity aspects. Throughout the study, new knowledge was developed that can act as inspiration for practical design principles. The framework of the applied method is The Design Experiment Model (Hansen, et al., 2014). In this transdisciplinary method, the design process relies on the thorough integration and combination of different scientific fields.

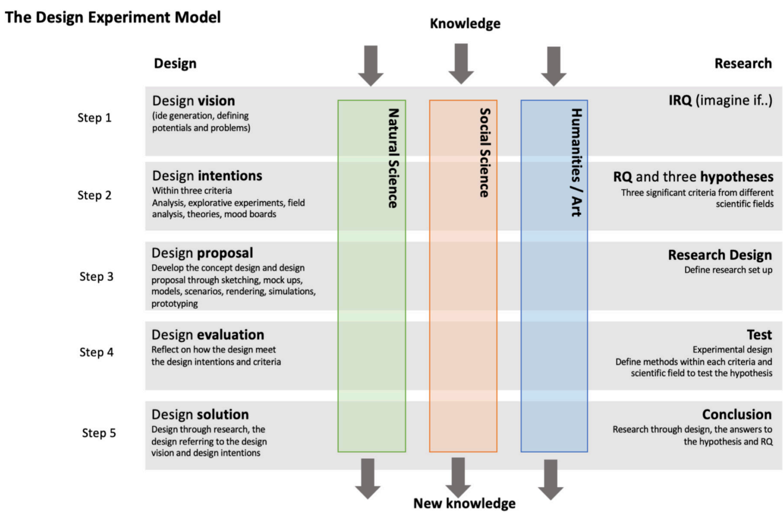


Figure 2
The Design Experiment Model
(Hansen, E. K., Hvass M. based on Hansen, et al., 2014)

It comprises five stages throughout the development: Design vision, Design intention, Design proposal, Design evaluation and Design solution. Three main criteria approach these as Social Science, Natural Science and Humanities. Each stage will be introduced one at a time as the design evolves organically.

Transdisciplinary

Go beyond the disciplines, not starting within any particular discipline but with a problem or issue, then bringing various disciplines to solve the problem or address the issue – knowledge is transformed. (Klein, 2015)

Design vision

The Design Vision precedes the development process. This stage consists of the background knowledge and experience I gained from my work at Light Bureau, which is the basis of this research. It also defines the challenges and the potentials that function as drivers for the entire process. The introduction of challenges and potential conclusions serves to define the initial research question. In this stage of the process, I got familiar with the applied lighting solutions in urban green areas in Copenhagen by walking on-site at night. I learned about lighting solutions that are more concerned about nature than conventional lighting (Signify Holding B.V., 2018). I observed the chosen site to gain a better understanding of how people use the space and what is its ecosystem be like.

Design intentions

Within the Design Intention stage, the design process integrates theoretical literature review about people's need for nature, their approach to darkness, biophilia and mental health by combining scientific reports about electric light's effect on certain species, human eye adaptation and light pollution. It integrates my field analysis of JC. Jacobsen Have and Søndermarken. On the sites, I used myself as an observer following Pallasmaa's method of observation; using multiple senses to experience the space, the way it looks, it feels, smell and sound. (Pallasma, 2005) The initial research question develops into its final form once three design criteria are created, based on knowledge from the three scientific areas, using different methods that guide throughout the process. Based on the research question, the hypothesis is defined and used to validate the three criteria in the design.

Design proposal

In this stage of the design process, the criteria develop into design parameters and a preliminary lighting design solution using theoretical and built references. Initial design solutions are created and validated by the combination of the three defined criteria. It follows the evaluation of the chosen method and the design revision to meet the design vision, research question and criteria. At this stage, I justify if my design fulfils the requirements of the three criteria and the research question.

Design evaluation

The evaluation stage of the design process covers the test of the essential elements related to how design meets the intention, criteria and research question. Obtaining various information from qualitative and quantitative measurements drives the conclusion of the hypothesis. The evaluation refers back to the research question, and it is a measure of whether the design fulfils the success criteria. Based on the deductive research approach, I created a 3D simulation, conducted on-site light testing, and used mixed methods research. Such a strategy requires a combination of both quantitative and qualitative methods (Bryman, 2016). With these elements, I can justify my design and compare it to recommendations and draw my conclusion about people's opinion from the light testing.

Design solution

From the previously created design proposal, I argue about how the design and findings meet the design vision, criteria, research question, hypothesis and the overall topic of this thesis.

Limitation

This thesis was written during the lockdown period of the COVID-19 pandemic, which delayed conducting my light test on-site and reaching out to professionals (Jens Rydell, who sadly passed away on the 8th of April and Hans J. Baagøe). This limitation delayed the development of the thesis and influenced my findings of the bat population in Scandinavia. Furthermore, due to the circumstances of the lockdown, the university's grounds were not accessible, which hindered me from having access to the Light Lab at the phase of determination of the final colour of my lighting solution.

My aim with this test would have been to understand human perception and bodily experience better.

Chapter 3
Theories

3. Theoretical Framework

3.1 Literature review

In this chapter, I gather knowledge from various study fields, intending to combine them and formulate a set of theoretical criteria. I began by analysing the importance of having access to nature, green areas in an urban context and its positive effects on mental health and mood. It follows by analysing the indoor generation's difficulties reconnecting to nature and mental disease that possibly have been enhanced by the lack of this connection. The following section describes the perception of darkness through our recent history and the importance of preserving darkness in an urban environment. By continuing the thread, I'm focusing on the human eye's dark adaptation to understand how we physically perceive the darkness. Until now, we understand that having access to green areas after dark, we need some kind of lighting to find it comforting and safe. Hence, the focus moves further to understand both natural and electric light effects on animals and plants. It follows the analysis of insects and bats perception of electric lighting. At last, this chapter talks about light pollution, the encouraging initiative of The Dark Sky Association and their aims to preserve the dark sky and the relevent UN sustainable goals.

3.1.1 Biophilia, care for nature

"...the particular way we affiliate with other organisms. They are the matrix in which the human mind originated and is permanently rooted, and they offer the challenge and freedom innately sought" (Wilson, 1983 p. 139)

Biophilia is a type of compassion shown to nonhuman living beings in general, whether wild or domesticated (natural or unnatural), and a wide range of biological species. It's related to our aspirations for the healthy, free development and life of our plants and pets. Still, it also refers to people's universal urge to care for the diversity of living creatures and their activities. Care about nature requires care about the Earth itself in a way, and we need a better way of caring about the natural surroundings than simply caring about its life. On the other hand, biophilia is an essential pathway for many individuals to develop fundamental care for nature. (Brown, 2017)

Figure 3-Biophilia, Khoo Teck Puat Hospital, Singapore
(The Death of Modern Hospital: Towards a restorative healthcare architecture, 2018)

What makes a city biophilic? Different cities in various parts of the world have other qualities, different paces of life. Biophilia in cities can be compared based on active efforts throughout a city to restore and repair ecosystems and to manage the built environment so as to support the local flora and fauna (e.g. Chicago's "lights out" program, where high rise buildings' lights were turned off during the critical period of bird migration), investments in education about local flora and fauna, support for programs to involve citizens in active, hands-on habitat repair and restoration. However, it's still a question, how to nurture biophilia sensibility in cities. (Stephen R. Kellert, 2008 p. 292)

Community gardens, spaces for gathering and meadows are all important to organise urban life around nature. But we should not forget about making people understand their place in the world more deeply and connecting with other people and creatures. More thought should be given to building and supporting a feeling of natural wonder in our neighbourhoods and living spaces. The task is to educate and engage our community in appreciating and celebrating the natural nature around them. (Stephen R. Kellert, 2008 p. 288)

3.1.2. Healthy state of mind

People of our age live a different lifestyle at its core than what our parents had 30-40 years ago. Multiple days can pass by without leaving our homes, especially during the past year (2020), but the tendency to spend time indoors was already increasing in the first decade of the 21st century (Bewley, 2019). This lifestyle relies on services that didn't exist a generation ago, amenities that have become part of our daily routine permanently. For example, a wide selection of online entertainment, multiplayer video games, online shopping, affordable daily food delivery, online lectures and meetings became recently available. Since introducing these new technologies, we no longer need to go to the cinema to watch a blockbuster movie, visit a grocery store to get food or go to a retail store to buy clothes.

Given the circumstances of the COVID-19 pandemic, we learned new ways of expression driven by social distancing, self-isolation, obligatory mask rules. They were brought into our life and daily vocabulary as a means of protection for our body to survive. By following these restrictions, our body might be protected from the virus, but what of our mental health? Since the pandemic began, we adopted new standards into our lives. We found alternative ways to fulfil our "old" standards as it concerns our social lives, physical activities, work, study, travel, and even dating.

We all experienced the limitation of our living environment. We work from home, study from home, have meals continuously at home, have friends over at home, working out at home. The increase of individual activities helps to reduce the fear of missing out. However, boredom and the feeling of loneliness are now present in many lives daily. Binge-watching TV programs occasionally feel pointless and

can quickly become monotonous. The inability to differentiate between boredom and depression leads to a more significant problem. It became harder to separate the absence of interest from the failure to express interest. With COVID-boredom, the absence of interest is exaggerated to the point where everyday life appears like an eternal existential discomfort. (Gardiner, et al., 2017) (Boylan, et al., 2020)
We aim to escape from this monotonous and dull reality when the days, weeks and months blend together, and we lose track of time. One way to find some peace and time to think is by being in nature, away from stressful environments, which can be our home, school, work or all of those places at the same time. Time spent in a natural environment stimulates the brain differently than a computer screen or being between walls. Contact with nature has various psychological benefits, and it can reduce stress (Thompson, et al., 2011), anxiety and depression (Beyer, et al., 2014), improve mood, social relations (Francesca, et al., 2020) and provide a healthier state of mind in the long term. (Taylor, et al., 2008)

Furthermore, green environments can restore exhausted resources like attention, and it can help people struggling with Attention Deficit Hyperactivity Disorder (ADHD). (Francesca, et al., 2020) ADHD is a neurological disease that many people associate with childhood. (Rösler, et al., 2010) The number of children diagnosed with ADHD between 1997 and 2002 increased by 33%, stated by Richard Louv (Louv, 2005). One suspected cause of ADHD symptoms is overstimulation from television or computer screens. (Watters, et al., 2017) Richard Louv claims that ADHD is closely related to "Nature Deficit Disorder" in the matters of social, psychological, and physical health and describes the phenomenon of children spending less time outside and having more behavioural problems. (Louv, 2005) Furthermore, studies revealed that ADHD could persist regardless of age through adulthood as well. (Faraone, et al., 2006)

Spending time in nature, whether it's sitting in a park, watching a sunset, travelling to the countryside, gazing at mountains or the ocean, or simply staring out the window, allows us to rest, contemplate, and restore our very selves. In a nutshell, Attention Restoration Theory, or ART, suggests that exposure to nature can help to restore people's attention. Eric Jaffe describes Attention Restoration Theory (Kaplan, et al., 1989) with the following words:

“The most significant understanding of nature’s salutary effect on the human mind has come through studies of attention. The foundation of this work is the Attention Restoration Theory, or A.R.T., set forth by APS Fellow Stephen Kaplan of the University of Michigan. The theory originated in the 1980s, says Kaplan, when he, APS Fellow Rachel Kaplan, and some of their students noticed that people had an astounding preference for scenes depicting natural environments. Kaplan and his collaborators soon discovered there was much more to nature than just a pretty face — they found that exposure to these scenes had a profound restorative effect on the brain’s ability to focus.” (This Side of Paradise, 2010)

Exposure to natural environments, according to ART, supports more effortless brain function, allowing it to recover and recharge its directed attention capacity. According to Kaplan, in order to have this therapeutic impact, the natural environment must have four characteristics:

- Being away (providing an escape from habitual activities)
- Other Worlds and the Concept of Extent (the scope to feel immersed in the environment)
- Fascination (aspects of the environment that capture attention effortlessly)
- Action and Compatibility (individuals must want to be exposed to, and appreciate, the environment) (Kaplan, et al., 1989)

Figure 4
Cafe Terrace at Night, painting
(Vincent van Gogh. 1888)

Considering that natural settings can improve our attention, problem-solving skills, positive emotions, and stress reduction, our connection to nature should be neglected, in general, would be a strong reason in favour of havin access to more urban green areas day and night.

3.1.3. Meaning of darkness

The perception of the night has thoroughly changed during

industrialisation in the nineteenth century. The introduction of gas and later electric light, in particular, required a radical rethinking of earlier nighttime attitudes. New requirements for the night led attempts to defeat the dark and conquer our environment through illumination, influencing circadian cycles artificially. For the first time, the night entered the public perception as an anonymous domain evoking frightening thoughts as urban life grew increasingly common. (Dunn, 2016 p. 47)
In our era of rapid technological development, the connection between people and the urban landscape is at risk. The available limitless information presented on a portable screen controls our life from the moment we wake up until we return to bed throughout the day. It tells us where to go, who to talk to, what to see or what to do, act to mediate our relationship with the city, distancing us from physical realities.
Walking into the night might help you restore some of what you've lost; it is possible to decrease the anxieties and weight of responsibilities. It is a quiet act against the monotony of the daily grind. A night walk, for one, refreshes the continual distracting character of the daylight hours, going beyond the evening's opaque borders, in a powerful way, the experiencing diversity of a far bigger universe than that which exists during the daytime. So, beyond individual psychological independence, what may the benefits of strolling at night be? (Dunn, 2016 p. 48)
Separating fear and darkness is not a small task, as darkness often described as dangerous and dramatic either in fiction or reality. Is it possible to look at the darkness positively? It's undoubtedly worth reconsidering our sense of it as something other than the absence of light. (Dunn, 2016 p. 54)

"There is something positive about it. While light space is eliminated by the materiality of objects, darkness is "filled," it touches the individual directly, envelops him, penetrates him, and even passes through him..."
(Caillois, 1987 p. 72)

The use of electric lighting enables the night to function similarly to the day and interfere with its true character. Schlör points to the direction of the night's fundamental essence, as it tells how the city is, how the "the whole" functions and as only the night represents the past, the myth in the city of the present. (Schlör, 2013 p. 242) Night walking is such a rich and multi-sensory experience because of

its magic of memory, presence, and attention. Only in limited areas, at the border of the urban landscape, has the body's ability to be entirely surrounded in the night. (Dunn, 2016 p. 67) Several positive aspects such as the improvement of creativity, thoughts, peace in mind and simply pleasure are often combined during a night walk. It enables breaking out from the "non-stop inertia" that define our lives. (Dunn, 2016 p. 68) As a result, night walking might be viewed as one approach for the body to find a more balanced relationship with its surroundings. It allows the awake to enjoy and maximize what is generally regarded as time lost. It also reconnects us with who we are and when we were born, providing a meditative space and time for reflection while allowing biological predispositions to take centre stage. Walking late at night not only clears the mind but also introduces new bodily sensations.
Cities are changing, the collective reclaim of the urban night is crucial, perhaps more so than ever before. To accomplish it, we have to start by relying on our own personal night walking experiences. (Dunn, 2016 p. 94)

3.1.4. Human perception

The widespread use of electric lighting at night has improved the quality of human life and is positively correlated with security, wealth, and modernity. Over the last six decades, the rapid global increase in electric light has radically transformed nightscapes, both in quantity (6 percent increase per year, range: 0–20 percent) and quality (i.e. colour spectra) (Hölker, et al., 2010).

Human eye adaptation to darkness

The human eye can see in a broad spectrum of light levels. Dark adaptation refers to the process by which the eye regains its sensitivity in the dark after being exposed to bright lighting (Aubert, 1865). When there is enough light, cones perform well. Colour vision is the ability to respond to different hues of light. When the light is bright enough, they allow seeing fine detail. Rods, on the other hand, are significantly more light-sensitive and unable to distinguish between hues. When needed, they also pool their reactions, making the eye more sensitive to light and making it difficult to detect small details.

We enter mesopic vision when we switch from a dark to a brighter environment or the other way. Cones adapt quickly, usually within minutes, whereas rods might take to 20 minutes to one hour to adjust to the change in lighting, which is why scotopic vision takes longer to activate than photopic vision (Gordon, 2015). The Duplicity Theory claims that above a specific brightness level (approximately 0.03 cd/m2), the cone mechanism controls vision; photopic vision (Stabell, 2009). The rod mechanism goes in below this threshold, allowing for scotopic (night) vision.

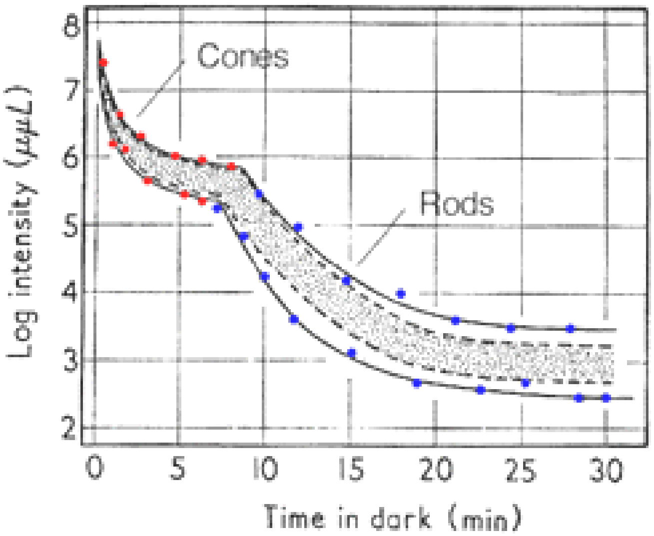


Figure 5
Dark adaptation curve.
(Pirenne, 1962)

The eye continuously adapts to the highest level of illuminance in the field of view, activating rods and cones. The pupil shrinks or expands in response to the amount of light that enters the eye, allowing the photoreceptors to adapt. Our eyes can perceive details within this range, but anything above or below it becomes gradually difficult. Moving from brighter to darker areas, our eyes and vision adapt to the specific lighting conditions by the continuous oscillation of rods and cones (Tregenza, et al., 2013). As the human eye adapts to the brightest light level, our vision is extremely sensitive in the dark; however, light fixtures that create glare or high contrast levels reduce the ability to see in the dark. Glare is more than just bright light; it is a high luminance level that enters the eye at a specific angle, causing extreme luminance in our normal field of view (Gordon, 2015).

