PARK OF DARKNESS

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ABSTRACT

This thesis investigates how we can create context conscious lighting design in urban green areas, challenging the current preconceptions about darkness and creating nocturnal experiences for the users whilst minimising the impact on biodiversity. Through an extensive literature review and site analysis of Søndermarken, including an exploratory test and a revised test protocol, a more holistic design framework is created on the back of current lighting design philosophies. This framework ensures minimal adverse impact on biodiversity and thus allows the lighting designer to focus on the creative aspects of a project and the creation of atmosphere. The framework stresses the importance of site specificity and is utilised in creating a design proposal for the park of Søndermarken. It features low-illumination luminaires to facilitate the adaptation to darkness and subtle pools of light to pique interest and encourage exploration. The design proposal visualises how the framework can be used to elevate the importance of darkness and expand the perspective on the simplistic duality of light and darkness.

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CHAPTER 1

BACKGROUND

As part of our master studies we have attended an internship semester in two lighting design consultancy firms in New York and Paris respectively, during which we have worked on projects of various scale , both indoor as well as outdoors. Both of our internship experiences dealt with private clients as well as institutions and allowed us to develop our critical approach to lighting. When deciding the subject for this graduate thesis, we have decided to combine the two subjects that we have been working with in the previous semester: biodiversity and atmosphere. This decision drove us to choose an existing park in Copenhagen and use it as a case study for developing a new framework for urban landscape lighting. We ultimately opted for Søndermarken, a rather large green area between the boroughs of Frederiksberg and Valby (figure 1).

With this thesis we are hoping to challenge the current views on how lighting in parks is approached, by offering a fresh perspective that takes into account a wider range of parameters. It is our intent to open the possibilities for future works to have a greater focus on the balance between man and nature with a newfound appreciation for the beauty that can be discovered in the darkness of the night sky.

Figure 1: Photograph of Søndermarken (personal archive)

INTRODUCTION

According to the United Nations, by the year 2050, 68% of the world population will be living in urban areas (United Nations, 2018). At this rate of development, green areas within the city landscape will become more and more precious and increasingly critical to preserve. Public parks are the lungs of industrialised cities and they help with the air quality as well as the mental health of the citizens, who are able to take a break from bricks and concrete to enjoy more natural surroundings (Van den Brink et al., 2016).

In order for a park to be healthy, it has to maintain a thriving and diverse flora and fauna, which is to be understood in its totality. Biodiversity is not limited to species diversity but it includes a broader range of factors such as variety, biological interaction and abundance. Specifically, there has to be genetic variety as well as an abundance of species, and all of them have to be part of a balanced circle of interaction.

With the advent of light emitting diode (LED) technology, general lighting has spread vastly around cities, making the night increasingly brighter (Bruce-White & Sharglow, 2011). LED lighting has many upsides compared to older technology, such as competitive pricing, low energy cost and a longer lifespan. Another aspect of LEDs is their potential for a high colour rendering (CRI) as well as control over colour temperature (CCT). Lastly, this technology allows for a variety of spectral power distributions (SPD). The commonly used white LEDs carry a peak in the short wavelengths. This is one of the issues that can negatively impact biodiversity as it has the potential to affect the natural rhythms of plants and animals if not correctly addressed.

Darkness therefore gains more relevance within the conceptualisation of lighting design in urban green areas, and it needs to be addressed from the human perspective as well. Humans' relationship with darkness has changed in the last two centuries, after the birth of electric lighting and its introduction in public streets and areas. Cities have gone from relatively dark landscapes at night to full blown artificial constellations of lights that make the night sky disappear. During this process, people have lost connection with the natural darkness that our ancestors had and have been progressively trying to exile it from cities.

There are those who claim that access to the night sky is a basic human right, but because of the race to illuminate cities, we have made it increasingly harder to experience (Bogard, 2013). Additionally, darkness is still seen negatively as something to fear, in opposition to light, but there is a growing sentiment that hopes to abandon this dichotomy and envision it as coexisting elements of the same space (Edensor, 2012).

In order to move in that direction we decided to approach this issue by looking into the aesthetic and philosophical implications of atmosphere in architecture. Atmosphere, being an often unspoken aspect of architectural projects, is difficult to describe, yet humans have an innate knowledge of how to grasp it (Zumthor, 2006).

By introducing an approach to lighting based on atmosphere, in combination with a considerate approach towards biodiversity, we aim to make people re-discover their lost connection with the nightscape, help develop a new sense of place in a welcoming dark environment that benefits both humans, animals and plants, all together contributing to a healthier ecosystem in the parks of the urban fabric of the city.

VISION

The overall vision for this thesis is to create a conscious lighting design for humans. Our core idea is to challenge the current perception that darkness plays in our society, by exploring the idea advanced by Roger Narboni of 'nocturnal urbanism'. We believe that by changing our approach to lighting we can rediscover our appreciation of darkness as something to treasure. By opting for non disruptive solutions we can decrease light pollution and preserve the ecosystems that are being affected in our city parks. By promoting a new approach on how to experience darkness and atmosphere in urban parks we plan on strengthening communities, while also developing a framework that can help municipalities invest in and design their green areas better.

We have explored our vision of bringing darkness to the city through the iterative interrogative technique known as the five whys, to boil our intention down and grasp the core issue surrounding the perception of darkness. Consequently, we have asked ourselves more open and practical questions to extract the subjects that we could tackle to realize this vision. Figure 2 illustrates the interrogation process.

PROBLEM STATEMENT

In order to set a clear path of investigation, we have developed the following problem statement which is at the base of this thesis:

"How can we through an emphasis on darkness and atmosphere minimize the adverse effects that light has on biodiversity whilst creating nocturnal experiences for the urban population."

Afterwards, we have subdivided the problem statement in smaller success criteria as guidelines that would allow us to tackle the main question more effectively:

- Facilitate darkness
- Limit impact on biodiversity
- Inspire nocturnal use of parks