The eye can adapt to darkness; with the right light height and position, we can enhance our perception of dark

3.1.5. Circadian circle and Photoperiodic Anticipation

Circadian rhythm

The circadian rhythms are the biological rhythms of almost all species, including plants. It is ruled by a constant biological clock, allowing species to prepare for changes in their surroundings instead of just reacting to them, such as sunset or sunrise. (Brody, 2013) The circadian rhythm is a system under nature's 24 hours rhythm. However, it is not driven by the environmental time cues but the light and darkness. (Andrew N. Coogan, 2016). It regulates physiological processes such as sleeping and feeding pattern, brain wave activity, hormone production, other biological activities related to the daily cycle. (David C. Klein, 1991)

Both humans and rodents have rods, cones and a third type of photoreceptor, called photosensitive retina ganglion cells(ipRGCs). The light enters through the eye and reaches the retina, where the photoreceptors are located, including the ganglion cells (ipRGCs). Some brain areas receive direct input from ipRGCs, such as the circadian rhythm generator (master clock) the suprachiasmatic nucleus of the hypothalamus (SCN) that stimulates the circadian rhythm. The SCN transmit the time-of-day signal to other parts of the brain areas, including the pineal gland. (Giulia Fleury, 2020) The measurement of the circadian timing system is mainly based on melatonin production. (Boyce, 2014) During the dark period of the 24-hour light-dark cycle, the pineal gland synthesises and secretes the hormone melatonin. Therefore, melatonin is quickly absorbed into the bloodstream, serves as a chemical courier in many parts of the body. Melatonin receptors are present throughout the body in both animals and humans, and they detect melatonin as a message of darkness. The melatonin's primary purpose is to synchronise many other physiological processes throughout the 24-hour period. (Boyce, 2014)

Photoperiodism

The length of a day (daylit hours) changes throughout the year; however, it periodically repeats every 12th months. The circadian clock allows species to keep track of changes in their surroundings regularly. While the photoperiodic timer will enable species to predict and plan for seasonal variations ahead of time as migration, dormancy, development, or reproduction. (Bradshaw, et al., 2010). Photoperiodism is the ability of animals and plants to determine the duration of the day by measuring the length of the night. (Borniger, et al., 2017)

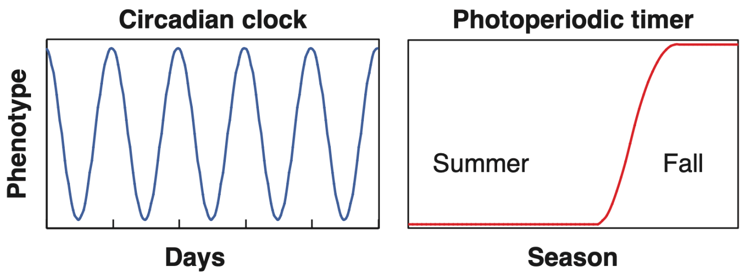


Figure 6
Properties of the daily circadian clock and the seasonal photoperiodic timer. The circadian clock cycles and can be reset on a day-to-day basis; the photoperiodic timer acts as a go/ no-go physiological switch that, once flipped, initiates a cascade of events that runs to completion and is irreversible in a seasonal, annual, or lifetime context."
(Bradshaw, et al., 2010)

The entrainment of the circadian clock occurs daily, while the photoperiodic response, once initiated, is permanent within a seasonal context or even over a lifetime. (Nijhout, 1994) The circadian clock does not count light-dark cycles. The photoperiodic counter counts and accumulates light-dark cycles previously perceived as long or short by the photoperiodic timer. When a certain number of inductive cycles are exceeded, the photoperiodic timer then activates the subsequent physiological reaction. (Saunders, 1981, 2021)

This knowledge is valuable for us lighting designers as electric lighting can be controlled and avoid unnecessary alteration of the natural surroundings; electric light can be used when animals and plants are the least sensitive.

3.1.6. Electric lightings impact on the ecosystem

Plants use light as a source of both energy and information. Plant physiological responses to light, as well as plant-animal interactions, have evolved a 24-hour cycle of light and darkness, as well as seasonal variation in day length. Over the last century, outdoor electric lighting has caused unprecedented disruption to natural light cycles.

In many cases, electric light is sufficient enough to induce a physiological response in plants, affecting their phenology, growth and resource allocation. (Bennie, et al., 2016)

Ecological systems are organized foremost by light, particularly by daily and seasonal light and dark cycles. (Bradshaw, et al., 2010) Electric lighting's effects on the biosphere are rarely discussed, but many of them are expected to be harmful.

3.1.7. Insects

For a long time, insects' attraction to light has been a well-known phenomenon. (Ingpen, 1839) However, the relentless increase of night sky brightness has been recognised over the last decades. (Garstang, 2004) Understanding which part of the colour spectrum of the light attracts insects is critical for selecting or developing new light sources that have the least negative impact on insects. (Travis Longcore, 2016) According to research (Langevelde, et al., 2011), most moths are drawn to light sources that emit more short-wavelength light, whereas long-wavelength light is less attractive. (Eisenbeis, et al., 2010)

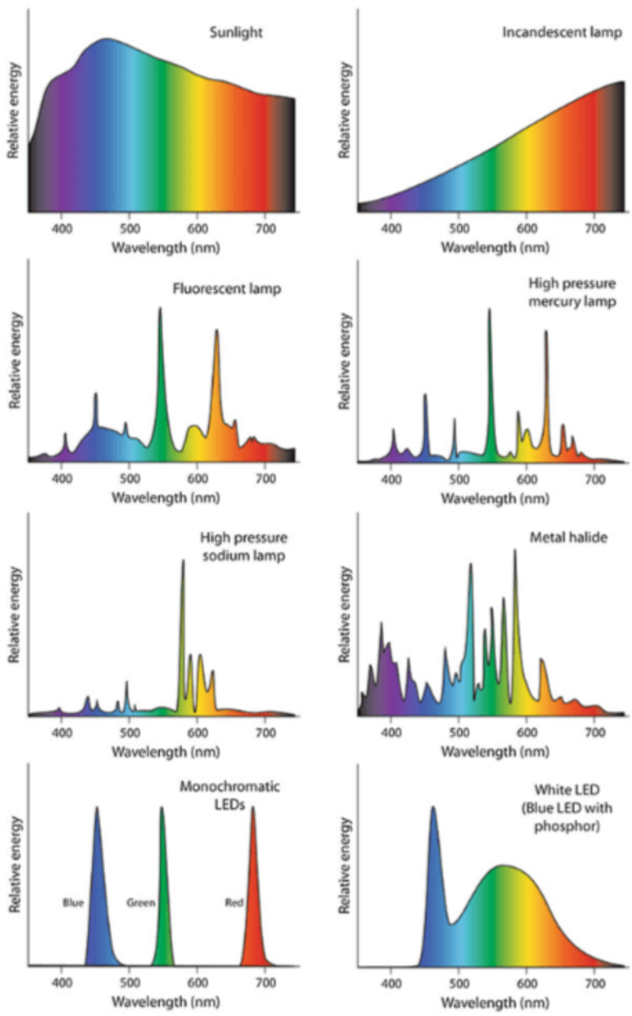


Figure 7
Spectral Power Distribution of different light sources
(Gupta, et al., 2017)

The effect of electric light on nocturnal flora and fauna is likely to increase. (Gaston, et al., 2012) However, to fully understand the consequences of this shift and assess light sources for their potential attractiveness to nocturnal insects, more comprehensive spectral responses are needed. (Eisenbeis, et al., 2000)

3.1.8. Bats

Why bats matter?

Bats are an essential part of our native wildlife, and they play a crucial role in a variety of ecosystems throughout the world. Some plants rely on bats to pollinate their blossoms or distribute their seeds in part or entirely, while others need bats to manage pests by eating insects. Some bats are recognized as 'indicator species' because changes in their populations can indicate changes in biodiversity. Bats may be harmed if there are insect population problems (since bats eat insects) or if habitats are destroyed or inadequately managed (for example, some bats only live in extensive woodlands). (Gaston, et al., 2012)

There are over 1400 species of bats in the world, and they account for around 20% of mammal species worldwide. Throughout the year, bats feed, rest, and travel in a range of landscapes or habitats. The majority of bat species use echolocation to find prey in the dark and collect information about their surroundings. Bats use commuting habitats to travel between roosts and foraging habitats and hunting grounds or foraging habitats to find food. This is why it's essential to preserve landscapes "bat-friendly". As bats eat insects, they look for places to hunt, such as waterways, woods or grassland. Some species are willing to travel further, seeking the habitat they prey on (Verboom, 1998 pp. 7, 21). Bats can return to their roost after they've been moved to a location that might be out of their home range, as landmarks and elements of space are stored in their cognitive space map. A special memory based on acoustic and visual cues. (Verboom, 1998 p. 73) The examination of Hans J. Baagøe about the general flight height of the Danish bat species in both foraging and commuting phases explains that the majority of them are flying between ground level and 10 meters. (Baagøe, 1991) Furthermore,

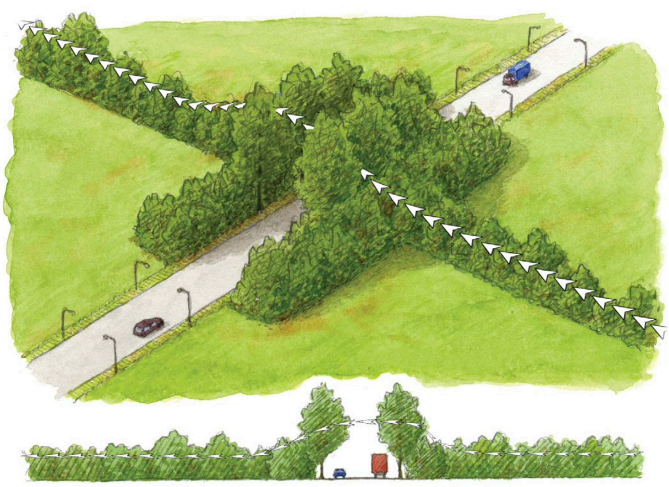


Figure 8. The so-called hop-over offers a safe crossing of roads for bats. (Møller, et al., 2011)

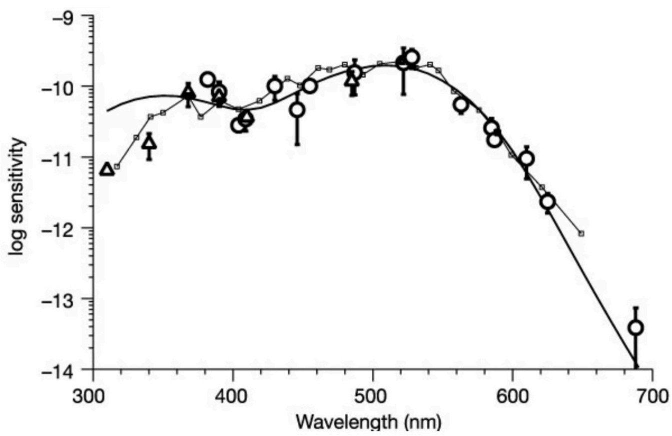


Figure 9. Spectral sensitivity of the bat Glossophaga soricina (Winter, et al., 2003)

it's relevant to know how close some species fly to vegetation, walls or buildings. (Møller, et al., 2011).

Bats commonly roost in buildings in urban areas; however, they forage in green spaces such as gardens, allotments, parks, and ponds. They commute following hedgerows, tree-lined footpaths and other linear features as a corridor from one area to another. These features act as navigational landmarks and offer protection from predators. They may be cut off from their habitat if roads or towering buildings separate their commuting routes, and hunting and survival for them will be challenging. (Hourigan, et al., 2006)
Most bats spend the winter in hibernation from November till February. During this period, they aren't as sensitive to light differences as during their active period of the year. However, they quickly sense if the ambient temperature rises. (Haarsma, et al., 2012) They usually fly out from their roost after dusk searching for food and water in their active period. A few hours later, most likely, they return and sleep the rest of the night. (McClosky, 2012)

3.1.9. Electric lighting impact on bats

Bats are nocturnal animals adapted to live in the dark, partially to avoid predation by birds of prey during the day. Bats use the natural light and dark cycle as a signal to time their activities in accordance with their surroundings. (Gaston, et al., 2012) Generally, nocturnal mammals have large pupils to receive light, large lenses to decrease spherical aberration and retinas controlled by rod cells. (Walls, 1942)
Many bats have ultraviolet-sensitive cones that help them in navigating during transition hours and avoiding predators. Hence, bats are more active around dusk and dawn than the rest of the night, although the peak activity varies by species. (Müller, et al., 2009) Electric lighting has various effects on bat behaviour, both beneficial and harmful depending on the species. (Spoelstra, et al., 2017) Insects

attracted to light help light-opportunistic species, which browse around lit up areas. (Longcore, et al., 2016)

The opposite impact changes the behaviours of light-averse species that avoid bright zones and escape to dark spots where insect prey may be limited due to insects' affinity to light. (Ingpen, 1839) However, bats' vision is adapted to low light levels, foraging near electric light is likely to reduce their perception of predator risk. As a result, the electrical lighting of bat roosts, entry points, and feeding trails can be very bothersome to bats and should be avoided. Electric light shining on or near a bat roost can pose a variety of issues for bats. (Baker, 2016)

Recent studies (Spoelstra, et al., 2017) (Bolligera, et al., 2020) about the bats' reaction to a different colour and brightness level of the light shows that its negative impact can be reduced. With the reduced white, green (short wavelength) light will decrease insects and bats attraction to the light sources, however with red light, and they stay unaffected. (Spoelstra, et al., 2017) More precisely, the bat species Glossophaga soricin's spectral sensitivity lies from 310 nm to 688 nm. (Winter, et al., 2003) Also, the light dimmed to 35% when there is no human activity in the relevant area, leaves more space for darkness, and insects and bats' presence decreases as well. (Bolligera, et al., 2020)

3.1.10. Conclusion

Understanding the ecological consequences of electric lighting at night requires research on the impact of light on plants and animals with knowledge of the intensity, spatial distribution, spectral composition, and timing of light in the nighttime environment. (Bennie, et al., 2016) Certain bat species' habitats are in and around urban surroundings, and some adapted to the built environment. However, they're more exposed to predators due to the circumstances of overall brightness in cities and often the lack of areas with green vegetation. As light-opportunistic bats, (as Pipistrellus, Nyctalus and Eptesicus) have larger areas to forage (Spoelstra, et al., 2017) than light-averse species (such as Myotis and Plecotus species) (Spoelstra, et al., 2017), in all likelihood, the distribution of the two kinds of species becomes unbalanced, which can have a greater impact on the biodiversity of a whole region.

3.1.11.Light Pollution

The disturbance of the natural ecosystem, which includes the alternation of night skylight, is one of the major problems of urbanisation. The change occurs in the form of electric light or electric lighting that generates a sky glow that brightens the sky and distorts the night sky's natural brightness and its colour. This phenomenon is known as light pollution, and it is considered pollution to the Biosphere. (Shariff, et al., 2016) Electric lighting during dark hours is identified as a significant driver of worldwide change in the 21st century. It has only recently forced animals and plants to adapt to or face the consequences. The primary problem with light pollution is that the light intensity for some wavelengths produced by localised sources is similar to natural daylight levels. (Hollwich, 1979) Nowadays, people who live in urban areas cannot experience starry nights as our parents did 30 years ago. The reason is more complex than we think. (Bogard, 2013) Electric light at night is increasing globally by about two per cent per year. (Pendoley, 2020) On a worldwide scale, the magnitude of light pollution is yet unquantified. However, a recent study using light pollution propagation software revealed that 80% of the world live under light-polluted skies; this number rises to 99% in Europe and the USA. (Fabio Falchi, 2016)

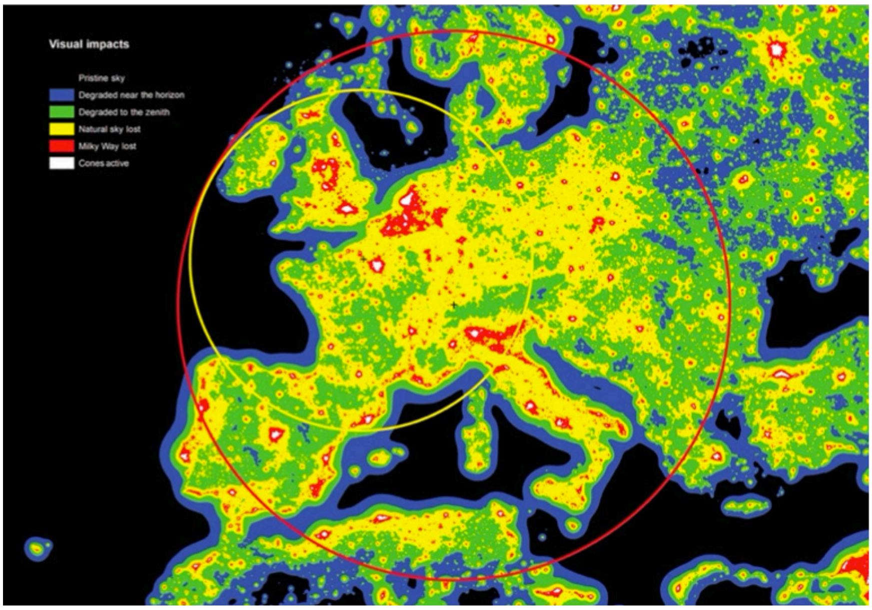


Figure 10. Places on Earth farthest from pristine skies and unpolluted zenith skies.
(Fabio Falchi, 2016)

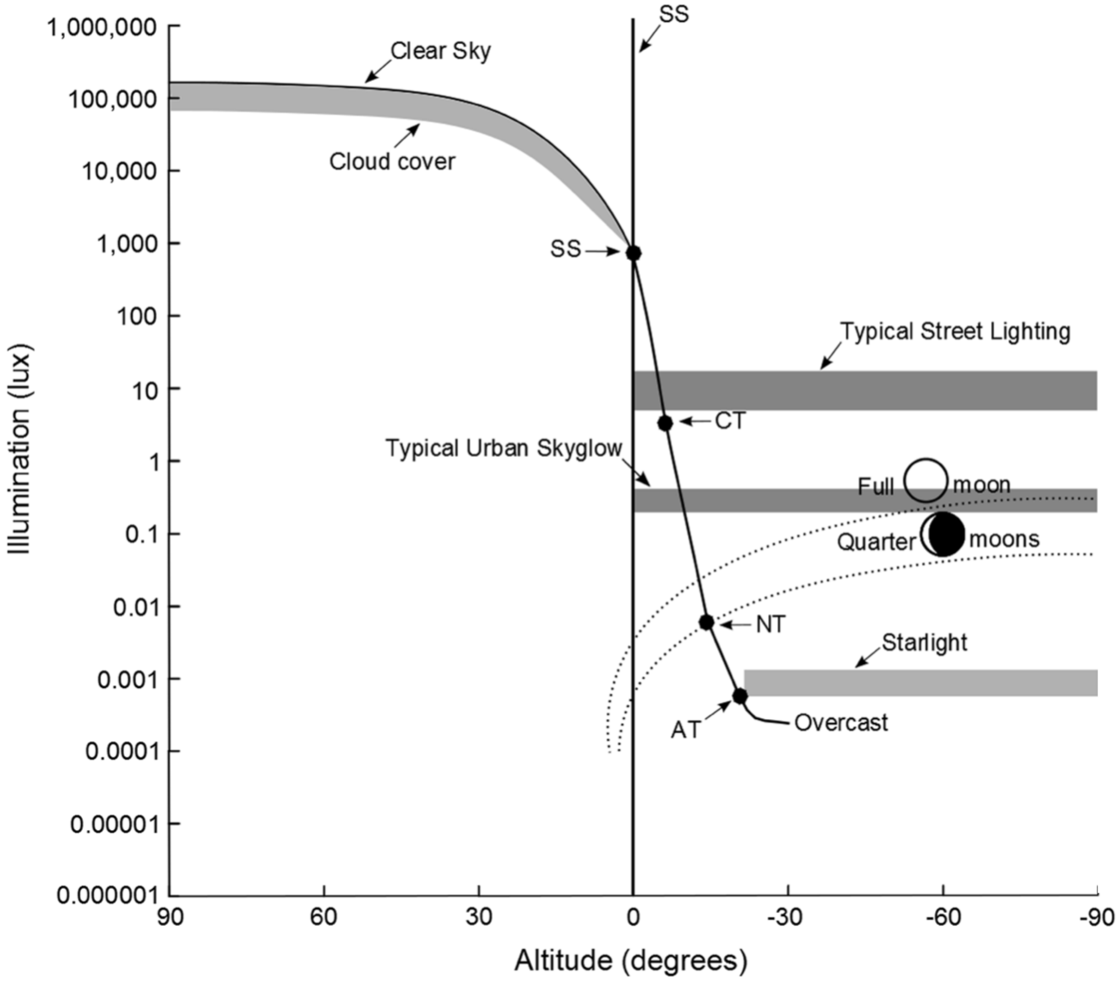


Figure 11. Change in illumination at the Earth's surface with solar (positive) and lunar altitude (negative) above the horizon; typical illumination levels of artificial light at night (ALAN); and levels at which night-time lighting has been observed to have biological effects.
(Gaston, et al., 2012) SS Sunset, CT civil twilight, NT nautical twilight, AT astronomical twilight

Light intensity

The amount of light that reaches the ground varies dramatically between day and night, and organisms rely on this rhythm to keep their circadian systems in sync. Furthermore, organisms can perceive small, short-term variations in light intensity, such as when a dense cloud obscures the sun. During the night, the intensity of light varies depending on the moon phase, which some organisms synchronise to, such as in a tidal environment where the moon significantly influences tide time and amplitude.