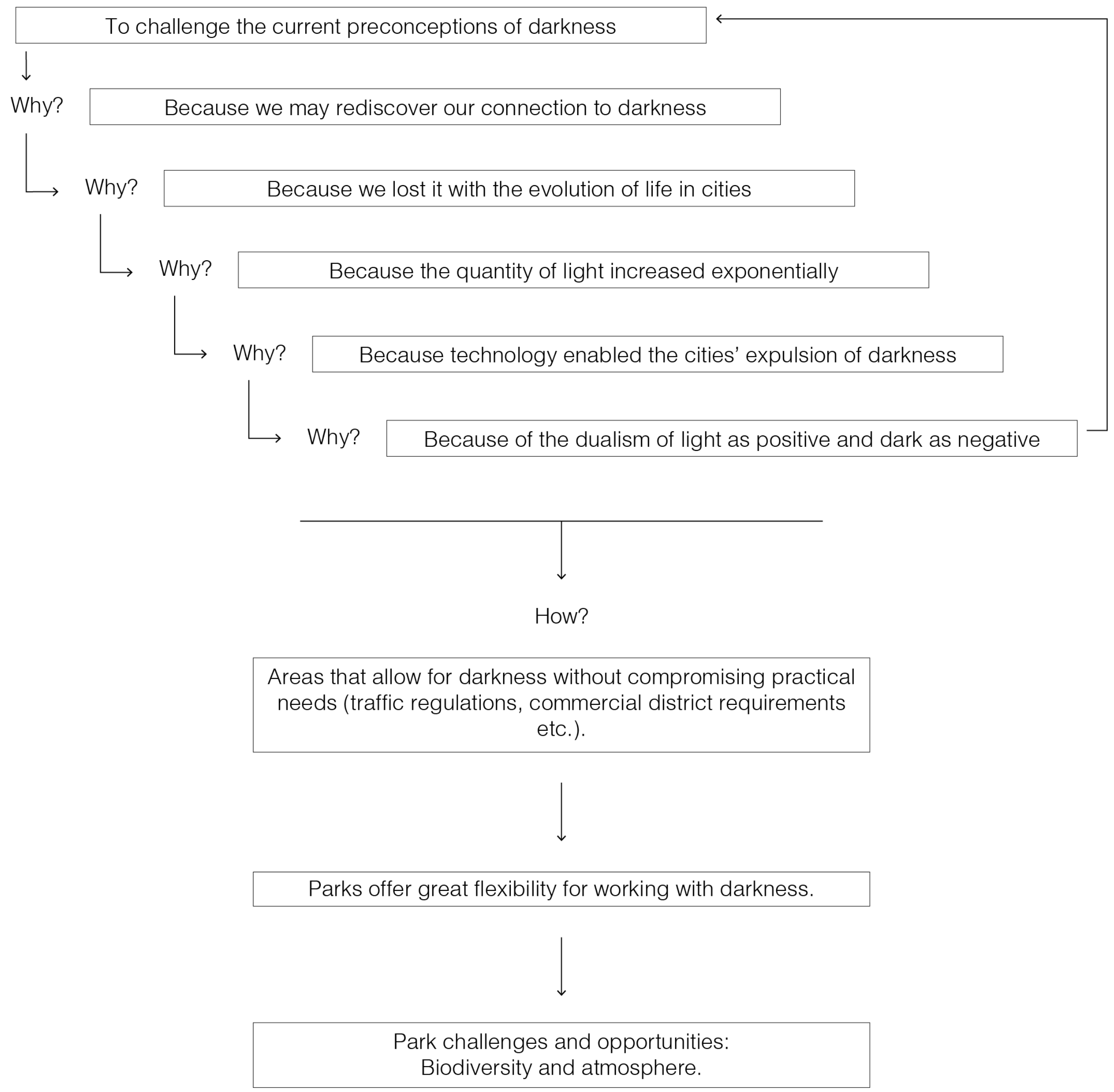


Figure 2: 5 whys model + development

METHODOLOGY

This master thesis investigates how we can create nocturnal experiences for people in the urban green areas without compromising biodiversity and our approach is inspired by the procedural model developed by Ellen Kathrine Hansen and Michael Mullins (2014). Their model describes how to engage in interdisciplinary research, utilising differing pools of knowledge to inform the creation of a research question, testing and generating design criteria and ultimately, new knowledge. Our own devised model of this thesis' process is split into three different sections: Input, the iterative cycle and output. The iterative cycle is inspired by the experiential learning cycle developed by David Kolb, who also states that "learning is the process whereby knowledge is created through a transformation of experience" (1984). His cycle is based on experiencing and reevaluating and reflecting on these experiences or observations to gain new insights and knowledge. Our own model is illustrated in figure 3 and is further explained in the following section.

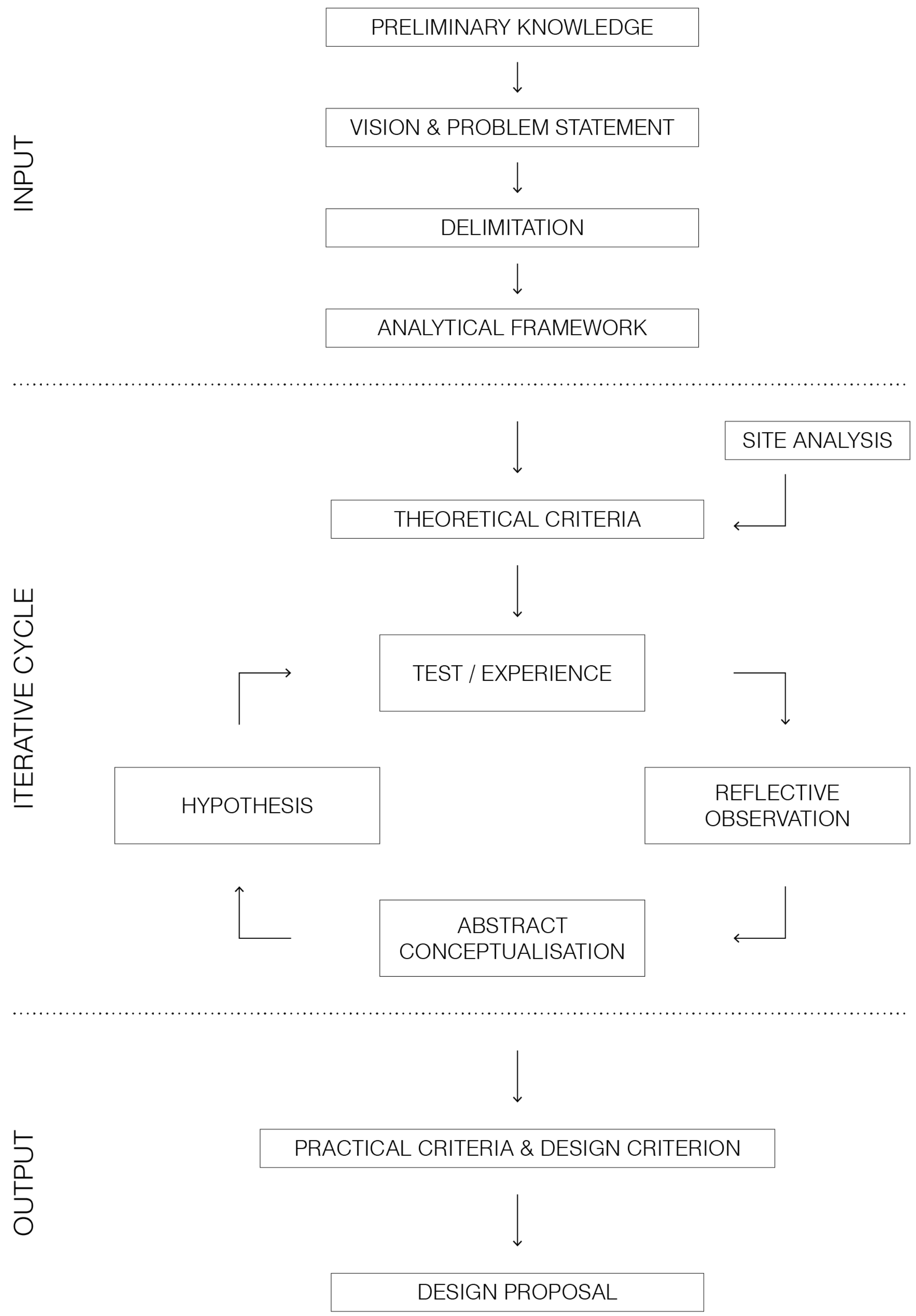


Figure 3: Methodology model

INPUT

The input section revolves around all the data, gathered and preliminary, as well as primary and secondary, that will fuel the iterative cycle serving to concretise and specify design parameters for the framework and ultimately, the design.

PRELIMINARY KNOWLEDGE, VISION AND PROBLEM STATEMENT

Our preliminary knowledge constitutes what we have gathered throughout our experiences in the first two semesters, the differing internships we went on, knowledge from our bachelor's degrees and personal preferences. These are moulded into the overarching vision for the thesis, subsequently reduced to an actionable problem statement from which the work begins.

DELIMITATION

The vastness of the scope is then narrowed down by arguing for and discarding elements of relevance, due to their overly far-reaching subject matter or less solid foundation.

ANALYTICAL FRAMEWORK

The interdisciplinary knowledge gathered for the thesis is approached in two branches. The first is the analytical framework, is the context independent literature and research review and the second one being the context dependent site analysis.

Relevant theories and literature on various topics are explored all in four categories, *lighting for people, darkness & atmosphere, biodiversity* and lastly*, sustainability.*

- *Lighting for people* concentrates on the human vision and how we perceive light and contrast, the physiological and psychological effects of light and introduces some of the current frameworks to create lighting for people.

- *Darkness & atmosphere* covers in depth how darkness is perceived and experienced, emotionally and culturally.

- *Biodiversity* focuses on light's potentially adverse effect on animals, direct and indirect and how to alleviate these effects.

- *Sustainability* reviews the UN Sustainability Goals and the sustainable use of lighting.

THEORETICAL CRITERIA

The above items of the model generate a substantial mass of knowledge on the subjects within our thesis, required to kickstart the iterative part of the process. They are formed into theoretically sound criteria to work from.

ITERATIVE CYCLE

The cycle is initialised through the theoretical criteria and the site analysis. The cycle goes through several iterations. During these iterative cycles, we reconsider our ideas, gain new insights and challenge our preconceived notions in order to eliminate the superfluous.

SITE ANALYSIS

The site analysis is the second branch of interdisciplinary data-gathering. The park of Søndermarken in Frederiksberg is chosen to be used as a case-study for the framework, however, the analysis of the site also guides the initial test of the iterative cycle, along with the criteria formed from theory, and the data is used alongside the cycles.

ITERATION PROCESS

The iterative cycle starts with a test/experience, revolving around observation through exploratory experimentation. The results from the test and experiences are reflected on and evaluated, and knowledge is derived from the evaluation to specify parameters for a new revision to be conceptualised. These parameters are concocted into a hypothesis for further testing, restarting the loop anew, ultimately ending with clearer design parameters for the output after iterations.

OUTPUT

The iterative cycle, after a number of iterations, will be exited with design parameters and the knowledge to create the framework of criteria.

PRACTICAL AND DESIGN CRITERIA

The framework created by the aforementioned process is a design tool for designing light in the urban green areas of cities, fostered with interdisciplinary pairings of fields to try and combat the pitfalls of negative lighting effects. The framework is formed from the knowledge derived in the input section and guided by the testing results from the iterative cycle to achieve cogent parameters for the design tool. They consist of practical criteria for achieving a successful lighting design in an urban park, and a design criterion to foster individual and creative designs based on the context of the specific parks.

DESIGN PROPOSAL

From the framework and space analysis, a new design proposal for Søndermarken is created, and the case-study complete.