On the other hand, light pollution can alter the night light intensity's temporal and spatial characteristics. According to a recent study (Davies, et al., 2013), the average light intensity in cities at night is six times higher than in suburban and rural areas. The amount of full moon equivalent hours has been increased while the seasonal variation in nighttime light intensity has nearly vanished. The consequence of such a transformation for both diurnal and nocturnal organisms is significant. (Dominoni, 2017) Light pollution is still increasing in most of the regions in Europe. At the same time, there are areas in developed European countries where the nighttime brightness significantly decreased, most likely due to the less industrial production and implementation of new policies about nighttime illumination. (Bennie, 2014)

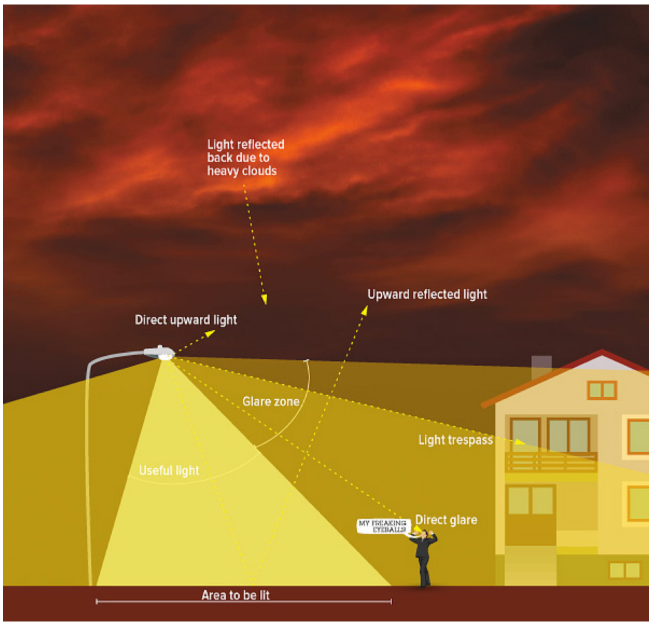


Figure 12
The image illustrating different components of light pollution.
(Gocova, Anezka 2013)

Spectral composition

Sunlight covers a wide range of wavelength during the day. It does, however, alter throughout time; for example, it enriched in short wavelengths during the transition period. While moonlight reflects sunlight, hence the lunar spectrum looks similar to the solar spectrum. The introduction of various anthropogenic night lights like electric lighting, on the other hand, has altered the intensity and spectral properties of the nighttime light experience. It's critical to analyse the impacts of different wavelengths of electric lighting to understand how organisms react to it. For example, the action spectra peak of birds and mammals are at mid-low wavelengths, as blue-rich light. It has the most significant impact on the expression of circadian behaviour, such as the reduced level of melatonin hormone. (Dominoni, 2017)

The International Dark Sky Association

The International Black-Sky Association (IDA) aims to preserve the night skies by certifying darker areas on the planet where the dark sky still can be seen. The IDA divides light pollution sources into four categories.

Glare – Excessive and uncontrolled brightness causes glare, a visual sensation. It can be disabling or merely inconvenient, and glare sensitivity varies a lot.

Discomfort glare is the sensation of irritation or even pain caused by extremely bright sources. In contrast, disability glare is the loss of visibility caused by powerful light sources in the field of view. Glare also reduces one's perception of space by forming a wall of darkness that performs as a visual barrier that the eye cannot pass. (Rea, 2000)

Sky glow – Dust and gas molecules in the atmosphere scatter light emitted directly upward by luminaires or reflected from the ground, creating a luminous background. Often can see above cities under an overcast sky. This effect makes the night brighter in cities and making almost impossible to see the starry sky. (Kyba, et al., 2012)

Light trespass – When spill light is cast in an area where it is not wanted, it is known as light trespass. Because it's difficult to determine when, where, and how much light is undesired, light trespass is largely subjective. Exterior light trespass occurs when light falls where it is not needed, and interior light trespass occurs when electric light enters through a window, disrupting the residents. (Boyce, 2014)

Clutter – Excessive groups of light sources characterise Over-lit urban areas. Clutter contributes to the sky glow, trespass, and glare of the urban sky(Stone, 2017). Businesses that compete with one another often strive to outshine one another.

With a Sky Quality Meter (SQM), it's possible to measure the sky brightness simply. Uploading our measurements into a global database, we can contribute to raising awareness of our sky quality. (Dark Sky Places Program)

Electric lighting is frequently too bright, inadequately protected, and poorly targeted, resulting in light pollution. Building exterior and interior illumination, billboards, factories, sports stadiums, gas stations, streetlights and parking lots are all causes of light pollution. Since LED technology has grown more affordable and simple to install, private gardens have become a source of light pollution too. (Bogard, 2013)

3.1.12. Sustainability - UN goals

Light pollution is one of the major concerns for the future of our cities, as shown by professionals in the lighting industry and international organisations such as the United Nations. Electric lighting is widespread in every city, and for many years, the lighting industry has prioritised quantity over quality, resulting in numerous poorly constructed fixtures. Many lighting fixtures scatter light in various directions, with just a fraction of the light efficiently illuminating the target area. This contributes to the sky glow, which is one of the crucial points that detract from the actual night sky experience. (Bogard, 2013)

It appears that light pollution is a problem in almost every city on the planet. Only a few cities seem to be trying to keep it under control. Cities like Paris, Berlin, Amsterdam and Copenhagen are also paying attention to their lighting. It has primarily been to save electricity up to this point, but more and more people realise that saving electricity and conserving the night sky are closely intertwined. (Bogard, 2013)

Light pollution negatively affects the majority of all living species on this planet (Chepesiuk, 2009) (Dominoni, et al., 2016) (Rekha Sodani, 2021). For us humans, the light at night disrupts our sleep patterns and leads to sleep problems, which are now related to almost every major disease. It disturbs our circadian rhythms and affects our interior workings. Melatonin production is reduced by light at night, and a lack of melatonin has been related to an increased risk of breast cancer and prostate cancer. (Bogard, 2013)
Since its establishment in 1988, the International Dark-Sky Association (IDA) has been at the forefront of educating the public about the dangers of light pollution and working for improved lighting that does not interfere with the night sky experience.

The International Dark Sky Association(IDA) and Illuminating Engineering Society (IES) introduced Five Principles for Responsible Outdoor Lighting and unanimously adopted them in their organisations. The five principles are: Useful, Targeted, Low light levels, Controlled, Colour. (Figure 13)

Figure 13 Five Principles for Responsible Outdoor Lighting
(The Dark Sky Association)

By applying these principles, accurately composed electric lighting can be beautiful, healthy, and functional at night-time. Energy and money will be saved, light pollution will be reduced, and wildlife will be less disturbed in projects that integrate these ideas.

UN Goals

“The 2030 Agenda for Sustainable Development, which comprises 17 Sustainable Development Goals (SDGs), was adopted by the United Nations General Assembly in September 2015. The new Agenda emphasises a holistic approach to attaining sustainable development for all, based on the principle of “leaving no one behind”.” (UN)

The UN Sustainable Development Goals define the challenges we need to address to achieve a more sustainable future.

Particularly SDG 11. addresses the built environment and how it affects the issues of inequality, safety, climate and environmental degradation.

The lighting design, alongside architecture, can contribute in many ways to make our habitats safe, inclusive, resilient, and environmentally sustainable. It can do that by enabling and reinforcing positive habits such as walking and biking, thereby reducing pollution. Furthermore, it can increase mobility and accessibility, thereby positively affecting health and inclusion/equality. An example of this is addressed in this thesis. I suggest a lighting solution that may provide universal access to safe, inclusive and green public spaces for everyone regardless of gender or age (11.7).

Figure 14. UN Goal 11.
(UN)

SDG 15 addresses the natural environment and how it affects the issues of deforestation, desertification and the degradation of biodiversity.

Figure 15. UN Goal 15
(UN)

New, more adequate lighting design may reduce the negative effect of the relentless urban electric lighting from the habitat of local animals and draw attention to the importance of their presence (15.5). In addition, it can enhance positive habits such as active care for surrounded urban green areas that can positively affect people's mental health and restore their connection to nature. The implementation of such a design can influence people and municipalities on a greater spectrum (15.9).

3.2. Summary of theoretical framework

This section, provides a review of philosophies and studies regarding our connection to nature and darkness throughout history, as well as psychological and physiological perception of light and darkness. In addition, it also examined the topics of biodiversity, especially insects and bats, and how they are affected by electric lighting, as well as light pollution and its effect on the entire biosphere. As each subject is examined separately, this summary is intended to synthesize the subjects and highlight commonalities.

Connection with nature is essential for humans and it has multiple positive impacts on mental health. Mental wellbeing can be improved by spending time in green environment, as well as applying biophilic design. However, in 2020 and 2021, much of the World's population had experienced limited access to public areas for physical activities and leisure. The demand for these areas has hardly been higher in recent history as most indoor facilities and amenities were at least partly unavailable due to Covid-19 restrictions.

Moreover, wintertime has made these restrictions even harder. Daylight hours are relatively short in Scandinavia, and many recreational areas are hard to access after dusk. At the same time unlit, dark places, are negatively perceived. Experience of evening darkness is hardly possible in today's urban environment. If someone is exposed to it, darkness triggers feelings of insecurity and discomfort, and is therefore regarded as something that has to be conquered by light. Consequently, unlit dark places are generally avoided or closed off.

However, Dunn explains that darkness not only benefits the ecosystem but humans too. (Dunn, 2016) For that matter, we should aim at 'reintroducing darkness' into our urban reality. This goes in line with the philosophy of biophilia, which proposes that humans greatly benefit from connecting with nature, which darkness is a part of. Darkness is a part of our nature and history, and should be a part of our lives.

Thus, finding minimum light level that meets human practical needs but still enables the experience of evening sky and the surrounding darkness, and doesn't harm the natural environment is highly desired. The anthropogenic, nocturnal electric lighting can adapt to the natural environment, with the consideration of the existing ecosystem. Common electric lighting greatly affects the circadian rhythm of almost every animal, humans included, ultimately altering their behaviour. Understanding the effect of different colour spectral power distribution (SPD) of the light, it's possible to reduce the negative impact on biodiversity, especially bats.

Studies show that due to bats' UV sensitive cone photoreceptors, they are sensitive to light with high level of short wavelengths. However, most of them are unresponsive to light with long wavelength. The right height of lighting sources and adequate distance between fixtures, allows bats to fly through the site with reduced exposure to predators. The light with reduced short wavelengths is less attractive to insects, hence light-opportunistic bats will also be less attracted to the area with fixtures. As a result, the balance of the two types of species (light-opportunistic and light-averse) in the ecosystem can be restored.

Urban green areas often used for recreational purposes away from the monotony of the stressful urban environment or pressure from work. Amber coloured or warm white light has a calming effect on people's mood and it has reduced short wavelengths of the spectral power distribution. With lower illuminance intensity, people in a dark environment are able to perceive a larger area of the site as the light with low contrast level allows the eye to activate scotopic vision, i.e. to adapt to the darkness. Furthermore, with fully shielded light sources, the possibility of glare can be minimised. The perception of the overall atmosphere triggers a psychological effect on people. Lighting that harmonises with the surrounded environment in terms of illuminance intensity, colour of the light and the allocation of the fixtures would help to relax and fulfil the bodily experience.

Common electric lighting has a significant anthropogenic impact on the biosphere. Light pollution not only decreases our visual connection to the night sky and the perception of darkness but also pollutes our biosphere. We are the only species on the planet who benefit of the presence of electric lighting. The impact of this recent phenomenon on the population in cities resulted in sleeping disorder that can trigger major diseases.

In order to reduce this negative impact, electric light should be shielded, used only where and when it's necessary, blue (short wavelengths) light emission should be minimised, and brightness reduced when it's not required.

3.3. Observations

The material of this chapter was gathered by first hand observations with the help of the information found on The Carlsberg Foundation's and Foreningen By&Natur's website. (J. C. JACOBSENS GARDEN, 2017; By&Natur)

Figure 17
Photos taken in Søndermarken
(Personal archive)

3.3.1. Applied light in Copenhagen Parks

To achieve a comprehensive design process, site visits play a significant role for a valuable input. Thus, numerous site visits had been executed for on-site observations supported with photo registerations as well as mapping of user behaviours. As this investigation forms the understanding and usage of such places, it was also strongly insightful considering the individual experience.

For mentioned purposes, following part introduces subjective observations on Fælledparken, Landbohøjskolens and lastly Søndermarken.

Fælledparken

Being the largest park in Copenhagen Fælledparken has wide open places which contains of numerous walking paths as well as event spaces for concerts and various activities. It is accessible in multiple directions since it is an unfenced, naturally bordered by the nature area.

The light distribution is quite uneven in Fælledparken at first glance. Only certain areas are lit up while the majority appears dark. On the main path crossing the park is equipped with bollards which provides low level of light and thereby the atmosphere can be described as insecure and undervalued. However it is only fair to evaluate guiding at night as sufficient. This might be a result of clear vision of the night sky in the area as the light is not scattered through the canopy of the trees and therefore let the observer access the sky, enhance the experience.

Figure 16
iGuzzini fixtures in Fælledparken
(Personal archive)

Landbohøjskolens

Unlike Fælledparken the area is surruounded by fences and hedges which limits the accessibility by allowing the user to enter the park only from specific points. In addition to this, the light is fairly poor as it is lacking and nighttime electrical light solution. Despite the light is absent, the atmosphere is quite welcoming and reinforces the feeling of private space rather than public. From a subjective point of view, the space feels decently safe as opposed to expectations from an unlit space at night. The vegetation and open sky view without tree branches interfering and block the vertical sight.

Figure 17
Photos taken in Landbohøjskolens
(Personal archive)

Søndermarken

Having a historical value enriches the potential of Søndermarken whilst accomodating the Copenhagen Zoo and Cisterns. The area is enclosed with the fences enabling the user to enter in through the gates, therefore guides them to plentiful walkpaths which lead to a large opening in the middle. Lighting on the outer edge is equipped with motion sensors providing a sufficient light level in nightscape. The size of the area breaks up the feeling of private in comparison to Landbohøjskolens .

Figure 18
CitySwan three armed pole fixture in Søndermarken
(Personal archive)

Quantitative Measurements

All measurement were taken at night, under a clear sky. Data sheets of the light fixtures can be found in appendix.

Measuring Tools

Spectrometer	AsenseTEK, Model no. ALP-01
DSLR Camera	Canon 500D
Digital Luxmeter	Testo 540

Fixtures

iGuzzini iWAY ROUND Bollard

iWay fixtures are located along the walkpaths in Fælledparken with a distance of 20 meters between each other. All measurements for the bollards were taken from the ground level.

Figure 19
iGuzzini iWay Round bollard
(iGuzzini)

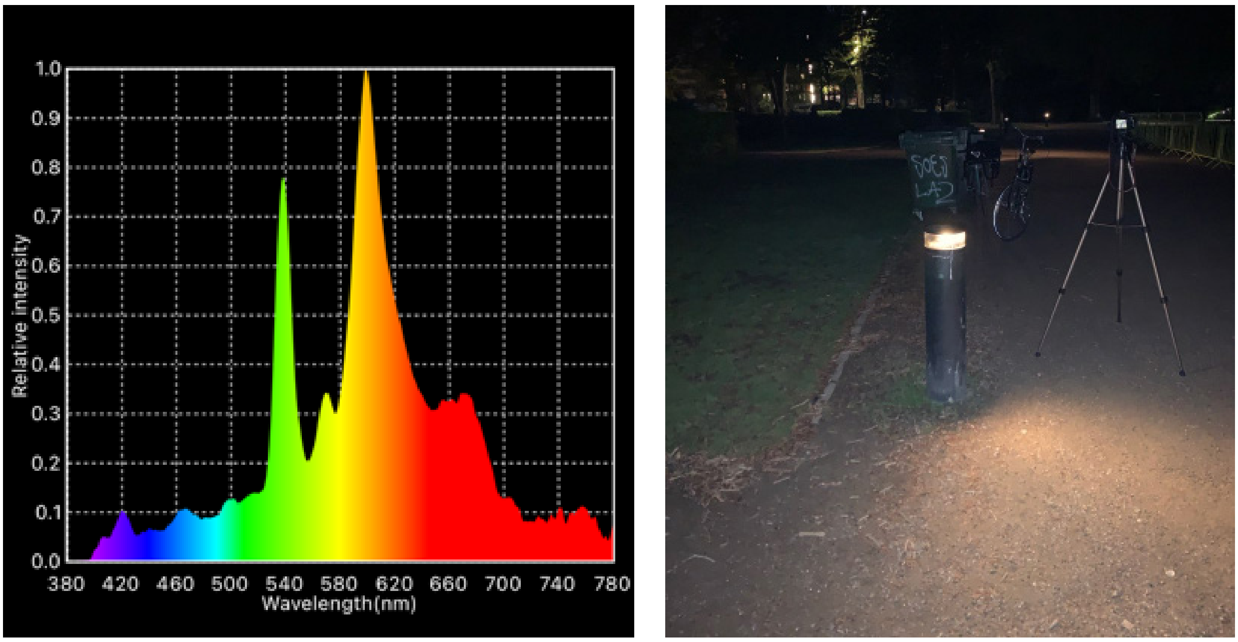


Figure 20
SPD measurement result(left)
Measured environment(right)

Illuminance level is measured as 17 lux whereas the SPD measurement shows that the electric light contains short wavelengths.

CitySwan Bollard

Cityswan fixtures are located along the walkpaths in Søndermarken with a distance of 16 meters between each other. All measurements for the bollards were taken from the ground level.

Figure 21
Philips CitySwan bollard
(Philips Lighting)

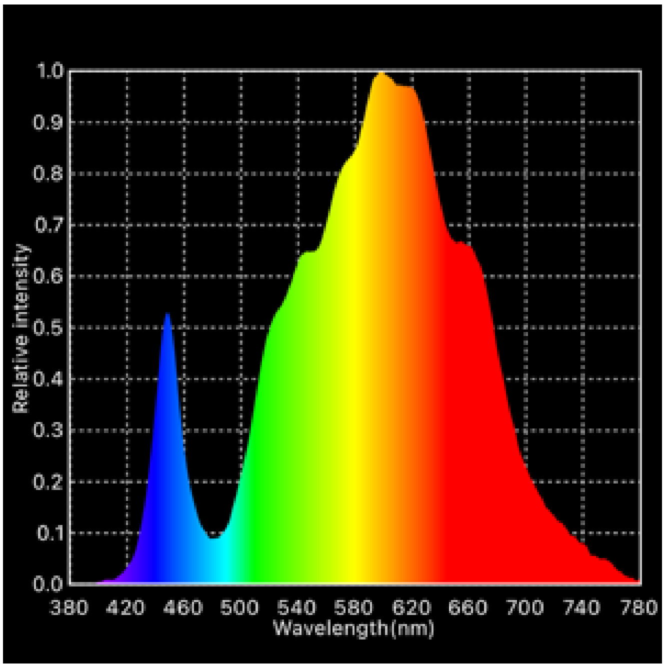


Figure 22
SPD measurement result(left)
Measured environment(right)
(Personal archive)

Illuminance level is measured as 52 lux whereas the SPD measurement shows that the electric light contains short wavelengths.

CitySwan Pole Light Single Armed

Figure 23
Philips CitySwan pole light
(Philips Lighting)

Cityswan fixtures are located along the walkpaths in Søndermarken with a distance of 2 meters between each other. All measurements for the pole lights were taken from the eye level.

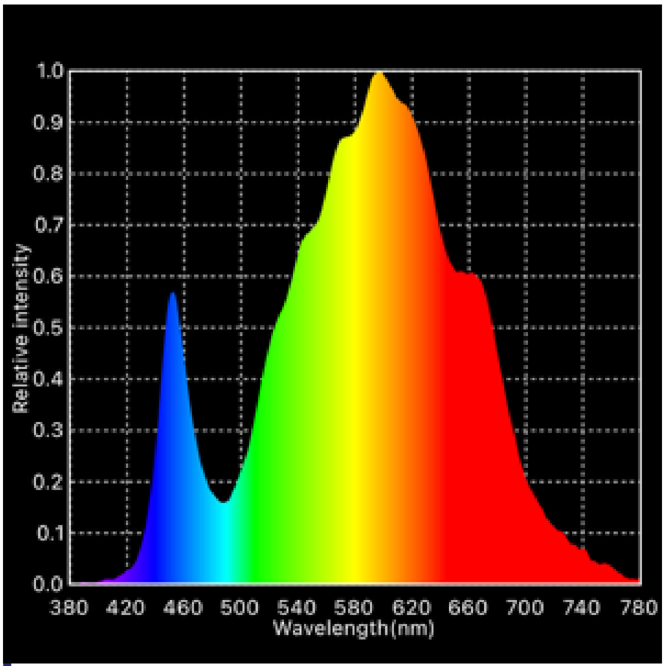
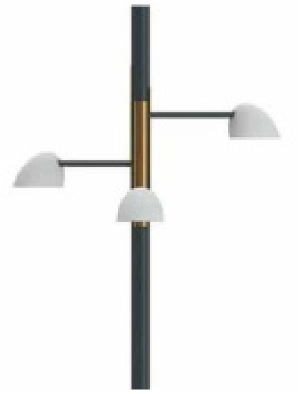


Figure 24
SPD measurement result(left)
Measured environment(right)
(Personal archive)

Illuminance level is measured as 55 lux whereas the SPD measurement shows that the electric light contains short wavelengths.

CitySwan Pole Lighting Three Armed



Cityswan fixtures are located along the walkpaths in Søndermarken with a distance of 16 meters between each other. All measurements for the bollards were taken from the ground level.

Figure 25
Philips CitySwan pole light 3 armed
(Philips Lighting)

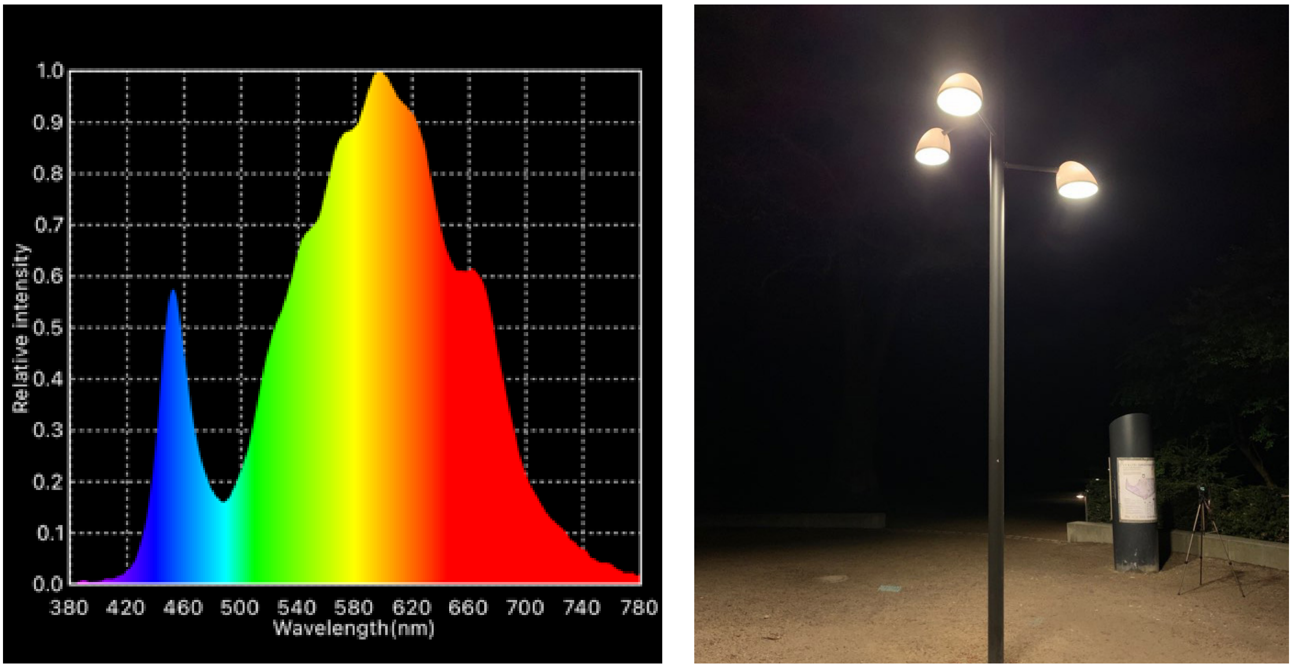


Figure 26
SPD measurement result(left)
Measured environment(right)
(Personal archive)

Illuminance level is measured as 122 lux whereas the SPD measurement shows that the electric light contains short wavelengths.

Figure 27
Photo taken in Søndermarken, shows the unnecessary light exposure
(Personal archive)

Figure 28
J.C. Jacobsen's house
(J. C. Jacobsens Garden, 2017)

3.3.2. "Secret Garden" - JC. Jacobsens have

I've chosen a specific location in Copenhagen in order to help my work with tangible parameters of the site, animal presence, the surrounding built environment and its historical heritage.

Heritage

JC. Jacobsens have planned and sketched by JC. Jacobsen, founder of Carlsberg brewery in 1848 and functioned as his private backyard. JC. Jacobsen was passionate about botany. From his travels, he brought back not just inspiration but also rare tree and plant kinds. The original garden plan was designed by Rudolph Rothe (1802-1877), landscape architect. The property's original topography was rather long and narrow, gently descending from west to east. The garden remained private over the years until 2008 when it opened for the public. It was renovated in the summer of 2017 according to the architect Kristine Jensen's design. The garden was re-opened on JC. Jacobsen's birthday, September 2, 2017, as a part of the Golden Days Festival, Copenhagen 850 years. (Mønsted, 2017)

The analysis of the site

In February, I spent a couple of weeks finding the most suitable place for my study, where my proposed approaches may be used for "providing access" to a natural area that is inaccessible now. Specifically, I was looking for an urban environment that people can't visit when it's dark. I spent numerous late afternoons and evenings walking to various natural areas, briefly registering movements and noting how people behave in the space. Besides focusing on people's activities at each location, I observed the surrounding vegetation, animals' presence and location's characteristics. Unfortunately, at that time of the year, the presence of animals was minimal in most of the places I studied. As a result, my knowledge of how other species influence these spaces is based on existing scientific studies.

Figure 29
J.C. Jacobsen Have, illustration by Kristine Jensen
(Kristine Jensen Landskab & Arkitektur ApS)

I've chosen J.C. Jacobsen's Garden based on its natural characteristic of rare and exotic plants, heritage, somewhat hidden location and the fact that the garden is inaccessible after dusk. On numerous occasions, I walked around, observed between February and May. (The dates and time of my visits are in the appendix) I also introduced the garden to my friends, and we started to spend sunny days and late afternoons there. During my observations, I was equipped with a notebook

Figure 30
Illustration Carlsberg Byen
(UDVIKLINGSSELSKABET CARLSBERG BYEN P/S)

and my Canon 500D camera. I marked on a sketch where and how many people walk, wrote about their sex, approximate age and their pace. Also noted where groups of people were doing different activities such as gathering or practicing yoga, (for example on one sunny afternoon (19th of May)).

The garden is located on the southwest side of Copenhagen, Denmark, in the neighbourhood of Carlsberg. (Olivia Hansens Gade 2, 1799 København)
The garden is secluded from the busy urban atmosphere. It provides a break from the pulsating life with its magical ambience and employs peacefulness in beautiful surroundings. Entering the garden is only possible through two gates; one from the west and another from the south. It is not easy to see from the street level; It's surrounded by the J C. Jacobsen Villa from the west, residential buildings from the north, the Hanging Gardens Building from the east and the Carlsbergruten bike path from the south. It is roughly the size of Kongens Nytorv and features the landscape of a romantic garden, including a pond, hill and winding paths. It had been closed for 160 years but reopened to the public in 2008.

Figure 31
The image illustrating different components of light pollution.
(Gocova, Anezka 2013)

Every square meter of the original garden was sketched and planned by the brewer. Nowadays, the garden is home to 74 different plants, including rare and unusual trees. From above, the garden is visible between Søndermarken and Vestre Kirkegård, providing a link between the two large green areas. The connection of greenery may be essential for endangered species in the area.

Approaching the garden from the south, through the closest gate nearest to Carlsberg Station (on the side of Bohrsgade 5), visitors will notice the unusual weaving paths, different zones with various vegetation and the elevation of the steep terrain. On the left-hand side, the iconic Hanging Gardens building (designed by Svend Eske Kristensen) delimits the space with its characteristically curved brick walls. On the far west end, visitors can discover the silhouette of the Jacobsen Villa between the dense tree canopies. On the east side behind a small hill, there is a newly built tower of Carlsberg Byen, creating a visual composition that evokes New York's Central Park. Following the latest development of the park, concrete benches are placed along the path, offering the possibility for small groups to gather around them.

Light - Daytime

JC. Jacobsen Garden's layout allows the sunlight to enter deep into the core of the park. The tall trees with dense canopy are spread out but mainly located on the small hill in the northern part of the park. In the longest stretch of the year, the sun sets behind J C. Jacobsen's Villa, creating long shadows on the ground as it's located on slightly higher terrain. I observed the garden only from the outside during evening hours, when it descends into total darkness. On the north side, a long newly built three storey building lays. Light is scattering through the windows to the darkness of the garden. From the other sides, including the bike path and S Tog racks on the south side, there is no light penetrating the site. However, once the Carlsberg Byen tower construction is finished, the newly built structure will look over the whole park and affect its surroundings.

Light – Night time

Søndermarken

As people have no access to JC. Jacobsen's Garden after sunset, I had to look for an additional natural location within an urban environment to conduct another set of observations regarding the matter of bodily experience and the lighting within a space. I was looking for a location with characteristics and vegetation similar to JC. Jacobsen's Garden. Søndermarken met all selection criteria, so I decided to conduct my observations there during evening hours. Søndermarken is located relatively close to JC. Jacobsen's Garden on the northwest side of Carlsberg Byen. The park is surrounded by tall vegetation along the fences, which filters out road lights and street noises. CitySwan (Signify) installed bollards along the main path in Søndermarken, providing a guiding light on the footpath for pedestrians. CitySwan poles are at the northeast entrance, where the central paths are crossing each other in the middle of the park.

Figure 32
Illustration Carlsberg Byen
(UDVIKLINGSSELSKABET CARLSBERG BYEN P/S)

Entering the park from Carlsberg Byen, our eyes quickly adapt to the slightly lower light level along the footpath where people often run, even at night. However, the light reflecting on the gravel has a blinding effect. The surroundings look pitch black compared to the illuminated bollards. When runners pass by, one can only see their legs illuminated, without being able to distinguish any colours or observe details of their face and physique. Farther away from the bright path, darkness consumes the entire space. It takes a good couple of minutes before the surrounding area start to become clear. At this point, it's easier to see the silhouettes of objects and formations in the distant environment. On a night with clear sky, it's easy to differentiate the path from its surroundings.

Users

One of my main reasons of choosing JC Jacobsen's Garden as one of the study area is that it's inaccessible after dusk. Since it was impossible to observe user activity at this location after sunset, I spent many hours at various times in JC

Jacobsen's Garden to observe and better understand the different visitor groups and their activities during the day. Since the gates of Jacobsen's Garden are closed when it's dark, I extended my study by conducting additional observations in Søndermarken, a park with similar geographical and natural characteristics that is accessible to the public both day and night.

Users in JC. Jacobsen garden

During my observation periods (observation day and time in appendix), JC. Jacobsen's Garden had slow dynamics in terms of personal interactions and activities. Visitors were mainly strolling, wandering around, sitting and chatting on benches or on the ground. Their ages ranged widely. Two out of six times, I saw families pushing a baby pram with small children, teenagers and young adults with their friends enjoying each other's company, and the elderly observing the surroundings and chatting with their companions. I haven't seen anyone jogging, running, or taking their dogs for a walk during my time there. One older man stretched using the side of the concrete furniture, but other than him, there were no other people taking part in physical activities.

As time passed and sunset approached, only the youthful visitors remained, all in the age bracket of 17-30 years old. They stayed until the park guard asked them to leave. Families and the elderly generation had long left by that time. Most likely, they were more respectful of the visiting hours of the Garden and did not want to get into conflict with the guards. It's also possible that they didn't find the park appealing after dark.

Users in Søndermarken

During the daytime, Søndermarken is a vibrant place with kids, families and groups from local daycares who are regular visitors of the space. People are typically jogging on the main footpath and doing exercises in the workout area. They watch animals from outside the zoo and play group games such as rundbold in the middle of the vast stretch of grass on the top of the cisterna.
When the sun goes down, the park takes on a completely different ambience. It's

quieter, and anyone within it is barely visible.

Over the few months of my observation there, I saw that people were typically running on the path along the fences most frequently under pleasant weather conditions. Only a few people used the footpaths after dark. The park is popular on weekend nights. I often saw a group having drinks and listening to music on their portable speakers on Friday or Saturday evenings. I assume they've taken it upon themselves to use the park as their form of nightly entertainment, as the places where people typically socialize, like bars and clubs, have been closed due to the pandemic.

Chapter 4
Design Criteria

4. Design Criteria

In chapter three, the research describes the importance of having access to nature on a daily basis for people, either day or night time. However, studies show that the electric lighting at night is only beneficial for human beings, and every other living species does not gain any benefits. Electric lighting enhances orientation, sense of the space and visibility. Although, the research in this thesis suggests that low contrast lighting can improve visibility and the nocturnal experience while reduce the negative impact on the surroundings. Based on these thoughts, I define the following three criteria.

4.1. Three Criteria

Natural science

The impact of lighting - with determined colour on the spectrum - on bats will be minimised and the presence of light shy bat species will increase by 40% by introducing a sensory system that dims the brightness on demand.

Social Science

The effect of the new lighting design will increase accessibility, visibility and feeling of safety for humans.

Humanities

The lighting design will balance darkness and light, create better harmony between humans and nature.

The initial research question and the three criteria lead me to the Research question.

4.2. Research question

How can the lighting - with reduced short wavelengths on the colour spectrum - of urban green environments be designed in order to create attractive and accessible spaces for humans, while minimising the light's negative impact on the local habitat of bats?

Chapter 5

Experiments

5. Experiments

Based on a review of recent research papers, articles and webinars, I learned about the electric light's long-term effect on plants and animal's circadian rhythm and photoperiodism (Bradshaw, et al., 2010), on plants physiological response (Bennie, et al., 2016), insects' attraction of long wavelengths of the colour spectral power distribution (Andrew N. Coogan, 2016) and that its long wavelengths are less attractive for insects (Eisenbeis, et al., 2010). Furthermore, I learned that certain bat species are benefiting from the insects' attraction to electric light at night however, the rest avoid any possible light exposures (Spoelstra, et al., 2017; Longcore, et al., 2016), the reduced cold wavelengths of the colour spectral power distribution will extend the area of prey of light shy bat species (Spoelstra, et al., 2017). At last, I learned about the negative effect of light pollution and its negative effect on the entire biosphere. (Thorsen, 2021);Shariff, et al., 2016)

5.1. Light Test

Moving forward in the design process, I aimed to understand how people perceive the darkness, light and overall environment in an urban nature area such as Søndermaken at night. The experiment I conducted, focused on to colour of the light and the perception of the surroundings lit up in this colour. It was an explorative experiment with the inclusion of 20 participants. I gained a better understanding of their perception of the atmosphere, their ability to navigate, see others and the dark night sky.

With the help of Jørn Brinkmann from iGuzzini and my colleagues in Light Bureau, I conducted a test in an environment that is very similar to where I initially imagined my design *described in Chapter 3.3 Observation*. However, at first, I had to figure out the limitations of the available fixtures and their controlling system. I received a Lander bollard, a Platea Pro floodlight and a DMX controller from iGuzzini. Platea Pro is an RGBW fixture and the Lander is a standard bollard.

Lander iGuzzini
Colour temperature: 3000K
System Power: 9.8W 1600lm - light source value
Optic: A60 - Asymmetric h = 7 / d = 2
Size (mm): 270x126x650,
Weight (kg): 6.20

Platea Pro
RGBW LED
System Power: 35W 2500lm - light source value
Optic: F - Flood 28°
Size (mm): 406x276,
Weight (kg): 8.60

Based on my analysis, I aimed to compose a light that is pleasing to the eye and has reduced short wavelengths (green and blue) with increasingly long wavelengths (red) of the visible light spectrum. In order to achieve this, I did several experiments with Platea Pro and the DMX controller.

Previous researches (Spoelstra, et al., 2017) concluded that red light is the least attractive for bats and insects in rural and naturally preserved regions. These areas are the natural habitats of animals such as bats; thus, their new lighting solution primarily focused on the animal factor and not that much on human perception.

One of the benefits of working for Light Bureau was that it provided me the opportunity to be able to test outdoor lighting while being sensitive to nature in Copenhagen. Being involved in these tests created a solid basis for the crux of my thesis. Before the experiment, my colleagues presented a visualisation that had the red colours you'd see in the natural world. The new lighting was intended to increase feeling of safety while having only a minor impact on what it landed on in the surrounding area. However, seeing the fixture and its red-light made the client sceptical about other peoples' reaction. The first comments were that it reminded them of a red-light district or being in Tivoli. At this point, the whole approach became very political, and the focus moved away from my concern about the protection of animal presence in the area. A few weeks later, they turned down the opportunity to introduce the presented lighting.

In my research, the design is taking place in an urban context, where people live. For this reason, I'm adapting the mentioned studies to an inhabited environment, which takes into consideration human perception. In numerous conversations with my supervisors and my colleagues, it became clear that introducing red light (which might be the least harmful colour to natural surroundings) would create an odd, hostile environment for people.

Thus, it became clear that my focus has to shift towards finding a balance between an inviting, pleasant atmosphere with the lowest brightness possible and the least harmful lighting for the natural habitat surrounding it. After experimenting with the Platea Pro fixtures and the DMX controller, I realised that the darkest light I could create was still too bright. Platea Pro is a powerful outdoor floodlight, and the DMX controller wasn't sensitive enough to provide the darkest shades. However, at this point, my focus was on finding the right colour on the spectrum instead of adjusting its brightness. In these experiments, I used an (AsenseTEK, Model no. ALP-01) spectrometer and a Canon 500D camera to confirm my findings.