DELIMITATION AND SCOPE

COVID-19

This thesis was written during the lockdown period caused by the Covid-19 pandemic, which has limited our capacity to conduct field tests with active participants. This limitation influenced the sample size of our experiment, forcing us to primarily rely on personal observations of people's behaviour and our own experience of atmosphere. The observations in Søndermarken of people, activities and behaviour may also differ from the norm. Additionally, due to this unique situation, the university's grounds were not accessible which impeded us from renting lighting fixtures and the chance to do any test in the lighting laboratory.

AIM

The aim for our thesis is to create an inclusive framework when designing light for parks and green areas in cities. In order to promote a sustainable and conscious nocturnal use of parks, we are combining very different fields that can result in a new way to look at existing issues. In order to achieve this we have initially widened our perspective as a context conscious design for lighting in an urban park cannot solely revolve around the human condition but must include the natural realm as well. The scientific approach of studying lighting's effects on biodiversity together with the aesthetic and philosophical concepts of atmosphere can inspire innovative and novel uses of the park in the dark hours. We believe that this new interdisciplinary approach can create a positive cycle of reinforcement, where good lighting, designed to safeguard biodiversity can become a welcoming atmospheric experience for humans. During the development of this thesis we have become increasingly focused on solving the contrast ratio of light and darkness as it proved to be a primary issue when building up a strategy. Our approach is holistic for the general lighting of the park. However, due to the large amount of landmarks present in the area, we are not proposing any one design as these require a case-by-case solution.

SAFETY

The subject of safety encapsulates a wide range of issues which stretch from battery to other forms of violence such as psychological assault. Because the issue of personal safety is so important, it deserves full attention and should be investigated in great detail, which is beyond the scope of this thesis. Therefore, we acknowledge its relevance but because Denmark is the 5th safest country in the world according to the Global Peace Index (Institute for Economics and Peace, 2019), we have decided to not focus on it. But, rather explore the intricacies of how we experience space through our atmospheric sensibility.

BIODIVERSITY

Biodiversity has been a somewhat passive but fundamental aspect of this thesis. Whilst we have researched the effects of lighting on fauna, we have decided to focus primarily on humans but keeping the acquired notions on biodiversity as a quality check. While it could be easier to create a design solely interested in the effects on humans, we believe that in order to achieve our vision we must include biodiversity as a control parameter. This would help us develop a design which is conscious and inclusive.

Biodiversity in a broad term encompasses the entire biota of a habitat and the ecosystems they are part of. This includes all plant and animal life. For the scope of this thesis, the focus will lie solely on animals. We acknowledge light's effects on plants, as they use light as a source of energy for photosynthesis but also for seasonal information (Bennie et al. 2016). Light can impact growth and budburst of plants and trees, physiology and behaviour and has the potential to shift, delay or advance seasonal events (Ffrench-Constant et al. 2016). Studies on this area are scarce when searching beyond the use of light in producing agricultural goods and the consequences it generates are harder to directly translate to effects on ecosystems and biodiversity as a whole. The long-term consequences and possible cascading effects are difficult to predict. Therefore, including plants in our study would have detracted from the overall vision that we are aiming to achieve in the time frame that we have at our disposal.

On the other hand, studies on animals have become far greater in number in recent years, and potential adverse effects are both more predictable and immediately available. However, flicker in animals have not been studied enough to be included in the scope. Flicker has a known impact on human health and well-being and it is assumed that such effects can also be found in animals. There are only a few studies on the topic at the time of writing, and while a study found that certain animal species can perceive flicker from widely used lamps, the effect it has on those species in question are yet unknown (Inger et al. 2014). As more studies are necessary in this field, it is beyond the scope of the thesis.

UN SUSTAINABLE DEVELOPMENT GOALS

The United Nations have issued a list of 17 sustainable development goals that it is promoting in order to "transform our world" in a positive way by the year 2030 and beyond (United Nations, n.d.). The goals cover a wide set of issues that all countries experience to various degrees and that are critical to resolve for the future of the generations to come. These span from access to healthcare, gender inequalities, use of cleaner energy and ending poverty, amongst others.

In order to develop a sustainable proposal we have analysed the guidelines on the goals offered by the UN to see which ones would be most relevant to our research. In conclusion, goals 11 and 15 have emerged to be the most pertinent to our work. They are concerned with developing sustainable cities and communities and life on land, respectively. The combination of these two goals was particularly relevant because of the overall result that our project is aiming to achieve. The key for this process to be successful is to not only deal with the human component, but taking into consideration multiple facets of the issue, particularly in this case, the preservation of healthy ecosystems composed of multitudes of different species. The interdisciplinary nature of this approach could encompass additional UN sustainability goals such as number 9: Industry, innovation and infrastructure and number 13: Climate action. Due to the vastness of the subject matters, they had to be left aside in order to focus more specifically on the intended vision and mission.

CHAPTER 2

ANALYTICAL FRAMEWORK

In the following section we gather knowledge from various study fields, with the aim to subsequently combine them and formulate a set of preliminary theoretical criteria. We begin with extrapolating information about lighting focusing on the effect that it has on humans, both from a physical standpoint as well as from a psychological point of view. To that we add a layer which analyses our relationship to darkness through the lens of history and culture, culminating in a study of the aesthetics of atmosphere. This section then proceeds to understand how lighting affects biodiversity, with particular emphasis on fauna rather than flora, because of the vastness of the subject as previously mentioned in the delimitations. Lastly, a section on sustainability fleshes out the notions of the sustainable development goals by various organisations. Our aim is then to synthesise the knowledge from these fields and extract our preliminary design criteria from this merge. In order to deliver a sustainable solution we keep the United Nations Sustainability Goals as a general guideline. The idea of conscious design and the subject matter implies our strive for developing a design which is sustainable, therefore we do not dwell heavily on the specifics of these guidelines but rather keep them as an overall direction for our endeavour.

LIGHTING FOR PEOPLE

Electrical lighting allows us to adapt and alter our daily rhythm and extend the usable hours of the day. Electrical lighting is therefore intrinsically meant as an aid to our species' continued well-being and prosperity. However, it is only relatively recently that light's physiological and psychological effects on humans has been evaluated and researched. The fundamental biological processes and aspects affected by light have evolved under the daily cycles of light and dark (Meek and Wymelenberg, 2015). The physiological effects, also known as the non-visual effects of light, include our sleep/wake cycles, performance patterns, core temperature, alertness and production of certain hormones (Bellia, Bisegna and Spada, 2011). The psychological effects of light include mood-altering, relaxation, comfort and perception of a given space (Wang et al. 2017). We acknowledge that the psychological and physiological, in certain areas, are linked and affect each other but the distinction simplifies the clarification of the subjects therein. We will in this brief chapter not delve into the various effects light has on our physiology or psychology, but rather the most prominent aspects that affect the creation of a lighting approach for the urban green areas. Including the subject of dark adaptation of the human vision as it comprises a substantial element of this thesis.

HUMAN VISION

Vision is the sense that is most easily associated with experiencing the world around us. For it allows us to navigate the environment that we are surrounded by and interact directly with the world. Light is what enables humans to see, and the human eye is incredibly sensitive to it, allowing us to see both in darkness as well as in highly bright environments. Although, light is not only responsible for our vision, it is also a fundamental element to our entire well-being, especially daylight. Because it regulates our circadian rhythm, alleviates depression and anxiety and helps us perform in working environments (Tregenza and Loe, 2014).

The eye is the organ that allows us to see although the optical images that we intake are processed and translated to recognizable information through the visual cortex of the brain (Tregenza and Loe, 2014). Humans have a binocular viewing system that allows for discerning 3D spaces and perceive depth and perspective. The eyes allow light to come in through the pupil that can be more or less open depending on the incident light that hits it. The light subsequently reaches the retina, a thin layer of tissue lining the back of the eye. In the retina, there is a tiny indentation called fovea, which concentrates the light on the photoreceptors, allowing us to see colours and details clearly. The retina is also affected by the light that enters the eye within the peripheral field of view and this area captures the changes that occur in the visual environment even though the vision is not necessarily focused on them (figure 4). The retina itself is composed of photoreceptors, cones and rods, that are sensitive to different characteristics of light. Cones are of three different types and are determined by the wavelength of light that they are sensitive to, roughly corresponding to the colours red (long), green (medium) and blue (short). The wavelengths referred to, all fall within the range of visible light to the human eye. What is perceived as visible light is defined as a range of wavelengths in between 380 and 780 nanometres (figure 5), between ultraviolet and infrared radiation respectively (Descottes and Ramos, 2011) Rods instead are sensitive to the intensity of light and are responsible for vision in low light but play no role in colour discerning (Markvart, 2018). Additionally, a neuron called ganglion cell also plays a role in the affective quality of light for humans, as it is sensitive to short wavelengths and it is associated with the non-visual responses effects on the body and circadian rhythm (Tregenza and Loe, 2014).