5.2. Pre-study (Indoor Light Testing)

This test was conducted based on the combination of deductive research approach, based on my findings from theories and research (*I describe in chapter 3. Theories and Observations*) and my visual perception.

I created two scenarios I consider pleasant - based on my visual comfort and perception of colours - that introduce reduced, short wavelengths using the Platea Pro RGBW fixture and the DMX controller. First, I installed the luminaire in my room and conducted the following test in the dark. Once I finalised the setup on the DMX controller, I placed the spectrometer at a 1-meter distance. In this setting, I was only interested in the colour spectral power distribution. I was aiming to recreate pleasant light for the eye that's wavelengths are minimise under 494 nm and reduce below 577nm. The results are visible below.

Indoor Light Test, Scenario 1

The light effect of the fixture in scenario 1 setting was slightly red, however, I considered the solution representing true colours. The sliders of blue and green colours were reduced to the minimum level (at level 0 on the scale, turned off), only the red (at level 3 on the scale) and the white (at 1.8 on the scale) slider were in the active zone. (The photograph of the DMX slider's position is in Appendix)
The reason of presence of green and blue wavelengths on the colour spectral distribution chart is that the white light is generated of RGB light on the DMX

Figure 32. Indoor lighting test, Scenario 1.
(Personal archive)

controller, so increasing the intensity of white colour, will increase the all the RGB colours as well.

The spectral power distribution isn't satisfying in terms of minimising short wavelengths as my aim was to minimise the wavelengths under 494 nm and reduce it below 577 nm.

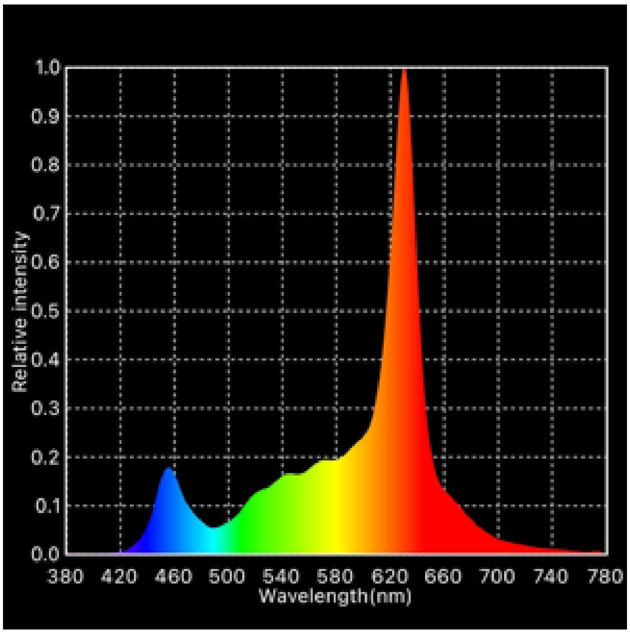


Figure 33. Indoor lighting test, SPD values, Scenario 1.
(Personal archive)

Indoor Light Test, Scenario 2

In scenario 2, the sliders of blue and green colours were reduced to the minimum level (0 on the scale, turned off), the slider of red (at level 3 on the scale) is untouched and the slider of white colour (at level 0.8 on the scale) is below than its position in scenario 1. (The photograph of the DMX slider's position is in Appendix)

Figure 35. Indoor lighting test, Scenario 2.
(Personal archive)

The spectral power distribution shows a slightly better result, however I expected to see short wavelengths on a lower level.

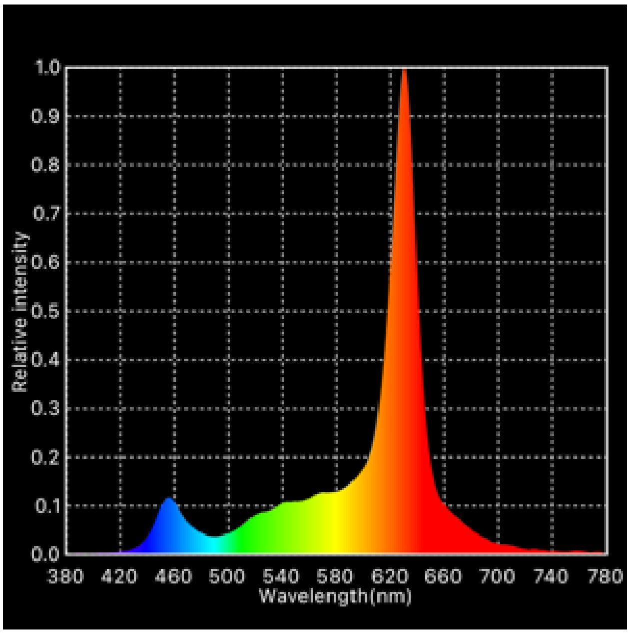


Figure 34. Indoor lighting test, SPD values, Scenario 2.
(Personal archive)

5.3. Outdoor Light Testing

After these experiments, based on the criteria of reduced short wavelengths and low illuminance level, I decided to go forward with the second scenario of the indoor light test . Using the Lander bollard with amber-coloured filters (Lee Filter Roll 442 H.C.T. Straw), I recreated the previously DMX-generated coloured light. The light effect was almost identical to the previously tested RGBW fixture, although, in order to reduce the brightness, I had to cover 9 out of 12 LEDs.

Equipment:
Fixture: Lander, iGuzzini, 3000K, 9.8W, 1600lm
Amber tinted filter: Lee Filter Roll 442 H.C.T. Straw
Camera: Canon 500D
Power generator: Digital Generator 1.200 W / 230V

With the second lighting test, I aimed to understand better the participants' preferences regarding light colour, brightness and the overall experience. I presented two scenarios to the participants in two rounds and applied the mixed-method research strategy. This strategy requires a combination of both quantitative and qualitative methods (Bryman, 2016). Quantitative research methods can, in broad terms, be described as the collection and analysis of numerical data, where qualitative research methods usually emphasize words rather than quantification in the study and collection of data. The combination of both strengthens this thesis examines the broad picture with closed questions of the questionnaire and specific coherences with open questions.

Scenario A

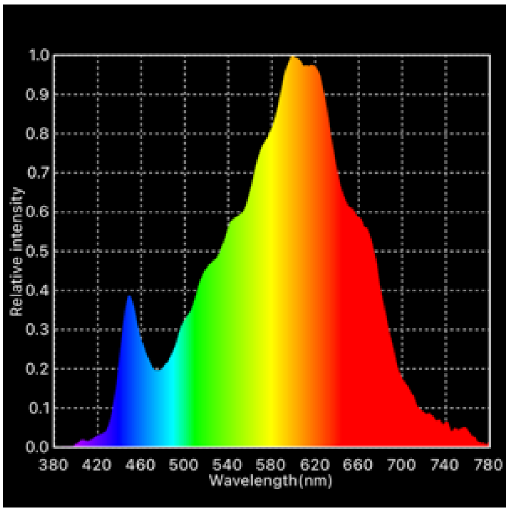


Figure 36. Outdoor lighting test, SPD values, Scenario A.
(Personal archive)

Lander, iGuzzini, 3000K, 9.8W, 1600lm

Colour temperature: 3000K

CRI: 80

9.8W 1600lm

Illuminance 75 lux

Figure 37. Indoor lighting test, SPD values, Scenario 1. Standard set-up of the fixture.
(Personal archive)

Scenario B

Lander, iGuzzini, 3000K, 9.8W, 1600lm

Colour temperature: 1678K (generated by amber filter: Lee Filter Roll 442 H.C.T. Straw)

CRI: 76

9.8W 400lm

Illuminance 49 lux (9 out of 12 LEDs are covered)

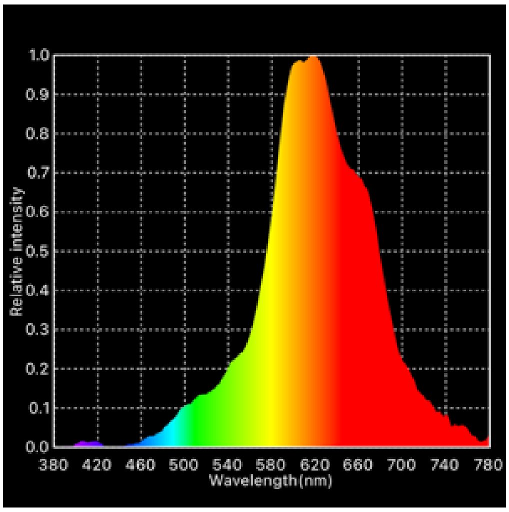


Figure 38. Outdoor lighting test, SPD values, Scenario A.
(Personal archive)

Figure 39. Indoor lighting test, SPD values, Scenario 1. Standard set-up of the fixture.
(Personal archive)

Twenty people participated in the lighting test. I divided them into two groups and sent them the questionnaires via messages. I asked them to explore the environment in total darkness first and reduce their phone screen's brightness to the dimmest setting while filling out the form. For 12 people, I showed Scenario A first and Scenario B later. For the rest, I changed the order. The goal of setting up this structure was to minimise biases, as people might compare their experience with the first seen solution to the second. (The questionnaire is in appendix)
A generator was providing the electricity for the bollard. I didn't want the noise to affect the results in any way, so I had to place it far from the footpath, which was about 40 meters away.
I turned on the light and asked the participants to walk around and spend a few minutes getting a feel for the colours, each other's appearance in those colours and the light effect. I asked them to do this before they started filling out the questionnaire. Once everyone finished, I turned off the light for a few minutes and prepared the filter for the second test. Then, after turning it on again, I asked them to explore the surroundings and let their eyes get used to the light. I repeated the same procedure in the opposite order for the second group.

After everyone participated in the testing, I explained my approach to them. Most had a very favourable opinion about my new lighting theory.

5.4. Evaluation of the questionnaire

With the following questionnaire, I approached the subject from four directions (visual orientation, visual appearance, experience of the night sky, visual appearance of nature and vegetation) in order to answer my Research question.

How can the lighting - with reduced short wavelengths on the colour spectrum - of urban green environments be designed in order to create attractive and accessible spaces for humans, while minimising the light's negative impact on the local habitat of bats?

The application of both qualitative and quantitative questions allowed me to gain insight into people's preferences and understand how they perceive the night sky, the surroundings and how they feel in space. After conducting the questionnaire, I analysed the answers, looked for patterns of the replies and enumerated the positive and negative attributes. With the quantitative questions, I categorized the participants into three groups.

1, agree: people who selected the option strongly agree or agree,
2, neutral: people who selected the option neutral,
3, disagree: people who selected the option disagree or strongly disagree.

Using this system, I could see through, if the majority of people agreed, disagreed or at time, stayed neutral. If the result of one group was not outstandingly higher than the rest, I describe it in the following section.
Analysing the qualitative questions required a deeper understanding of the person. For this reason, I analysed one participant answers at a time (e.g. if one considered the brighter solution (Scenario A) already too dark, I kept it in mind when I analysed their answers about Scenario B.). In the short descriptive answers, I looked for patterns and furthermore compared the quantity of positive and negative tone replies.

I attempted to collect answers to critical questions of my thesis, such as:

Is the lighting of the place inviting for people?
Is the lighting solution making people feel safe?
Is the lighting allowing people to experience he night sky?
Do people think that the atmosphere with the lighting solution is pleasant?

The majority, 70% of the participants were 20-29 years old,
25%, 30-39 years old,
5%, 40-49 years old.

Out of 20 people, 80% were male,
20% were female.

Orientation

that the light with a higher brightness level (Scenario A) might make the direct surroundings more visible, help people to navigate the footpath and differentiate the gravel from the grass more than the light with lower brightness (Scenario B). However, slightly more people considered Scenario B a more pleasant environment to walk in than the light setup from Scenario A.

Respondents described the lighting in the environment of Scenario A as follows:

"Strong enough to show the path."
"Blinding, too white, too low and creates a space where you feel insecure."
"It's nice that you can see stuff, but I wouldn't call the light pleasant since it's very bright." "Not pleasant, rather functional."
"Disturbing for the eye."
"Aggressive."
"Too much light."
"It's bright enough to see the path. You can still experience the surroundings."
(The questionnaire replies are in the appendix)

There were both positive and negative comments regarding the atmosphere in terms of orientation. Most answers were related to the brightness of the fixtures, which were praised and dismissed equally. It became clear that cultural differences, the field of the profession, gender and other variables very much affect our perception and what we consider pleasing to the eye.

The following statements were describing the lighting in Scenario B:

"Cozy."
"The atmosphere is so dark."
"It creates a warm and comfortable atmosphere."
"It is a bit too reddish and spooky. I can't imagine if it being more than one fixture, how it would be all together. It creates a misperception of the surroundings."
"It is soft, but a bit too warm."

"The light is very natural and pleasant. It has an appearance of a campfire."

The majority of the answers described the environment as warm, soft and comfortable. They also mentioned that the lower brightness level helps them see farther.

Facial recognition, people

During this part of the experiment, I wanted to know if test subjects could see the facial features of the other person they weren't acquainted with from at least four meters away.
With the lighting of Scenario A, 50% of the participants could see the face of the other person, while with Scenario B, 70% of them had a hard time distinguishing facial features.
The majority of the participants felt safer being in the space with Scenario A's lighting than with Scenario B.

Experience of the night sky

60% of the participants stated that they could see the night sky with the light of Scenario B, while only 30% could see it with lighting Scenario A.

For the question on how they experience the night sky, 80% of the participants left a positive comment about Scenario B's light. On the other hand, only 50% were happy with Scenario A's light.

Scenario A:

"If I stand far enough, at least 5 to 10 meters, I can experience the dark sky."
"Given that the lights point at the ground, it is possible to see the sky. However, there is a high contrast between the two levels of the ground and the sky."

Scenario B:

Almost everybody stated that the lighting setup did not influence the way they perceive the night sky:

"The light doesn't affect me."
"Bright and more visible to see since there is no 'pollution' from the light"
"The vision of the sky is not altered by the lighting at all."
"It's clear, easy to see."

One person found the environment too dark, and one mentioned that the fixture could be better shielded.

Experience of surrounding nature

In both scenarios, the majority of participants agreed that the colours of the surrounding vegetation look close to what they expect. However, 30% of them did not agree with Scenario B's approach. Their approval was even lower at 20% for Scenario A.

During Scenario B, where the light was dimmed and had an amber tone, people didn't ascribe much importance to the fixture's colour rendering value. However, when I asked the same question during the standard setup of the fixture (Scenario A), 20% of them shifted towards the side that cares about the represented colours.

For Scenario A, people recognised that the lighting offers the chance to see colours better than using Scenario B. However, despite most respondents being satisfied with the colour rendering, someone called the light effect "artificial" during Scenario A. In Scenario B, most of the answers were critical about the light's warm, amber colour. However, some feedback gave the impression the colours were reflected correctly. These positive responses also noted that the lighting is cosier than conventional lighting.

13 out of 20 people (65%) used positive words when I asked them if the lighting solution allows for a better experience of / connection with the natural world than with the conventional lighting from Scenario B:

"It is a more pleasant experience due to the intensity of the light."

"It makes the experience smoother."

Unfortunately, due to an IT issue, I only received five answers for this question concerning Scenario A. Two of them felt more connected to nature than with conventional lighting:

"It is very bright yet pleasant for the clarity it provides. The rest was to the contrary for me; it's overpowering the area and makes me feel less connected to nature."

For the last question, I asked the participants if they were made aware that this lighting is better for the environment and if that would make this lighting solution more appealing to them. In both scenarios, the majority agreed or strongly agreed with this statement. However, 25% supported the idea more than Scenario B.

5.5. Conclusion

The majority of the participants found it easier to navigate and to see the immediate surroundings of the brighter solution (Scenario A). Despite this preference, some called the amber coloured, dimmed solution (Scenario B) a more pleasant light for walking on the path. When considering the ability to see others' faces from a short distance, it was undeniable that the higher the brightness of the light, the stronger the likelihood that participants can see facial features easier. However, after all the aspects of functional needs were considered, most people perceived the night sky and the space they were more pleasant. They felt more connected to nature with the light of Scenario B. Most participants did not consider colour accuracy to be a determining factor for their choices. However, some were critical about the amber colour of the light.

People are exposed to conventional light in most urban areas. As a result, they consider the lighting of Scenario A familiar. The introduction of a different lighting solution might be received with scepticism at the beginning. However, the benefits of this solution outweigh the drawbacks and can be convincing enough for people to adapt to it. The reduction of the brightness level in a given space will enhance the ability to see the surroundings and shapes in the distance. It will also reduce the chance of being able to identify facial features. That brings up a question: Is it possible to see others' facial expressions at night and outdoors, using a fixture on a low height without over lighting the surroundings? Most of the widely utilised bollards these days are underwhelming regarding peoples' facial recognition. (Park fixtures of Copenhagen references in analysis) Without causing glare or employing a high reflective surface, it's simply not possible to fulfil some visibility expectations with a 60-80 cm tall bollard. However, test subjects agreed that being able to experience the night sky without disturbance from their closest surroundings while fulfilling the city's basic needs is a powerful incentive. Furthermore, the lighting they're not used to would become more appealing if they were made aware of its positive impact on the surroundings.

Most of the participants are good friends of mine, which means I know where they're from and have a solid grasp of their cultural background. After the tests I conducted, we stayed on site a little longer and started to talk about the two lighting scenarios. It was interesting to see that my friends from southern Europe, northern Africa strongly favoured the brighter solution in many aspects. Meanwhile, most of the others preferred dimmer, warmer light. As we live in a multicultural environment, it's impossible to please everyone, as the way we've been raised and how we've spent the early days of adulthood can be quite different. Therefore, our perception and preferences are highly dependent on those individual experiences.

It was refreshing talking about light with designers who were not familiar with using light for aesthetic purposes, as they learn and work with it from a practical standpoint. I was positively surprised that they were aware of many rules of natural lighting, given their experience and cultural background. I believe this test identified that a small change could be perceived in a variety of ways. Despite this, all the participants agreed that in order to make more (naturally preserved) places accessible for people in the dark, the current conventional lighting scheme might not be a suitable solution anymore.

5.6.Dialux Simulation

After concluding my findings and the results from the light testing I created a simulated environment on a 3D software, with the lighting solution that carries the outcome of the analysis.

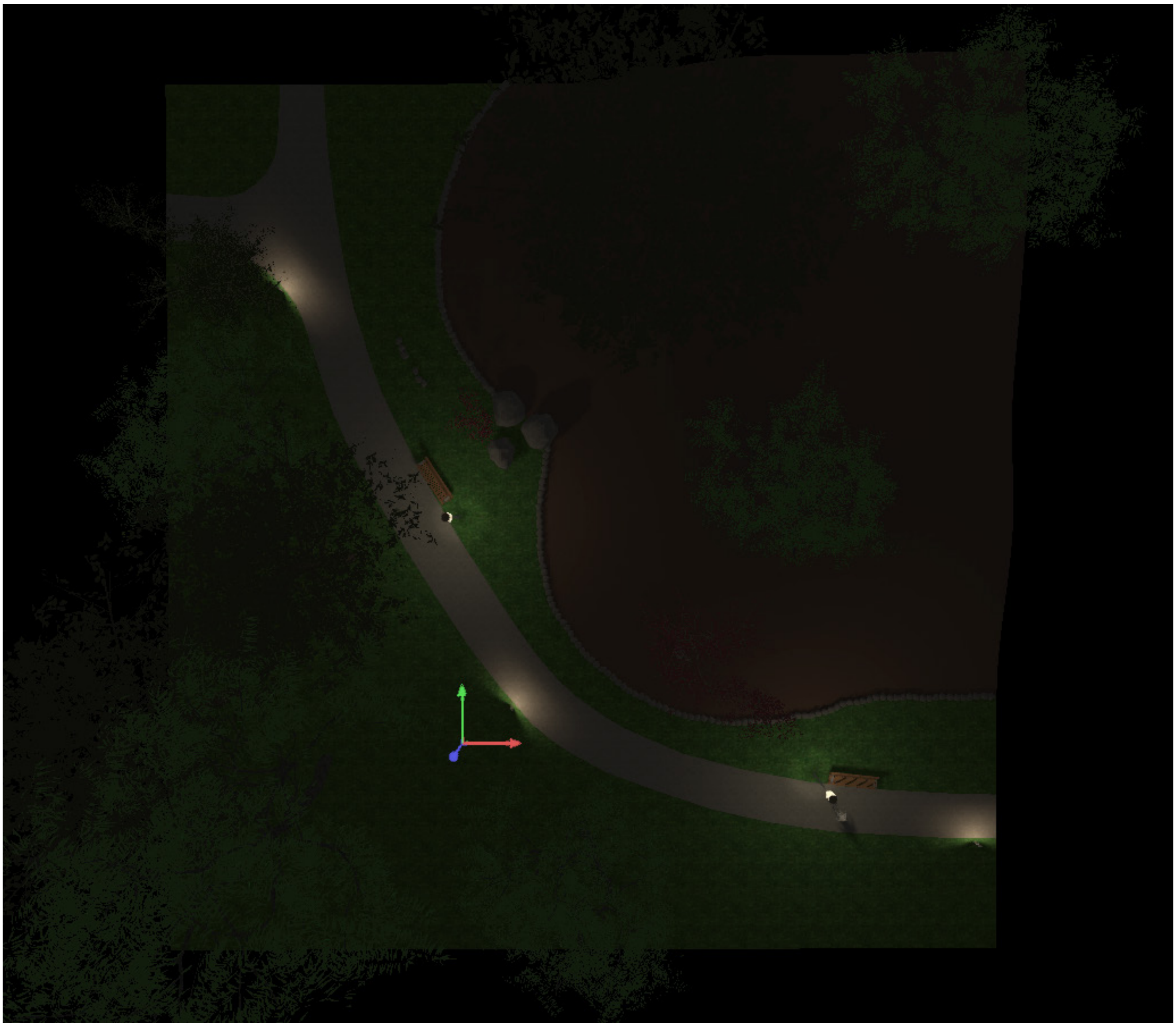


Figure 40. Rendered image of the initial design solution
(Personal archive)

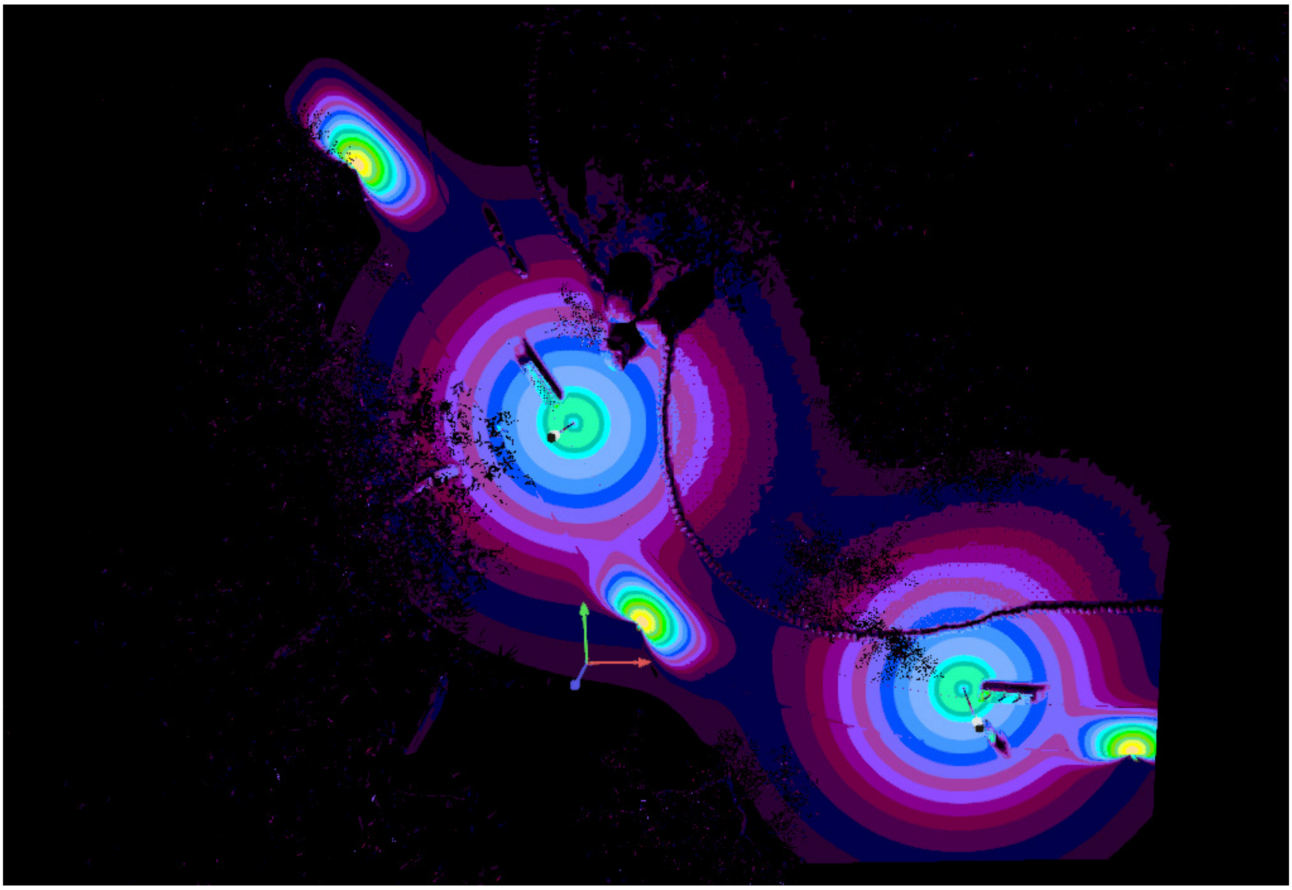


Figure 41. Pseudo colour of illuminance distribution. Top view
(Personal archive)

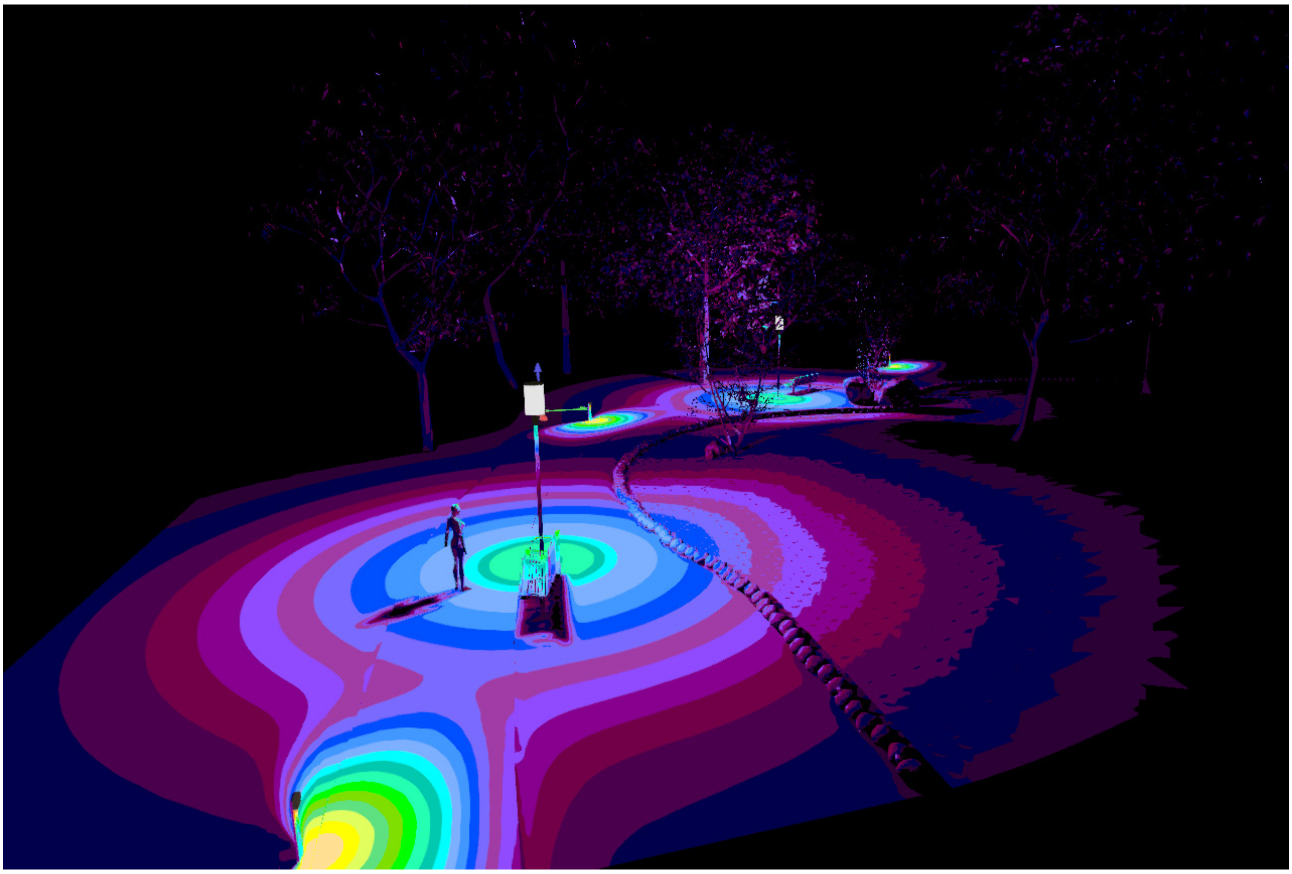


Figure 42. Pseudo colour of illuminance distribution. Side view
(Personal archive)

Chapter 6
Final Design Principals

6.1. Hierarchy - Richard Kelly
6.2. Allocation, the height of fixtures
6.3. Intensity
6.4. Colour spectrum
6.5. Uniformity
6.6. Control System
6.7. Timing
6.8. Sensory system
6.9. Discussion
6.10. Conclusion
6.11. Further development

6. Final Design Principals

In the previous chapter, I introduced my testing of two lighting scenarios, which from I concluded that people can perceive more the surrounding nature and the dark sky after sunset with a lighting solution that is dimmed, has a lower brightness, has a warmer colour tone than conventional urban lighting in a green environment. The majority of the people feel more connected to nature with the dimmed lighting solution. At the same time, most of them consider the brighter solution more effective for navigation and to see the direct surroundings.

"The concept that in darkness, one gains an alternative understanding of an object or space, it's beauty revealed through the absence of light, is one that we as human beings can experience on a daily basis with the natural cycle of day and night."
(Architectural lighting: designing with light and space / Hervé, Descottes)

Reflecting on the test results *from Chapter 5.*, *Theoretical Framework and Observations from Chapter 3.*, I came up with the following lighting design recommendation that provides a solution for my research question.

How can the lighting - with reduced short wavelengths on the colour spectrum - of urban green environments be designed in order to create attractive and accessible spaces for humans, while minimising the light's negative impact on the local habitat of bats?

The following recommendations give people the theoretical, technical, and practical information they need to know to determine whether electric lighting will affect wildlife and, if so, what management tools they can use to minimise and reduce the impact. These methods can be used in a variety of settings, from small projects to large-scale developments.

With this paper, I'm not determining the fixtures that can be used, but I'm specifying the recommended intervals of the colour spectrum and the intensity of light based on my findings. I'm also giving a recommendation for the allocation of the fixtures regardless of their beam angle. Furthermore, I'm describing possible lighting solutions for different elements of a green urban environment reflecting on people's activity.

6.1. Hierarchy - Richard Kelly

To create a lighting design that primarily fulfils basic human needs creates an attractive environment for people, and highlights details that entertain the viewers, I applied Richard Kelly's three principal techniques: Focal Glow, Ambient Luminescence, and Play of Brilliance. To preserve darkness in space and make sure the solution has the least negative impact on animals, mainly the bats, I introduce a hierarchy. It allows the user of this guide to decide if the application of additional layers is necessary based on the activities of people at the specific site.

Human (biological) needs mean orientation, physical security, relaxation of the body and mind, adjustment of the biological clock, contact with nature and with other living beings, the definition of personal territory. (Lam, 1977)

Figure 43. Illustration of Core Layer - Focal Glow of the lighting solution
(Personal archive)

Core layer – Focal Glow

The core layer, as Focal Glow, is functioning as a guiding light (as bollards); light on a low height without causing glare or spill light in the surroundings. It fulfils basic human needs such as orientation, visibility and a feeling of safety. The application of it has the least negative impact on the animals living in the surroundings.

Layer 2 - Scale level 1 – Ambient Luminescence

The first additional layer, as Ambient Luminescence, brings additional value to space. While the application of the core layer focuses on basic human needs, this layer creates an intimate atmosphere, enhances the sense of privacy, interactions between people, and supports the overall visibility in space. With this layer, the

Figure 44. Illustration of Core Layer - Focal Glow of the lighting solution
(Personal archive)

imminent surroundings are more exposed to electric lighting than with the core layer alone. For this reason, the allocation of the fixtures is critical. Prior observation of animals and registration of the vegetation is recommended before the installation of the fixtures.

Layer 3 - Scale level 2 – Play of Brilliance

The second additional layer, as Play of Brilliance, enhances people's experience in space. This layer can create an identity, landmarks by highlighting a particular element of the space or creating an entertaining light effect by itself. That highly affects the perception of people about the overall space.
The type of fixtures for this purpose can be various, such as spotlights, projectors, fluorescence light elements etc.

For this reason, it's a complex task to set up boundaries in terms of light effect, but one has to strive for using only the necessary light level. Their impact on the surrounding nature needs to be investigated.

6.2. Allocation, the height of fixtures

With all three layers, one has to position the fixtures near areas where the light effect is desired. Their placement should be avoided near possible habitats of bats.

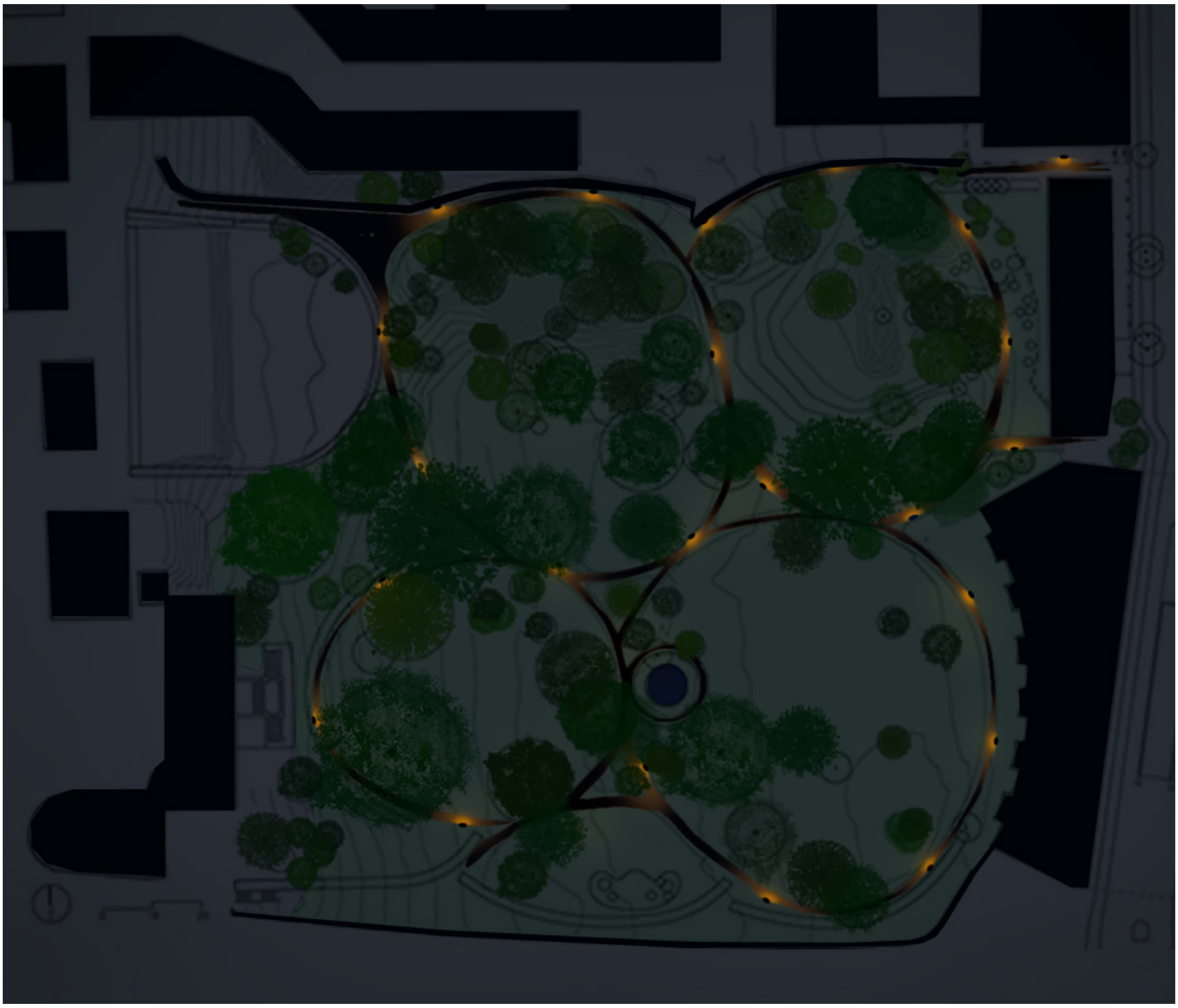


Figure 45. Illustration of the allocation of the Core Layer - Focal Glow fixtures
(Personal archive)

Core layer – Focal Glow

The fixtures that fulfil the core layer's functions should be installed on the side

of footpaths or pedestrian areas with asymmetric beam angle. Their purpose is to enhance visibility, orientation and support the sense of space. Their position along the footpaths has to be equally distributed to create a coherent structure that people can easily see through and understand their position in space. The fixtures should be aligned with the path in a distance of 15-25 meters depending on the spread of the fixture's light beam, the height of the light source and the density of vegetation in the surroundings. This distance allows people to see where the path is leading, but the fixtures are positioned less frequently to allow space for darkness.
The light sources of this layer should not be positioned higher than 80 cm, as this layer aims to guide and offer a better understanding of the space, which can be fulfilled from a low light level as such.

These fixtures highlight their imminent areas, where people are present, and their dynamics are slow paces. However, the reduced brightness creates low contrast with the surrounding darkness; hence people can see further, and others movements between the light sources. In areas that are surrounded by high vegetation, the frequency of the position of fixtures might need to be increased.

Layer 2 - Scale level 1 – Ambient Luminescence

This layer complements the lighting of the Core layer. As the base of orientation and visibility is supported by the core layer, integrating this layer will create brighter zones. In these nodes, people feel more private and comfortable than in darker areas. (Brands, et al., 2014) The application of lanterns on a maximum 3,5 meter height ensures to fulfil the needs mentioned above. It will leave enough space for bats to fly above the fixtures, as most of them fly between 0-10 meters. (Møller, et al., 2011 p. 20) (Baagøe, 1991) The determination of the distance between two fixtures can be various; their allocation needs the be based on previous observations of people's movement in space and the density of the vegetation. If the desired lit up area cannot be covered by one lantern at a 3,5 meter height, the number of fixtures should be increased instead of increasing the height. This way, the is space above the fixtures should not affect more bats flying habits than a single fixture.