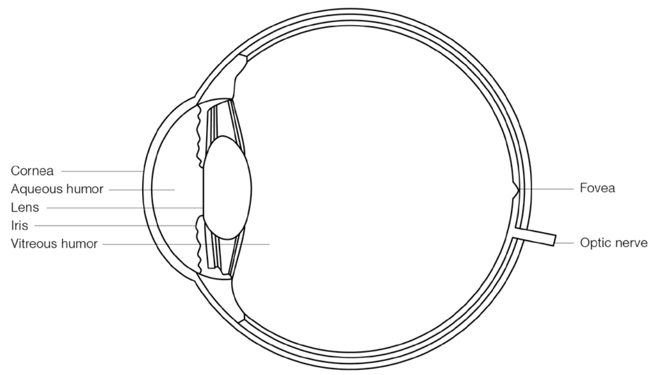


Figure 4: Eye schematic diagram

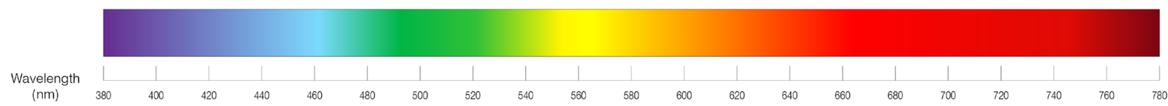


Figure 5: Visible spectrum of light

As mentioned, rods and cones are in constant oscillation depending on the light level and determine how we see in specific lighting conditions. The terms photopic and scotopic vision are determined by luminance levels. Photopic vision is active primarily during the day and is governed by the stimulation of the cones. In this condition the luminance levels are high (3 cd/m2 and above) and the eye has higher acuity permitting colour perception. Scotopic vision on the other hand, is triggered when the light levels fall below 0.001 cd/m2 and is dominated by the rods, allowing for seeing at night but not for very good colour perception (Markvart, 2018). The passage from photopic to scotopic is not immediate though and the period in between these two states is called mesopic vision or dark adaptation.

DARK ADAPTATION OF THE EYE

During the transition from a dark environment into a brighter one or vice versa, we enter the mesopic vision, when the rods or the cones start having a predominant role respectively. Cones adapt relatively fast, commonly within minutes, whilst rods can take up to an hour to absorb the change in illumination, that is why it takes more time to trigger scotopic vision rather than photopic vision (Gordon, 2015). The level at which we have scotopic vision is an extremely low luminance level, below 0.001 cd/m2, therefore these visions should not be considered as absolutes because the eye is constantly adapting to its environment balancing rods and cones (figure 6).

The pupil changes in size depending on the amount of light that enters the eye allowing the photoreceptors to adapt accordingly, within this interval amount our eye is capable to discern details, whilst above or below it becomes increasingly more difficult. This interval is defined by Tregenza and Loe as the 'zone of discrimination', outside of which we experience phenomena such as glare or indiscernible differences in darkness (2014). Glare is not just high brightness levels, it is in fact a high luminance level that enters the eye at a particular angle which causes extreme luminance in our normal field of view (Gordon, 2015). Our sense of sight is adaptable to a wide range of luminance levels, however our perception is independent from the general quantity of light. Our perception is guided by the occurrence of contrast, the difference between light and darkness and the average intensity of light in the field of view (Gordon, 2015).

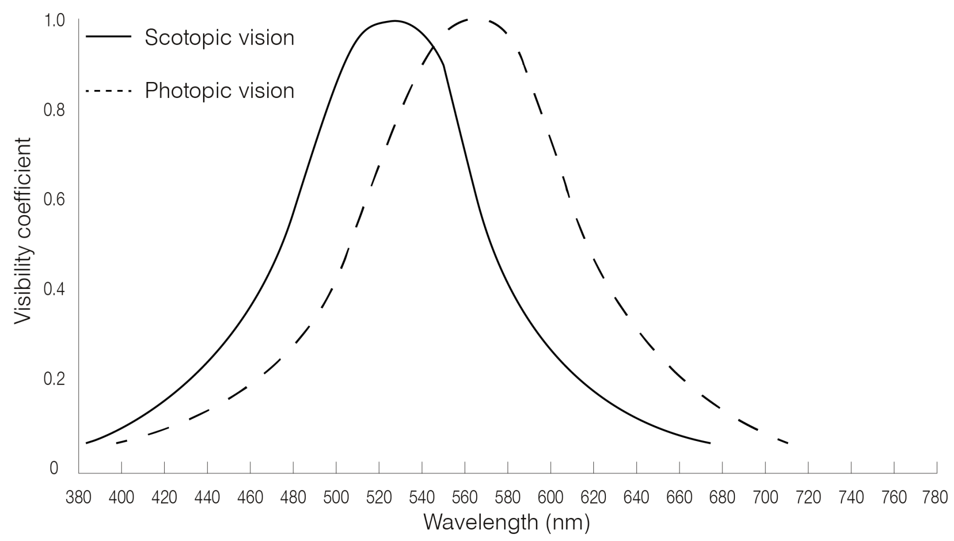


Figure 6: Scotopic and photopic vision sensitivity curves

CONTRAST

Contrast is what allows us to perceive a space and understand depth by interpreting the difference in luminance in our field of view. This does not only affect our navigation though, it also impacts our impression of a space and how we relate to it emotionally (Gordon, 2015). Brightness contrast establishes hierarchies in the environment and it can affect the overall appraisal of a space, influencing the behaviour and level of enjoyment. Contrast can vary in degrees but generally speaking when an object is highly lit against a dark background it will seem larger and more vibrant, often becoming the protagonist of our attention (Descottes and Ramos, 2011).

Low and high contrast environments are neither good nor bad, it all depends on the function and the intended behaviour of people in it. There is value in both scenarios as long as they are designed coherently with the activities and level of awareness that those activities require (Gordon, 2015). Gordon states that low contrast environments allow for random circulation as they do not attract the user's attention on any one feature of a scene as a high contrast environment would (2015). Higher contrast can make a scene more dynamic and welcome a certain level of visibility but if inadequately designed it can overpower a scene resulting in discomfort and unwanted glare (Descottes and Ramos, 2011).

Glare is an effect caused by an excessive amount of luminance directed at the eye leading to physical discomfort as well as loss of accurate perception of a space. Glare can create a visual barrier in our field of view, impeding us to adequately see beyond the source causing it and therefore rendering the entire space unreadable (Descottes and Ramos, 2011). In figure 7, Gordon demonstrates how the perception of brightness is affected by the intensity of the surroundings (2015). If the surroundings are dark, a given region appears brighter and vice versa. This phenomenon can vary the appearance of a space and if utilised correctly it can enhance it and make it more interesting. In smaller quantities, for example, glare is acceptable and even welcome as it can be referred to as sparkle or play of brilliants as pioneering lighting designer Richard Kelly described it in 1952. Sparkle can stimulate visual interest as it can break the monotony of a scene, awakening curiosity and inspiring the viewer to explore (Gordon, 2015).

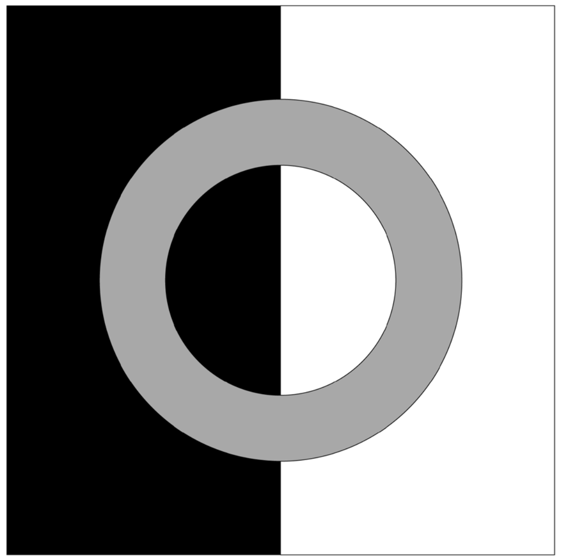


Figure 7: Simultaneous contrast (Gordon, 2015)

PHYSIOLOGICAL EFFECTS

Our sleep/wake cycle, or biological clock, is controlled by the circadian system which relies on our retinal ganglion cells that contain melanopsin. The melanopsin is a photopigment most sensitive to short wavelengths between approximately 460 nm and 480 nm (blue light) (Bellia, Bisegna and Spada, 2011; Souman et al., 2018). This sensitivity has shown that electromagnetic radiation in the aforementioned spectrum stimulates a wide range of physiological responses. It suppresses the production of the sleep-hormone melatonin, thus altering the timing of our circadian pacemaker. The natural secretion of melatonin starts in the evening and does not taper off until the morning, and following a normal circadian rhythm, melatonin secretion would begin around nine o'clock in the evening and fade after half past eight the following day (figure 8). Blocking the production of melatonin increases our alertness and changes the natural fluctuation of the core body temperature. An increase in alertness and focus due to the use of short wavelength radiation can be used effectively to create zones conducive to more efficient work and is often associated with a high correlated colour temperature (CCT) (Wang et al. 2017; Souman et al., 2018). Generally, lights with a high CCT have a spectral distribution with a concentration in the wavelengths which the retinal ganglion cells are sensitive to. A study has shown that you can achieve a high CCT whilst avoiding a high concentration in the specific range of ~460-480 nm, thus creating blue light sources without an increased response and suppression of the melatonin secretion (Souman et al., 2018). It is recommended to avoid light sources with concentrations within this spectral range in the evening and night due to their ability to alter the sleep/wake cycle, which may lead to advanced or delayed sleep phase disorders (Meek and Wymelenberg, 2015). This is in part due to the circadian system's relatively slow response to light stimulus that may cause a cascading effect on sleep (Bellia, Bisegna and Spada, 2011).

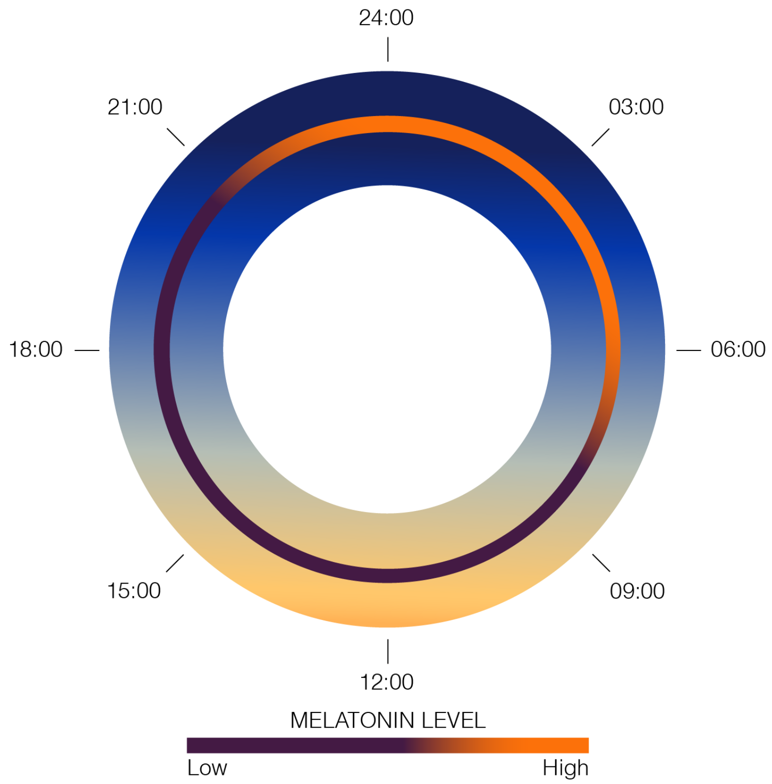


Figure 8: Circadian rhythm and melatonin level

PSYCHOLOGICAL EFFECTS

Light is the most important facilitator for us to perceive space. This gives light the intrinsic ability to change how space is perceived. Light functions as a precursor to generating our cognitive maps of space and drives our psychological perception of space (Tomassoni, Galetta and Treglia, 2015). Our impressions of space can be explained as the correlation between brightness and contrast, which evokes emotions, similarly to that of background music (Gordon, 2015). Beyond brightness and contrast, also colour and colour temperature can guide one's emotions. Colour temperature, as touched upon in the previous section, is not a metric perfectly suited to predict non-visual effects of light. Sources with significantly differing spectral distribution can have the same measured CCT. CCT, however, can be used appropriately when addressing preference and subjective comfort (Gordon, 2015). A study found that the preferred working condition of their test participants was via lights utilizing a high CCT (Wang et al. 2017). The high CCT was both preferable, as well as comfortable for working, whereas low CCT was found to be best suited for relaxing. Low CCT lighting was found to be more inviting and intimate whereas high CCT is perceived as brighter, vibrant and more invigorating. This coincides with the natural rhythm of daylight which is a cool white in the middle of the day and turns warmer at sunset (figure 9).

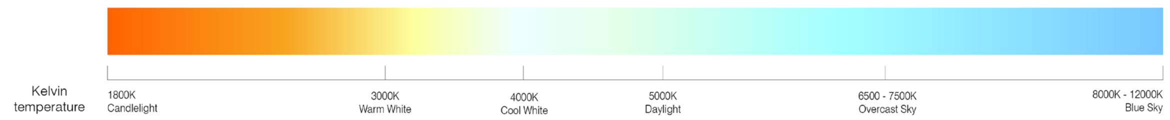


Figure 9: Correlated Colour Temperature (CCT)

LIGHTING APPROACHES FOR PEOPLE

The above mentioned effects of light and more have been studied at length and have fostered new terminology and approaches in the lighting industry. "Biodynamic Lighting'' and "Circadian Lighting" are two sides of the same coin, both approaches to lighting predicated on the non-visual effects of light on us humans. If a given lighting design is to be labelled by either of these two terms, the design should endeavour to mimic or replicate the dynamism and variety of daylight to ensure the least disruption of our circadian clockwork and thereby foster well-being. A popularized term grew out from these, namely "Human Centric Lighting'' (HCL). The focus shifted from solely being based on the non-visual effects, to also recognizing the importance of and incorporating the visual effects of light on our psyche. These three terms sprung from a necessity to label innovative efforts in the industry but have often been purposed as catchphrases and thus used for marketing (International Commission on Illumination, 2019). In a position statement from the International Commission on Illumination (CIE), a new approach is underway; "integrative lighting" (2019). The research conducted for integrative lighting is ongoing but seeks to officiate this term for lighting approaches focusing on both the visual and non-visual effects of light on people. The physiological and psychological effects are well documented but will be gathered and synthesized under the integrative lighting approach to provide guidance based on solid scientific evidence. This reasoning for a clearly defined term is to foster excellence in lighting and to combat miscommunication, misinformation and mislabelling of efforts in the field of lighting, where the terms HCL, "Biodynamic Lighting'' and "Circadian Lighting" are vaguely defined concepts.

DARKNESS AND ATMOSPHERE

In the following section we will dive into the connotation of darkness in western culture and how it has affected humans throughout history. As part of our vision to promote nocturnal urbanism as a standard for the lighting design of urban green areas, we analyse the importance of darkness and how it can be used to our advantage through the aesthetic lens of atmosphere. By intertwining these subjects, we are arguing for a shift in perspective and portray darkness as a valuable experience able to enhance our emotional sensibility and develop a stronger sense of place in the urban landscape.

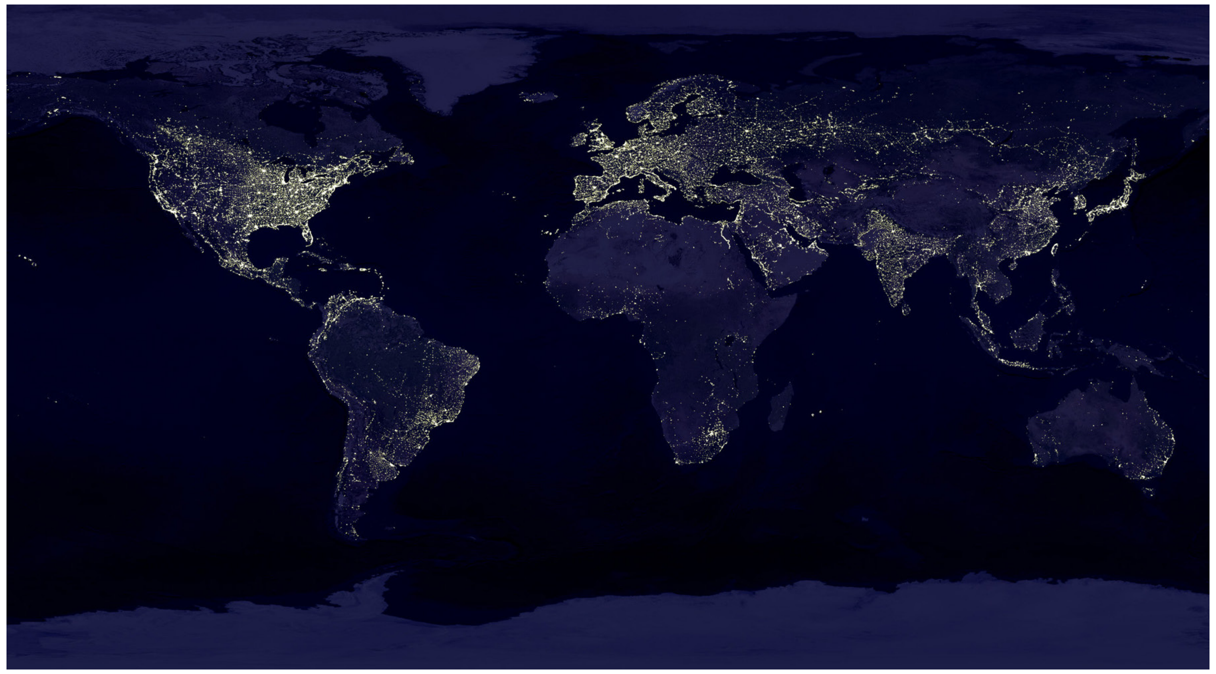


Figure 10: Satellite composite of the earth at night (Mayhew and Simmon, n.d.)