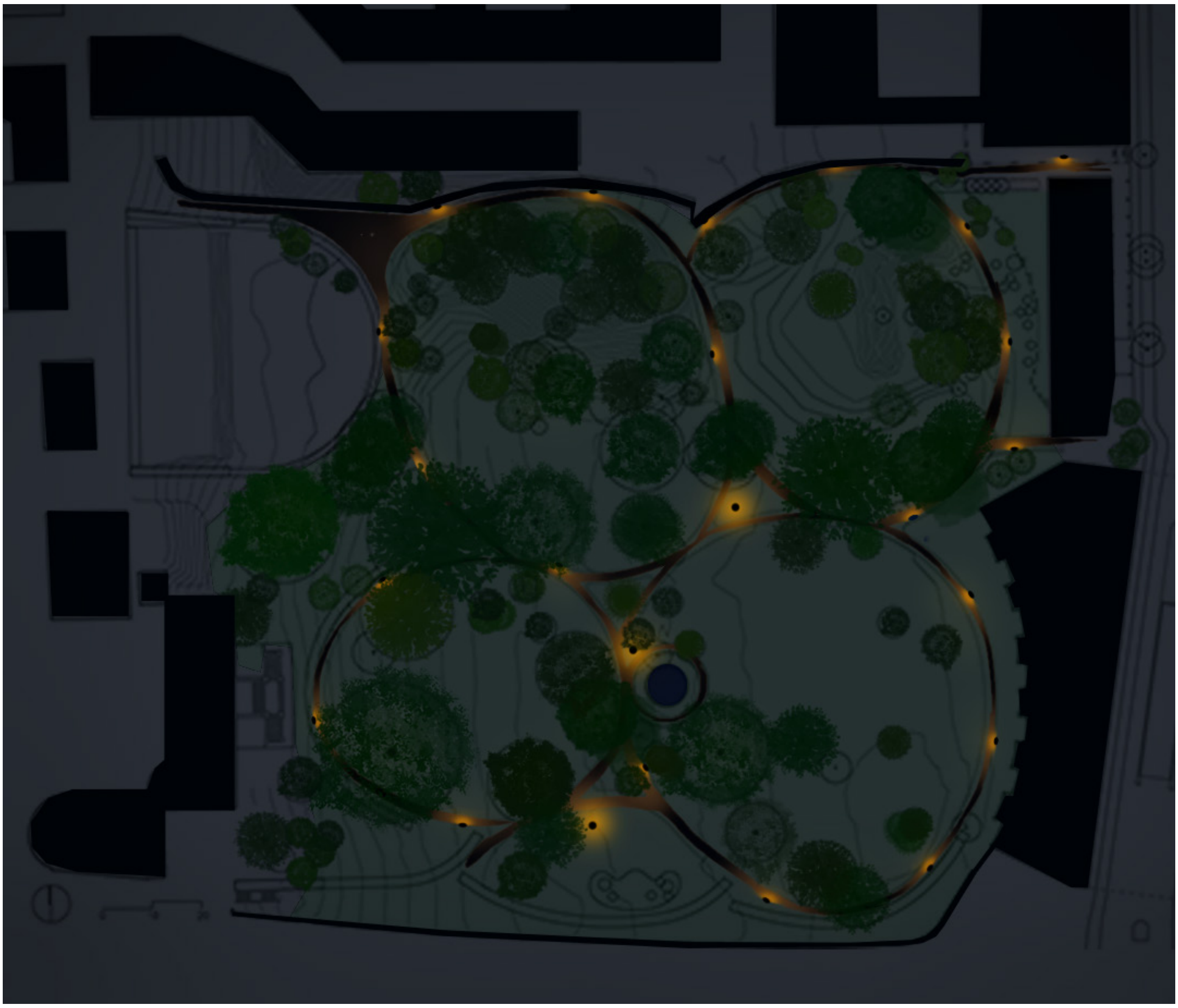


Figure 46. Illustration of the allocation of Layer 2 - Scale level 1 – Ambient Luminescence
(Personal archive)

Layer 3 - Scale level 2 – Play of Brilliance

The application of the third layer brings an additional value to space by highlighting particular elements or creating a unique light effect itself. The allocation of the fixtures depends on the structure and the position of the specific elements in the site. Light sources on over 5 m height should be avoided (to leave enough space for bats to fly over the fixtures) (Møller, et al., 2011 p. 20) (Baagøe, 1991) as the light should not spread to bigger surfaces to avoid glare and the possibility of spill light.

With the integration of the third layer, the light scene is complete. It results in a memorable, comforting lighting solution that enhances the feeling of safety and orientation for humans. The optimisation of activation, brightness, and colour of the light strives to minimise the negative impact on the local bat population.

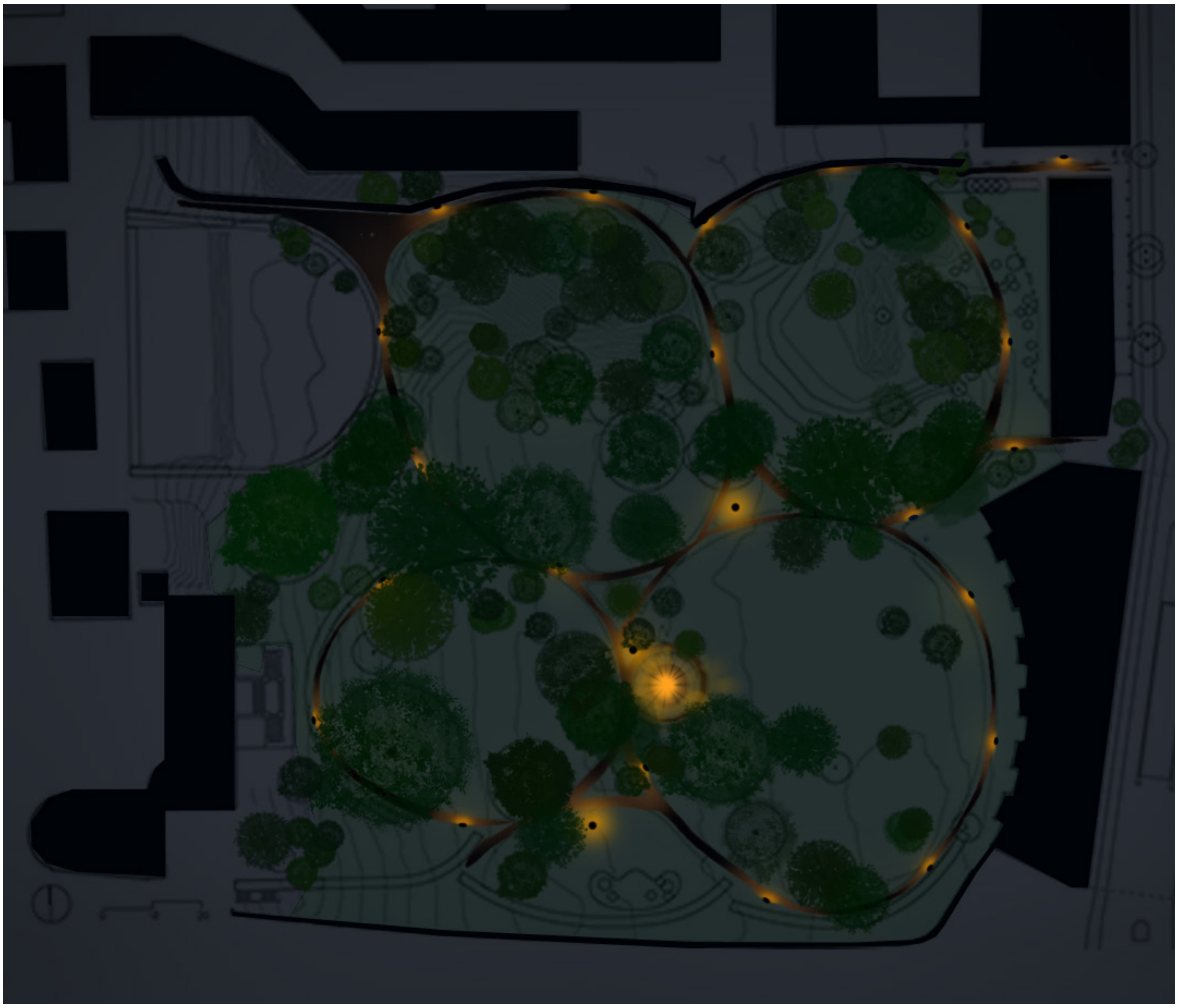


Figure 47. Illustration of the allocation of Layer 3 - Scale level 2 - Play of Brilliance
(Personal archive)

6.3. Intensity

The brightness intensity is varying for layer to layer as each of their purpose are very different. *Core layer – Focal Glow* provides an overall subtle lighting, spreading out on the footpaths offering a better understanding of the site, while, *Layer 2 - Scale level 1 – Ambient Luminescence* and *Layer 3 - Scale level 2 – Play of Brilliance* focuses on certain zones based on people's activities and the surrounded nature.
However, one rule applies to all layers: to provide sufficient light for the intended tasks but never over-light them.

"A principle in good lighting design maintains that the brightest areas in a

person's field of vision should not exceed ten times the brightness of the average level to which the eye is adapted.
Zone E3:
Areas of medium ambient brightness. These will generally be urban residential areas. Lighting Zone E3 or E4. Then, a parcel zoned for commercial use in the rural area might be permitted 25,000 or 50,000 lumens per net acre, while a parcel with the same zoning in the urban area might be permitted 100,000 or 200,000 lumens per net acre" (IDA)

Core layer – Focal Glow

The application of the fixtures used as elements of the core layer provides sufficient light for activities that are slow-paced, recreation, walking. The goal is to keep the overall brightness level as low as possible to protect the darkness in the surroundings and allow the human eye to adapt to the darkness and perceive the characteristics and movements in between light sources. For this reason, this layer would not provide sufficient brightness for fast-paced activities in space such as running or cycling. The brightness on the ground underneath each fixture should not be higher than 40 lux. Preliminary analysis of the material of the ground (soil, gravel, concrete, cobalt stone, grass etc.) needs to be conducted as their reflectance ratio is highly affecting the perceived brightness (luminance).

For such activities as running or cycling on the footpath, more densely allocated fixtures are required with the result of a light carpet that ensures the safe conditions for running, provide sufficient light for detecting the quality and changes of ground levels. However, this direction would go against my goal that is to be able to perceive details in darkness as well.

Layer 2 - Scale level 1 – Ambient Luminescence

The second layer mainly functions as an atmosphere creator element of the three-layer system by using limited height (maximum3,5 meter tall) lanterns, illuminating specific zones. People would rather interact with each other under lit up zones than in areas that are left in darkness. (Brands, et al., 2014) (Rahm, et al., 2021) The light level should support needs as seeing each other faces in a small distance (1-2 meter) while talking, however still being able to sense the movements in the dark surroundings. The light level on eye-level should not exceed 50 lux (as reference Philips City Swan pole light's value is 55 lux in Søndermarken) underneath the fixture that is equipped with a light source with a narrow beam angle.

High contrasted, increased brightness that's focused on a small zone should be avoided as it would trigger the feeling of being exposed for people who are staying under the lit-up area. With the high contrast of bright and dark areas, they would lose their ability to adapt to the surroundings. Spotlighting and projectors on a 3,5 m pole should be avoided due to possible glare and vandalism.

Layer 3 - Scale level 2 – Play of Brilliance

The third layer is functioning as an aesthetical element of the composed light in space. My aim with this layer is to trigger an unexpected, sensual feeling in people around the highlighted surface(s) to enhance people's connection to nature or the site's landmark. The light effect should be subtle instead of explosive, while bright enough to attract the visitors' attention to it. The fixture is either a projector or a spotlight highlighting a sculpture or an alternative light source illuminating an area in its direct surroundings. The beam angle should be adapted to the need, and the brightness should be lowered to the lowest possible level that still fulfils its purpose.

6.4. Colour spectrum

The colour spectrum of the electric lighting has been determined based on the studies about the peak of colour sensitivity of animals, more precisely bats (Spoelstra, et al., 2017; Eisenbeis, et al., 2010; Pendoley, 2020 p. 5; Langevelde, et al., 2011).
With the reduced short wavelengths of the spectrum, electric lighting has a low impact on bats habitat in the surroundings (Spoelstra, et al., 2017). All three layers of the composed lighting in space adopts the warm, amber coloured light.

6.5. Uniformity

Uniformity is measured on the walking paths in two different cases,
(1.) where the Core layer of lighting is present alone, and
(2.) where the second layer is also activated.
In the 1st case, the lighting solution strives for a low contrast environment, where the value of uniformity would not trigger concerns.
Regarding the 2nd case, the lanterns would increase the difference between dark and bright areas. However, following the International Dark-Sky Association (IDA) recommendations, if the brightest area in people's field of vision does not exceed ten times the average level brightness to which eye is adapted, it's considered good design.

The third layer's light sources are not base functional elements; they're integrated into the design to highlight particular areas, enhance aesthetics and attract people's attention. The recommendation from IDA of the brightness level should not exceed ten times the average is also applied. However, their allocation is site-specific, might not align with footpaths or pedestrian areas, for this reason, I do not consider including them in the light calculation in the matter of uniformity.

6.6. Control system

DALI protocol is the main controling system to be used with the solution offered in this paper. It manages the diming of the electric lighting with predetirmind colour temperature and works in synchronisation with other controlling systems.

6.7. Timing

The electric lighting system turns on when the sun sets, reaches the horizon (civic dusk – twilight) and stays on until the sun rises (civic dawn – twilight. The timer follows the atomic clock to ensure its precise accuracy.

6.8. Sensory system

To create a lighting solution that recognises the need to activate the luminaires in space when human beings are present, the application of a sensory system is necessary.
The combination of motion and LiDAR sensors will only react to people's movements and presence in space, as it recognises large elements as a human body. With the proper sensitivity setup, animal activity will not affect the activation. (Datasheet of the LiDAR sensor can be found in the Appendix)

Core layer – Focal Glow

The motion detectors are integrated into every bollard. The brightness of the fixtures is reduced to 30% when there is no human activity on site. People's movement would activate the closest and the two surrounding bollards; the brightness level increases to 100% in order to ensure wayfinding and enhance the feeling of safety.
The light stays on 100% as long as there are movements in the range of the sensors and for an additional five minutes. Once the visitors moved forward, the light dims down to 30% again.
Motion sensors are the most affordable sensors available nowadays, however, their range and sensitivity are limited and their sensitivity adjustment is required.

Layer 2 - Scale level 1 – Ambient Luminescence

The LiDAR (Light Detection and Ranging) sensor with Infrared (850 nm) rays detects objects in its working range that wasn't present when it was calibrated. The LiDAR sensor is recommended to be positioned around sitting areas and where people might gather.
As people might stay in the lit-up areas for a longer time than on the footpath, the motion detectors would not stay activated without major movements. For this reason, the integration of the LiDAR sensor is necessary to detect people who

might be still without movements.
Due to its high price range, the integration of this layer would greatly increase the costs.

Layer 3 - Scale level 2 – Play of Brilliance

People's behaviour in areas where this layer is applied is similar to the **Layer 2 - Scale level 1 – Ambient Luminescence**. People are still spending time in one place, enjoying the view or each other's company. For this reason, the applied solution would be the equivalent to **Layer 2 - Scale level 1 – Ambient Luminescence**.

6.9. Discussion

The primary objective of my thesis was to develop some guidelines and make recommendations for new lighting design that harmonises with the surrounding nature in green areas, creates a pleasant atmosphere for people and has limited negative impact on bats habitat in the area. Another objective was to show an example to illustrate how small changes made to current lighting solutions can benefit both nature and human beings in an urban green environment.

Studies have shown that people living in urban areas need access to green areas even during dark hours. Although typical electric lighting may provide improved visual orientation, better sense of space and feeling of safety for humans, it may have some negative impacts on plants and animals. Therefore, a more in-depth investigation is required to assess the effect of coloured light on various species that are habitat in our immediate surroundings.
A better understanding of human's perception of darkness is also necessary and information is needed on how it can be enhanced with a minimal increase of illuminance. Furthermore, for future lighting solutions we need to learn more about eye adaptation to coloured lighting and to look into their possible applications.

The principal scope of my thesis is to find a proper balance between light and darkness, and determine how can both them be simultaneously present in urban areas. I considered these aspects essential as in the 21st century we are facing difficulties with making people aware of the major challenges associated with light pollution and its long-term effect on the ecosystem. Not even mentioning the fact that the milky way disappeared right in front of the eye of 60% of European citizens (Thorsen, 2021). Until now actions to reduce light pollution were only made in certain countries but not acknowledged the overall negative effect world-wide.

6.10. Conclusion

Emphasizing the importance of preserving darkness in our urban environment at night while granting feeling of safety for people is crucial. I believe, finding the balance between darkness and light is the right way to achieve this. However, if the new lighting solution is optimised to people's needs and dynamics, and it is controlled in terms of intensity and light colour of spectrum, the negative impact on nature can be kept at a minimum level.
The avoidance of highly positioned fixtures will allow bats to fly above the light sources during time periods when they are active, and will ensure that they are not disturbed in their flying paths or when they into hibernation (deep sleep).

It became clear that having access to nature areas in an urban environment even during dark hours have a positive impact on supporting mental health and reduce stress.

Mainstream view of darkness in an urban environment is considered unsafe and often commented in a negative tone. As until now, people in cities have a common view about electric lighting that says "the brighter the better". In order to introduce a light design, which could be called a "dark" design, a valid explanation and some transitional time is needed for people to change their mind-set and not consider darkness negative. The introduction of dark zones and lighting solutions using lower light levels than conventional lightings, must be preceded by deeper research taking into account human perception and biodiversity as well as crime rates in the relevant area. A positive result of this investigation could prove that crime rate and darkness may not be correlated. (Marchant, 2004) The involvement of politicians to promote the concept of a new lighting design could lead to a better acceptance from the community. However, if they do not believe in the success of this innovation, I don't see a chance to get closer to the implementation of a more sustainable lighting system in our cities.

6.11. Further development

To increase the acceptance of a sustainable lighting using dimmed and coloured (amber) light in our urban surroundings can be challenging. As the example shows (light testing Light Bureau experiment) convincing municipalities and decision makers about the benefits of reducing overall brightness and implementing colour lighting is crucial. Furthermore, widely accessible information, studies about light effect on urban nature would be beneficial and good way to educate the greater public.

On the other hand, I'm aware that the implementation of a new lighting solution in a small scale as my chosen example of my thesis, will not have a major impact on biodiversity. For this to happen, the development of an updated master plan is necessary. The updates should introduce light level intervals with maximum values for various needs.

Based on my work with manufacturers over the last year, I experienced that most of their standard fixtures are not available in colour temperature lower than 2700-3000K without the potential negative impact of short wavelengths. There are a few good examples like iGuzzini and Philips who started to integrate luminaires with lower colour temperature or coloured lighting, but as long as it's not introduced to greater production, it's not affordable to work with custom made fixtures long term, regardless of the scale of a project.