DARKNESS IN HISTORY AND CULTURE

With the advent of electric lighting in the late 19th century, and its development in the following decades, the urban nightscape started to drastically change and evolve into what we are accustomed to today. Nowadays, the night skyline of a city has become the symbol of technological advancement and an emblem of modernity (Stone, 2018). Up until the commercialization of electric lighting to the common folk and its introduction to public streets, it was limited to illuminate the aristocratic mansions of the wealthy and a few other upper class sites, leaving most of the general population in the dark during the night (Van Liempt, van Aalst and Schwanen, 2014).

The image of a dark city is hard to imagine today for most people as technology has evolved so much that our streets are not only filled with street lamps but also illuminated advertising billboards, business signs etc. along with light coming from inside apartment buildings and houses (Stone, 2018). This has created what Stone calls a 'sort of human-made constellation' where the night sky is completely outshined by artificially generated stars of the city (2018).

The desire to light up our cities (particularly in western cultures) seems to have been a goal for a long time, given the common negative connotation of darkness inherited from Christian culture (Edensor, 2012; Edensor, 2013). In fact, within the Christian religious belief system, good is associated with light, whilst evil is represented by darkness. Many examples of this association can be found in the arts. Painters and sculptors were often commissioned by clerical institutions who would ask them to create compositions of religious nature. They would often depict God as light and defiant figures in shadow and darker tones (figure 11 shows an example of the contrast between light and dark).

Aside from the cultural influence of Christianity, the desire of lighting the streets rose from a necessity to make them navigable at night. For centuries, the streets of cities were hazardous paths encapsulated in darkness, where it could have been easy to misstep and fall, take the wrong turn or be assaulted without any chance of defense. All these factors combined, contributed to this notion of urban darkness being something negative that we should steer away from, and it has been sustained for a long time, especially in western culture (van Liempt, van Aalst and Schwanen, 2014; Edensor, 2012; Stone, 2018; Bogard, 2013). Although, there is a growing sentiment for re-evaluating the positive qualities that darkness brings to an urban environment, which is skewing the perspective of new lighting designers and older professionals alike (Narboni, 2016; Edensor, 2013).

Going forward, lighting designers will be challenged with approaching their lighting schemes with a more holistic idea in mind, taking in consideration more than just levels and standards, but also social and political values, ecological concerns, artistic visions, interactivity and modularity (Narboni, 2015).

Figure 11: The Fall of the Rebel Angels by Charles Le Brun (1685)

EXPERIENCE OF DARKNESS

As previously illustrated, in western societies darkness still generally holds a negative connotation. A reason for that being the association that Christianity has made between God and light, and between the Devil and darkness (Edensor, 2012). Nevertheless, the darkness of the night in an urban environment has a certain appeal to people as it creates a unique atmosphere which allows for behaviours that feel less permitted during the day (van Liempt, van Aalst and Schwanen, 2014). Edensor, in multiple works, describes darkness as a catalyst for rediscovering lost forms of conviviality and intimacy as well as an opportunity to explore new aesthetics of atmosphere (2012; 2013).

However, experiencing real darkness in western countries is not as easy, nor common as one might think. Over the last century, countries have worked industriously to illuminate as much of their cities and lands, that the experience of an untainted night sky is almost impossible to experience. Paul Bogard, in his book “The end of night”, tells the chronicles of his travels across the United States and Europe in search for the true dark sky experience (2013). Furthermore, Bogard refers to the Bortle scale to evaluate each site that he visits and as illustrated by Edensor (2013), the darkest place in Europe is in the Galloway Forrest Dark Sky Park in Scotland which ranks “only” at level 3. This scale takes its name from John Bortle who designed it and introduced it in 2001 in the Sky & Telescope magazine (figure 12). The Bortle scale consists of nine levels of classification of the dark sky, 9 being the brightest (also called ‘inner city sky’) and 1 being the darkest (Bortle, 2006). This goes to show that despite the common interpretation of darkness in western culture, many people do not have a personal experience to draw that conclusion from, and simply rely on what has been handed down to them. Therefore the very notion of darkness as being inherently “dangerous” must be challenged. Edensor argues, that it is more productive to abandon the dualistic idea of light and darkness, diurnal and nocturnal in favor of a more holistic and complementary view of these conditions which are not to be considered as absolutes but rather temporal and spatial qualities of the same environment (2012).

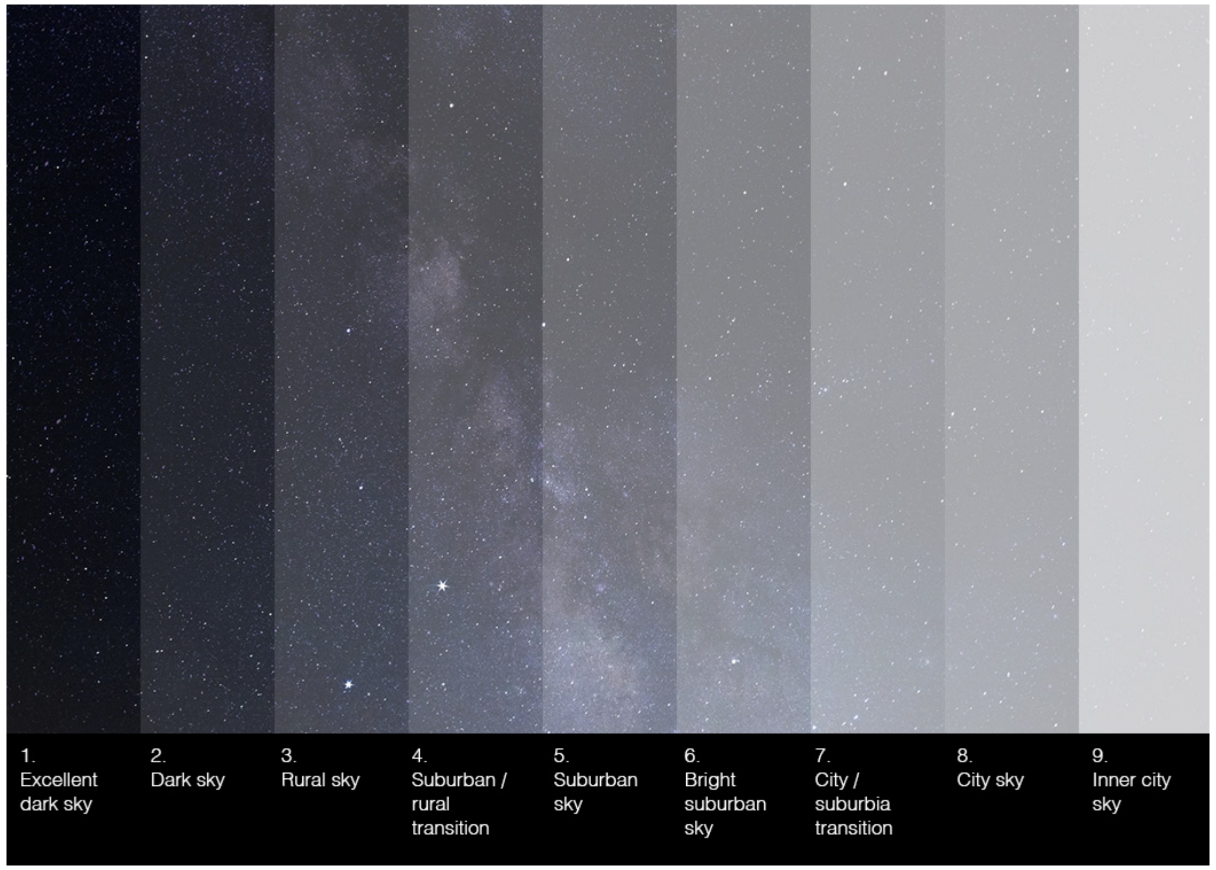


Figure 12: The Bortle scale

One persistent issue for the experience of darkness in cities is the unnecessary overuse of highly glary lights, which creates harsh contrasts and act as visual barriers to whatever is beyond them. As Bogard illustrates, in many western countries, people have a tendency to over illuminate their homes with excessively bright lights, as a security and safety precaution (2013). Even though, doing that actually creates visual barriers that because of the high contrast ends up concealing rather than revealing more of the scene, as shown in figure 13 (Descottes and Ramos, 2011). This same issue is also found in public spaces where unshielded lighting fixtures and poorly laid out designs attract the user's sight onto the luminaire creating a sensation of disorientation and discomfort, rather than showing whichever feature it was intended to (Descottes and Ramos, 2011). This pursuit of exiling darkness from our cities has made us accustomed to higher light levels that we are in need for, leading us to assume that more light is what we need rather than evaluate and assess how we use light (Bogard, 2013).

Figure 13: Visual barrier of light

Taylor Stone argues that reintroducing the dark sky in the city landscape is a form of urban restoration, which will allow the public to see darkness differently and assign it a new value, allowing us to potentially see our cities "in a new light" (2018). Requalifying the night (and darkness with it) is going to be the next phase of the ever evolving discipline of lighting design according to Roger Narboni, who believes that the industry's focus on illuminating cities will gradually shift towards the pursuit of 'nocturnal urbanism' (2016).

ATMOSPHERE AND EMOTION

Compared to other disciplines, architecture has the unique value of shaping not only the environment around us but also the way in which we experience it, for it is designed to be enliven and not simply admired from a distance (Zumthor, 2006). This further extends to the practice of landscape architecture where the engineered design of nature allows us to experience a garden/park in one way or another. Our experience of space is influenced by a spectrum of different inputs, may they be cultural, geographical, social etc. and it is a complex combination of multi-sensory stimuli that go beyond the human five senses (Pallasmaa, 2014). It is rather grasped by humans' capacity of what Tony Hiss describes as 'simultaneous perception' (1990), that is an innate human quality that is arguably needed for our very own survival (Zumthor, 2006). What Zumthor refers to, is the human capacity to recognize the tension in a given space and situation, being able to decipher whether one is in danger or not, regardless of the ability to explicitly describe it (2006). As such, one's senses cannot be isolated from external inputs like temperature, the movement of air or the presence of other individuals when discussing atmospheres, as the combination of all these elements give the atmosphere its character (Edensor and Sumartojo, 2015). All these elements contribute to the experience of atmosphere, but whilst the parameters and situations can change, one can only experience an atmosphere if they are physically present (Böhme, 2017). Additionally, there is a certain level of 'intersubjectivity' in the quality of an atmosphere. As it is 'something' that one experiences personally and has a subjective perception of, yet it is possible to articulate and describe it to others in a way that they can understand it on an emotional level (Böhme, 2017). This underlines Pallasmaa's concept of atmosphere as an experiential 'creature' that humans are capable of grasping without necessarily being able to understand intellectually (2014).

A large amount of studies have delved into the concept of the "sense of place" to understand the human perception of urban environments based on 'prior experiential knowledge' (Abusaada and Elshater, 2019). These experiences can be translated to perceiving a certain atmosphere and can to some degree be shared collectively, therefore they can be 'staged' (Molt, 2018). As philosopher Gernot Böhme suggests, "atmospheres are always something spatial, atmospheres are always something emotional" (2017). Light plays an important role in the creation of atmosphere and place, as it can change the character of an entire scene by changing a few parameters. Light can manipulate the experience of duration of time as well as space, with accents, glow and overall theatricality of its nature (Descottes and Ramos, 2011). "Light is an element of environmental design. Therefore you must be able to analytically visualise your environment and be emotionally guided through that vision" (Brandston, 2008).

Particularly experienced in this field are stage designers, as light has been one of their primary tools to convey emotion and tell stories that can alter our state of mind or our mood. Through the thoughtful play of colour, light and shadow it is possible to guide the viewer and inspire their curiosity whilst opening their minds to a higher degree of suggestibility (Böhme, 2017). Robert Wilson is a prime example of skillful use of light to create a scene that interplays seamlessly with darkness without going against it, as shown in figures 14 and 15. A similar concept in architecture is also described by Peter Zumthor, who describes his design process as "hollowing the darkness" to reveal the "light on things", letting materials and the atmosphere express themselves (2006).

Figure 14: Robert Wilson's Woyzeck (2000), Photograph by Hansen-Hansen

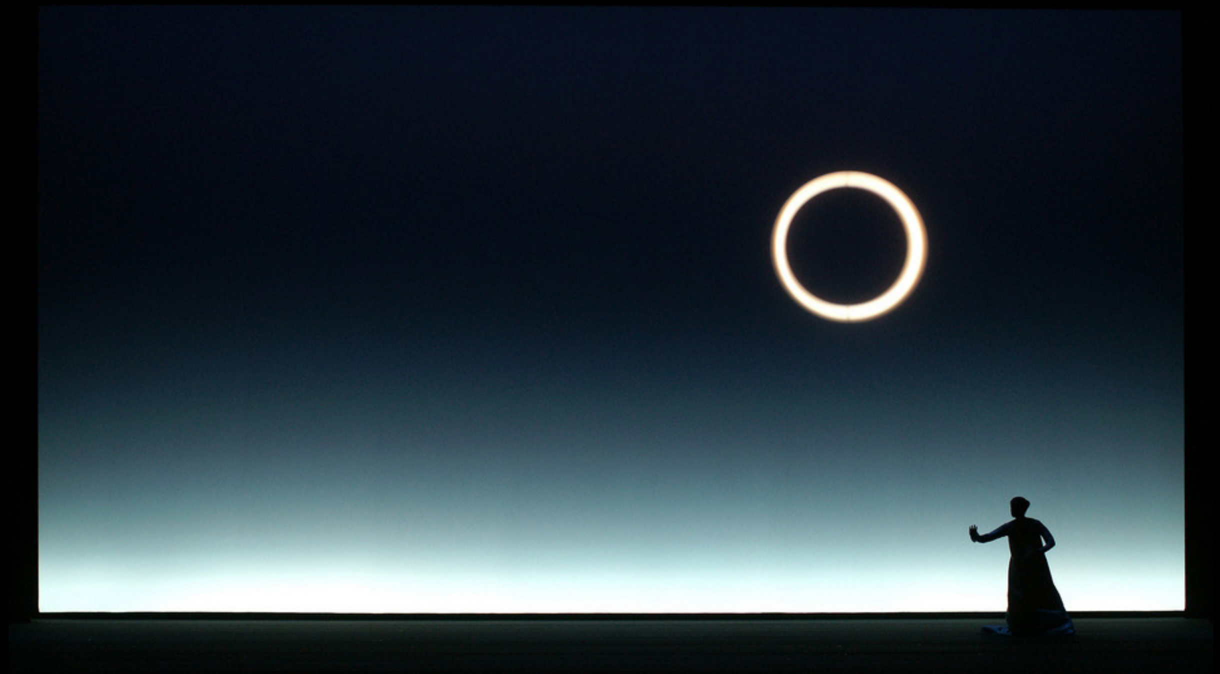


Figure 15: Robert Wilson's Pelléas and Mélisande (n.d.), Photograph by Javier del Real

BIODIVERSITY

This part of the analytical framework is focused on how the various aspects of light can affect biodiversity in different ways. As mentioned previously, this literature review forming the biodiversity branch of our analytical framework will not be concerning light's effect on flora.

The effects of light on fauna, as a field of study, has only started growing in recent years, however, there is tangible data and sources that would warrant our search for a lighting approach that encompasses the animal as well as human denizens. A further prompt for this, is the rapid expansion of lighting in urban areas where preservation of biodiversity is commonly not considered (Gaston, Bennie and Hopkins, 2012).

It is well known that lighting affects us, both physiologically and psychologically, and plays a role in our understanding and perception of space, our circadian rhythm and general well-being. This sensitivity to light, as mentioned previously, has been developed through our evolution in conjunction with the daily movement of the sun. As can be said for the plethora of animals that have evolved into their niches and functions in their respective ecosystems (Lazareva, Shimizu and Wasserman, 2012). The visual processing of animals, although functionally similar to ours, has evolved differently across most species and the individual species' sensitivity to the qualities of light, such as spectra and intensity varies greatly. Animals depend on the natural rhythm of day-night and seasonal changes to illumination levels for their activities, and artificial light can influence this rhythm in animals as well as ourselves (Bruce-White and Sharglow, 2011). This change in day-night rhythm can stagger animals' periodic behaviour such as mating, hibernation and other important events that are coordinated through seasonal and/or lunar lighting (van Grunsven et al. 2014; Jägerbrand, 2018).

This section of the analytical framework is structured to explore the various effects that light has on biodiversity, and thereby the ecosystems that depend on it. The section will be split into two parts, one reviewing literature regarding the direct effects of light on animals: Fragmentation of population, attraction of species and maladaptive responses. The second will delve into the indirect consequences of light on biodiversity.

DIRECT EFFECTS OF LIGHT

FRAGMENTATION OF POPULATION

In the urban space there are physical barriers that may cause fragmentation of a species' population. These barriers split and isolate populations into separate areas which could have grave implications for either side, if not both. A denial of one side to common feeding grounds or other necessary resources could severely limit the chances of succession in that group of animals. It could also limit the genetic diversity of the population of a species; however, this mostly affects species of a certain mass that due to their size, is naturally less abundant. These barriers to movement can also be caused by lighting, deterring certain species from using a given path or crossing. A bridge under-road passage for animals was tested with various settings of light and sand track data was collected to review which species used the crossing in the different scenarios (Bliss-Ketchum et al. 2016). In their study they found that animals such as deer, mice and opossums chose to avoid the path when lit directly, and the deer even avoided the path with just the ambient road light. Other animals were less affected by the lighting when it came to cross the path. Another study showed that some species of insects did not inhabit areas with an illumination level above ~0.2 lux, suggesting that even low levels of light can deter species from inhabiting and utilizing a given area (Picchi et al. 2013).