Chapter 7
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7. Biblography

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7.2 Appendix

1, Observation time periods:

JC. Jacobsen have

11th February 2021, 16:30-17:40

27th February 2021, 16:40-17:30

13th March 2021, 17:00-17:50

24th March 2021, 17:40-18:50

19th April 2021, 20:00-20:45

5th May 2021, 20:30-21:30

19th of May, 18:00-20:00

Søndermarken

13th March 2021, 17:50-18:30

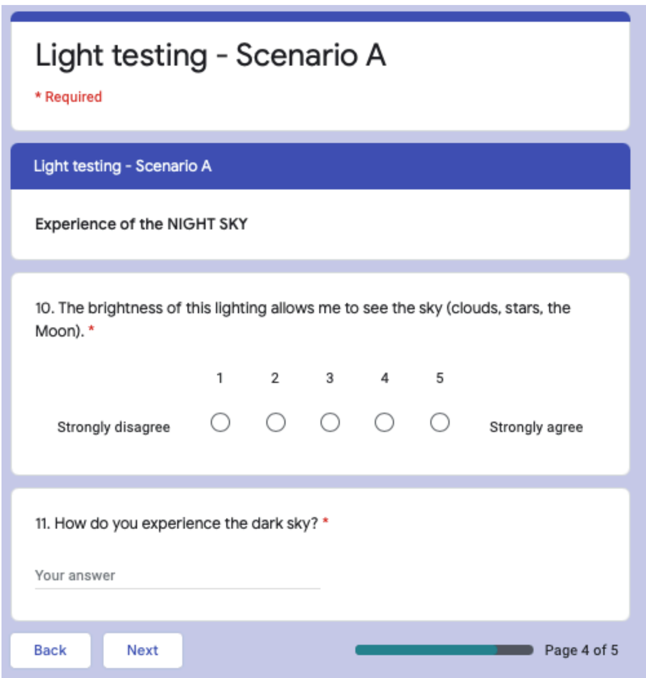
24th March 2021, 18:50-19:50

19th April 2021, 20:45- 22:00

2nd May 2021, 20:30-23:00

19th of May, 20:00-21:00

2, Outdoor lighting test Questionnaire; Scenario A (Equivalent to Scenario B)


Light testing - Scenario A

* Required

Light testing - Scenario A

Experience of the NIGHT SKY

10. The brightness of this lighting allows me to see the sky (clouds, stars, the Moon). *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

11. How do you experience the dark sky? *

Your answer

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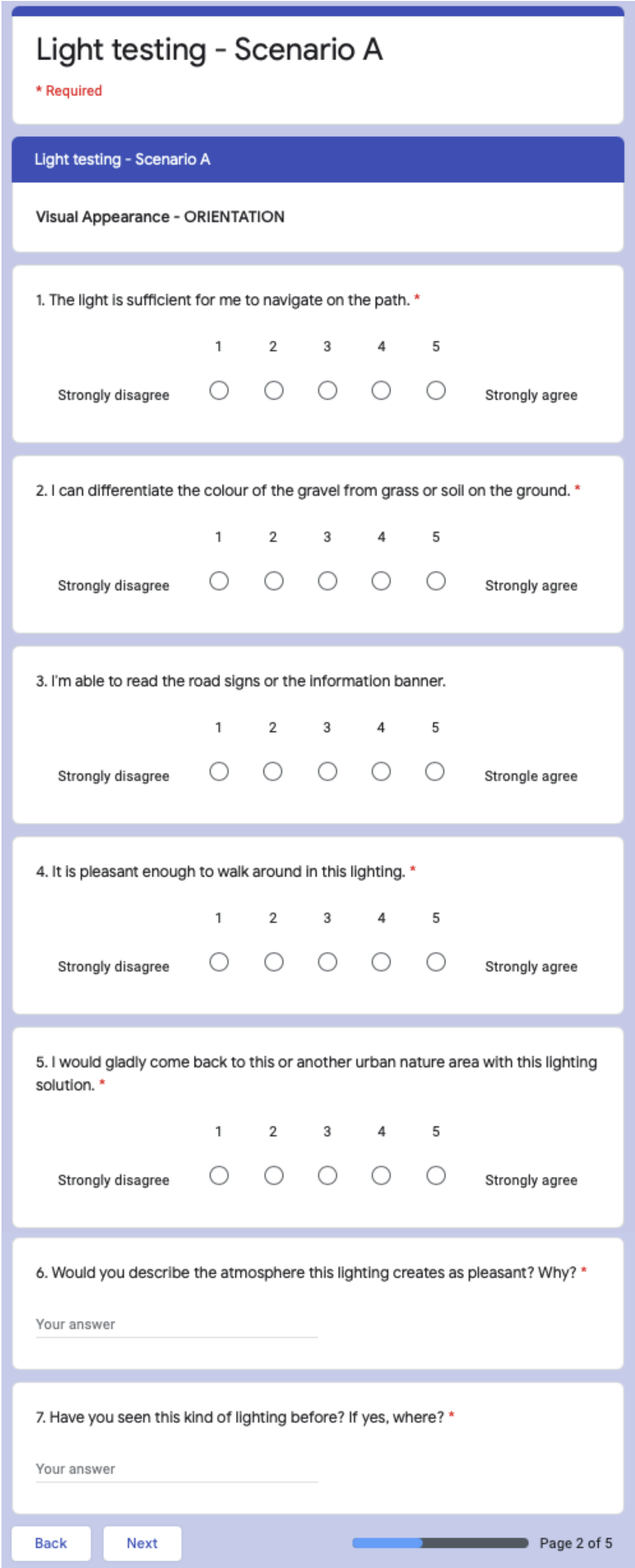

Light testing - Scenario A

* Required

Light testing - Scenario A

Visual Appearance - ORIENTATION

1. The light is sufficient for me to navigate on the path. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

2. I can differentiate the colour of the gravel from grass or soil on the ground. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

3. I'm able to read the road signs or the information banner.

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongle agree

4. It is pleasant enough to walk around in this lighting. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

5. I would gladly come back to this or another urban nature area with this lighting solution. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

6. Would you describe the atmosphere this lighting creates as pleasant? Why? *

Your answer

7. Have you seen this kind of lighting before? If yes, where? *

Your answer

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Light testing - Scenario A

* Required

Light testing - Scenario A

Visual Appearance - PEOPLE

8. I can see the faces in the distance, where the marker is placed. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

9. I feel as safe with this lighting as I would with a conventional lighting solution. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

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Light testing - Scenario A

* Required

Light testing - Scenario A

Experience of the NIGHT SKY

10. The brightness of this lighting allows me to see the sky (clouds, stars, the Moon). *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

11. How do you experience the dark sky? *

Your answer

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Light testing - Scenario A

* Required

Light testing - Scenario A

Visual Appearance - NATURE, VEGETATION

12. The colours in the surrounding vegetation look close to what you expect. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

13. It is important for me that the colours stay as true as possible in the electric lighting as they are during the day. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

14. Do you think colours stay true with this lighting compared to conventional lighting? *

Your answer

15. In contrast to conventional lighting, does this lighting solution allow for a better experience of / connection with the surrounding nature? *

Your answer

16. If you were made aware that this lighting is better for the environment, that would make this lighting solution more appealing for you. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Back Submit Page 5 of 5

3, Answers of the questionnaires:

Scenario A
https://docs.google.com/forms/d/1mCFnbPQajx-FoBp0ltHvInsQLCmeMEbaq1zMoqZElU8/edit?usp=sharing

Scenario B
https://docs.google.com/forms/d/1ZtzaG9D1agNnoEu9K2s5-2DiynL5Z21eHoP5Em4rnX8/edit?usp=sharing

3, Data sheets

LiDAR sensor

cdn.sick.com/media/pdf/4/44/444/dataSheet_TiM571-2050101_1075091_en.pdf

TiM571-2050101 | TiM5xx

2D LIDAR SENSORS

Ordering information

Type	Part no.
TiM571-2050101	1075091

Other models and accessories → www.sick.com/TiM5xx

Detailed technical data

Features

Measurement principle	HDDM
Application	Outdoor
Light source	Infrared (850 nm)
Laser class	1 (IEC 60825-1:2014, EN 60825-1:2014)
Aperture angle	
Horizontal	270 °
Scanning frequency	15 Hz
Angular resolution	0.33 °
Working range	0.05 m ... 25 m
Scanning range	
At 10% remission	8 m

Mechanics/electronics

Connection type	1 x "Ethernet" connection, 4-pin M12 female connector 1 x connection "Power/Synchronization output" 5-pin, M12 male connector 1 x Micro USB female connector, type B
Supply voltage	9 V DC ... 28 V DC
Power consumption	Typ. 4 W
Housing color	Gray (RAL 7032)
Enclosure rating	IP67, applies only when the plastic cover of the "Aux interface" is closed (IEC 60529:1989+AMD1:1999+AMD2:2013)
Protection class	III (IEC 61140:2016-1)
Weight	250 g, without connecting cables
Dimensions (L x W x H)	60 mm x 60 mm x 86 mm

Performance

Response time	Typ. 67 ms

[1] Typical value at 90% remission up to maximum scanning range; real value depends on ambient conditions.

[2] Typical value at 10% remission up to a sensing range of 6 m, actual value depends on ambient conditions.

2 DETECTION AND RANGING SOLUTIONS | SICK

Product data sheet | 2021-05-07 20:11:24
Subject to change without notice

iGuzzini iWay round bollard datasheet

https://www.iguzzini.com/bw79/

iWay round

Design Jean Michel Wilmotte **iGuzzini**

Last information update: June 2021

Product configuration: BW79
BW79: Bollard D=170mm H=1000mm Warm White Led with electronic ballast and symmetrical optic

Product code
BW79: Bollard D=170mm H=1000mm Warm White Led with electronic ballast and symmetrical optic

Technical description
Outdoor direct light luminaire which can be planted in the ground, designed to use warm white LED lamps, with symmetrical optic. The product consists of the lamp assembly and the body. The cylindrical body is made of extruded aluminium with chromate coating treatment and painting. It houses the three stainless steel rods fixed to the base, giving the product a high level of resistance to impacts. The product is anchored to the ground by the fixing base made of corrosion-resistant low copper content die-cast aluminium alloy. The diffuser screen is made of transparent polycarbonate, and is secured to the component-holding box by a die-cast aluminium internal fixing ring. The sheet aluminium lamp cover guard includes housings for accessories. The ring for coupling the cover is made of die-cast aluminium with chromate coating treatment and painting. The top of the luminaire is closed by a die-cast aluminium outer cover, with a bayonet catch and a fixing screw. The screw can be removed with an Allen key (or with a special key upon request). The super-pure aluminium reflector is fixed to the inner cover plate by captive screws. The component-holding box is made of die-cast aluminium. All accessible parts have a top temperature of 75° C. All external screws used are made of A2 stainless steel.

Installation
Can be installed directly using Fischer fixings (on the ground), or using a fixing base and fixing plate with clamps coated in Dacromet, for an additional guarantee against corrosion (to be ordered separately).

Colour	**Weight (Kg)**
Grey (15)	9.86

Mounting
ground anchored

Wiring
Inside the luminaire is the removable component-holding plate, secured to the box with captive screws and the quick coupling for the electrical connections. Electronic control gear. A wiring box fitted with a double PG for pass-through wiring is available on request. Complete with rubber output cable H05RN-F 2x1mm L=1700 mm. Accessories available for electrical connections, to be ordered separately, include a IP55 (B511) wiring box supplied with a double cable gland for pass-through wiring.

Notes
Product complete with LED lamp.

Complies with EN60598-1 and pertinent regulations

IK10 IP66 S&E A++

Technical data

lm system:	1180	Life Time LED 2:	80,000h - L80 - B10 (Ta 40°C)
W system:	12.4	Ballast losses [W]:	2.4
lm source:	2000	Lamp code:	LED
W source:	10	Number of lamps for optical assembly:	1
Luminous efficiency (lm/W, real value):	95.2	ZVEI Code:	LED
lm in emergency mode:	-	Number of optical assemblies:	1
Total light flux at or above an angle of 90° [Lm]:	94	Ambient operating temperature range:	from -20°C to +35°C.
Light Output Ratio (L.O.R.) [%]:	59	Power factor:	See installation instructions
CRI (minimum):	80	Inrush current:	9.2 A / 25 µs
Colour temperature [K]:	3000	Maximum number of luminaires of this type per miniature circuit breaker:	B10A: 27 luminaires B16A: 44 luminaires C10A: 45 luminaires C16A: 74 luminaires
MacAdam Step:	3	Minimum dimming %:	5
Life Time LED 1:	80,000h - L80 - B10 (Ta 25°C)	Overvoltage protection:	6kV Common mode & 6kV Differential mode

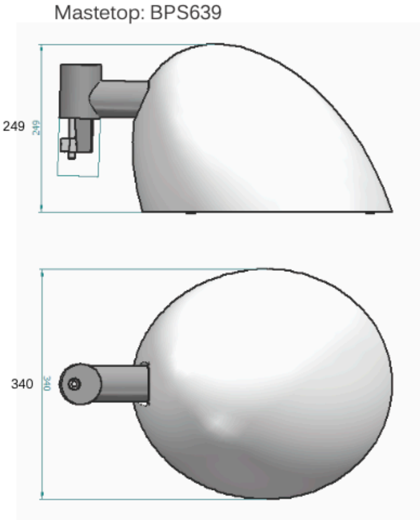
CitySwan Pole lighting

https://www.assets.signify.com/is/content/PhilipsLighting/comf1250-pss-global

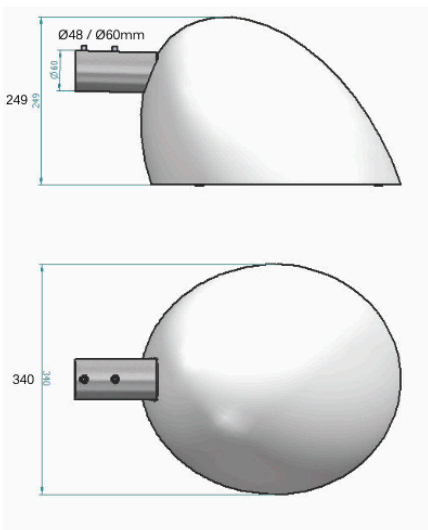
Produktinformation

Type	Mastetop: BPS639	Mastearm: BRS639	Vægarm: BWS639
Bredde	Ø384/340 mm		
Højde	249 mm		
Vægt	Max 5 kg		
Farve	Opalhvid		
Materialer og finnish	Armaturhus: slagfast PMMA. Afskærmning: fladt glas. Beslag: pulverbelagt aluminium		
Marinesalt beskyttelse	Ja		
Spænding	220 - 240 V / 50 - 60 Hz		
Klassifikationer	Klasse I eller II, IK10, IP66		
Montering	Mastetop: Ø60 mm	Mastearm: Ø48 eller Ø60 mm	Vægarm: Via 3/4"
Installation	Leveret med 10 meter forudinstalleret kabel (HO5VV-F 2x1,0 mm2 eller FQQ halogenfri 2x1,5 mm2)		
Driftstemperatur	-30 to +25°C		
Systemeffekt	16 - 74 W		
Lysudbytte	2.000 - 9.800 lm		
Systemeffektivitet	Op til 126 lm/W		
Konstant lysudbytte (CLO)	Valgfri		
Farvegengivelses-indeks (CRI)	>80 (>70 for 4.000K)		
Farvestabilitet (Mac-Adam)	5 SDCM		
Farvetemperatur (K)	3000K, 4000K		
Levetid (L100B10)	100.000 timer (forkobling: 100.000 timer, 90% overlevelse)		
Transientbeskyttelse	6 kV (10 kV valgfri)		
Optikker	Mediumstrålende (MDM), Bredstrålende (MDW), Symmetrisk (MDS), Asymmetrisk (MDA), Vådvej optik (DK), Symmetrisk Bred (DSW)		
Lysstyring	LumiStep, Dynadimmer, AmpLight, RF Starsense. DALI, CityTouch		

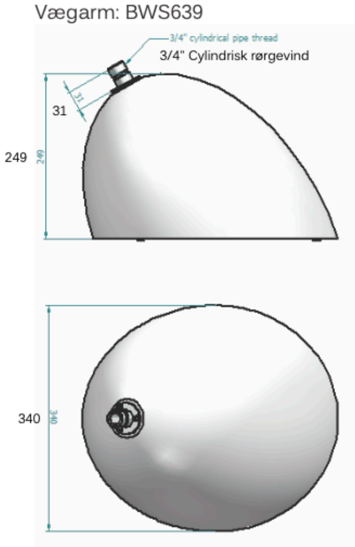
Mastetop: BPS639



Mastearm: BRS639



Vægarm: BWS639



CitySwan Bollard, BGP444 LED/740 230V II PCC BK-200

https://www.lighting.philips.com.eg/prof/outdoor-luminaires/road-and-urban-lighting/bollards/cityswan-bollard/910502610226_EU/product

PHILIPS Lighting

CitySwan Bollard

BGP444 LED/740 230V II PCC BK-200

CitySwan Pullert - LED LUXEON® K2 - 230 V - Polycarbonate bowl/cover clear - Black Noir 200 Sablé - Safety class II (II)

Being part of the CitySwan family designed by Danish architects Bjarne Schläger and Morten Weeke Borup, the CitySwan Bollard has a stylish, discreet, graceful appearance. The luminaire provides downward functional surface light from high-performance LEDs with incredibly low energy consumption. It is made of dark grey die-cast aluminum, and the housing has a characteristic ellipsoid shape familiar from the CitySwan road luminaire. CitySwan Bollard comes with a choice of three different optical covers: a transparent flat cover for the slickest design, a convex transparent cover for a more elongated light distribution, and a flat, opal cover for optimum uniformity.Nominated for the German design award "Designpreis" in 2009 Danish Design Award 2010/2011Design: Bjarne Schläger, light + architecture and Morten Weeke Borup, GHB Landskabsarkitekter A/S

Product data

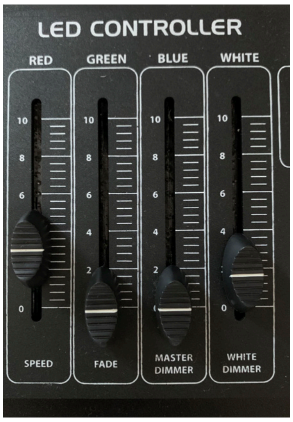
General Information	
Lamp family code	LED-K2 [LED LUXEON® K2]
Light source replaceable	No
Driver included	Yes
Optical cover/lens type	PCC [Polycarbonate bowl/cover clear]
Control interface	-
Cable	-
Protection class IEC	Safety class II (II)
Colour choice	Black Noir 200 Sablé
CE mark	CE mark
ENEC mark	-
Constant light output	No

Product Family Code	BGP444 [CitySwan Pullert]
Operating and Electrical	
Input voltage	230 V
Input frequency	50 to 60 Hz
Controls and Dimming	
Dimmable	No
Mechanical and Housing	
Dimensions (height x width x depth)	NaN x NaN x NaN mm (NaN x NaN x NaN in)

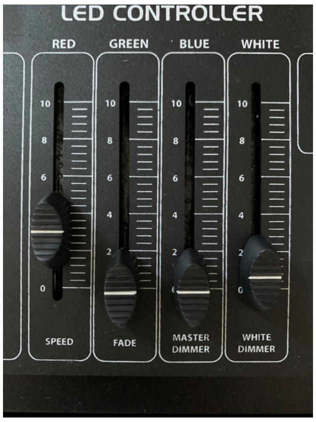
Datasheet, 2020, July 29

data subject to change

DMX Controller slider position from the indoor lighting tests



Indoor lighting test, DMX Sliders Scenario 1.
(Personal archive)



Indoor lighting test, DMX Sliders Scenario 2.
(Personal archive)