ATTRACTION OF SPECIES

In continuation of the last section, this may seem contradictory to the common belief that all insects are attracted to light, however, the belief is not entirely unfounded. Light emitted at certain wavelengths attract various species of insects (Bennie et al. 2018). The spectral composition of light is an important factor in the attraction or repulsion of animals to a space, and insects attraction to light emitted in the short wavelengths is likely tied to the attraction many of these groups have to UV light (Bruce-White & Shardlow, 2011; van Grunsven et al. 2014). Thereby, large groups of insects are more drawn to light from a white LED source than the previously used High Pressure Sodium lamps due to their peak in short wavelengths (figure 16).

Why the short wavelength then keeps some insect groups away is in part due to these groups potentially being prey items for the attracted insects where increased visibility would harm their chances for survival (Bennie et al. 2018). Lights that attract insects have been shown to increase the diversity of species, even within the same order, however, this may not be a strictly positive occurrence. If insects are attracted and thus move to an area that is unfit to sustain their population, it effectively creates what could be considered a biological sink, where populations of insects gather to simply perish (van Grunsven et al. 2014).

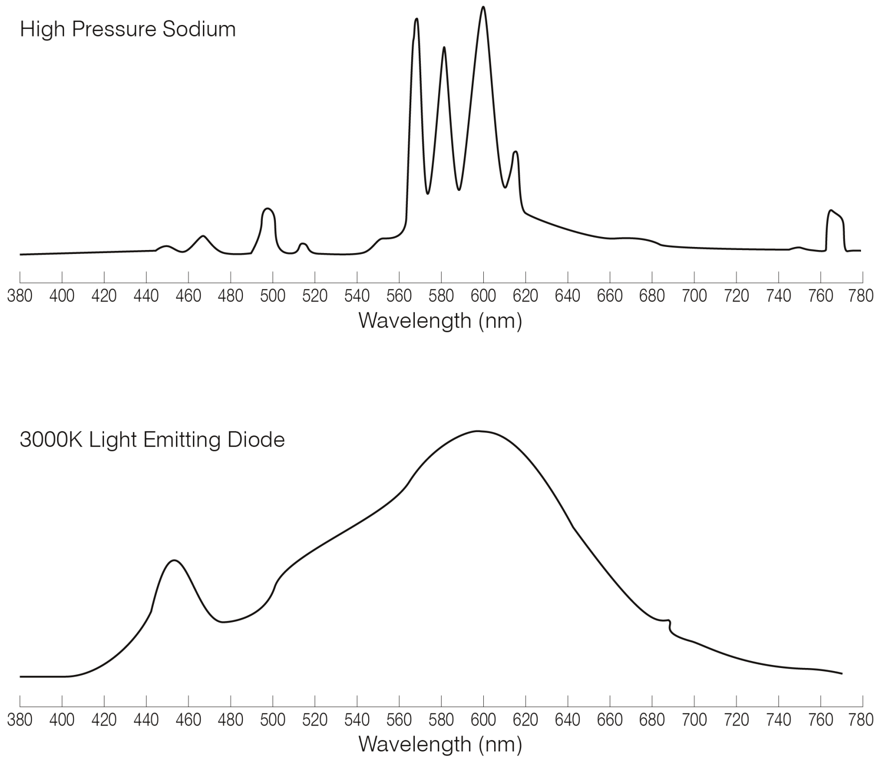


Figure 16: Spectral comparison of HPS and LED lamps

MALADAPTIVE RESPONSES

This attraction to high frequency electromagnetic radiation, or blue light, can be considered a maladaptive response in the insects as a direct consequence of light. Such maladaptive responses to light stimuli are also seen in other species. These reactions vary greatly from species to species, but the commonality is that they break the norm. A such example is a study of green frogs and how light reduced the amount of mating calls from the male frogs and made them exhibit a response of moving around more erratically, possibly due to the increased risk of predation (Baker and Richardson, 2006). A vastly different example was found in a laboratory study of rats' behaviour in light. The rats' response was a reduction in their normally skittish and anxiety-like behaviour commonly exhibited by them at night (Russart and Nelson, 2018). Rats are commonly less afraid in the daytime as their predators are primarily nocturnal which is likely the difference here between the green frogs and rats. The rats' reaction can lead to increased predation and thus shift the natural balance of the prey/predator relations. This can lead to cascading effects on ecosystems as these responses of lowering their defense-mechanisms have also been observed in other animals (Minnaar et al. 2014).

Studies have shown that maladaptive responses can be minimized utilizing wavelengths the animals in question respond the least to. A study of roost emergence of bats, testing red, white and blue light found that red light had the least impact compared to the no-light control test (Downs et al. 2002). Their tests showed white light to have the highest impact, which is due its wider spectrum of wavelengths. They also tested for different intensities and found that intensity had the highest impact on roost emergence overall, suggesting that for bats, low intensity illumination utilising long wavelength radiation is least impactful. The same was found for a large subset of insects as they respond mostly to light with peaks in the short wavelengths (Bruce-White & Shardlow 2011). In a large study by Travis Longcore, Airam Rodríguez, Blair Witherington, Jay F. Penniman, Lorna Herf and Michael Herf, a compilation of a great many resources was conducted to calculate the actinic power per lux of different lights on different groups of species (2018). Actinism is the effect of solar radiation in terms of the photochemical and photobiological effects, which was then transformed into a system to calculate for different lamp spectra across different intensities. The values for the actinic response of different lights on various species was calculated relative to sunlight to allow for comparison across species. The study used data for the vision of insects, general wildlife response curves and others. Their calculations predict that short-wavelength radiation with a high correlated colour temperature (CCT) would have the highest impact, whereas amber LEDs would have the lowest (figure 17). Their study only takes into account the spectral composition of light for the result and intensity of the different light sources may change the response of the species evaluated.

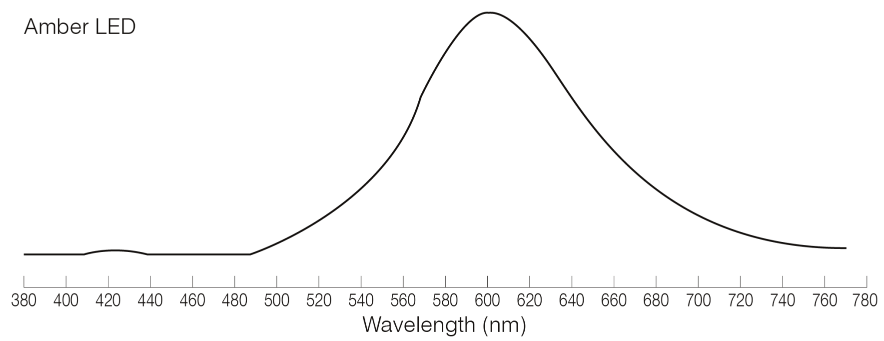


Figure 17: Amber LED spectral composition

INDIRECT CONSEQUENCES OF LIGHT

NOCTURNAL DISRUPTION

There is a trend in the studies that suggest blue-rich light to be the most harmful or elicit the greatest response in the various species. The variable intensity also factors into the animals responses and low-intensity illumination naturally has a lessened effect as opposed to bright light, however, some species are deterred even by low intensity (Picchi et al. 2013). Blue-rich light also increases the general intensity of the surrounding area due to an increase in Rayleigh scattering at short wavelengths in the vicinity of 10km from the light-source, increasing skyglow (Gaston et al. 2012). This does have a backside for long wavelength light, for beyond 10km the order is reversed, and long wavelengths produce more skyglow. Lamps lighting up certain areas directly can thus indirectly increase a large area's average illumination level, potentially disallowing certain light-sensitive species to inhabit the otherwise dark areas or disrupting their rhythm (Picchi et al. 2013). This can affect nocturnal biodiversity adversely, but light also has the potential via its impact on nocturnal animals to also harm the diurnal biodiversity.

POLLINATION AND SEED DISPERSION

The diurnal animals can be affected by light's impact on the nocturnal animals as ecosystems function in a way where every species (animal or otherwise) has its role and their cycles of interaction. This is easily seen in the relation between pollinators, nocturnal and diurnal. The nocturnal pollinators, such as moths, are less likely to visit plants in lit areas which reduces the plants reproductive process (Knop et al. 2017). It was found that the nocturnal visits to plants in a lit area were reduced by 62% compared to a control dark-area which subsequently resulted in a reduction of fruit set of a focal plant in the study by 13%. This reduction in fruit set occurred although these plants still received numerous diurnal pollinator-visits. This leads to less food overall for the ecosystem, for the diurnal as well as nocturnal pollinators, creating a negative feedback loop with less prosperity among the nutrition-providing plants and biodiversity (figure 18). This problem of creating negative loops was also found in the dispersion of seeds by nocturnal creatures, where bats (a natural nocturnal seed disperser) simply avoided lit areas entirely whilst foraging (Lewanzik and Voigt 2014).

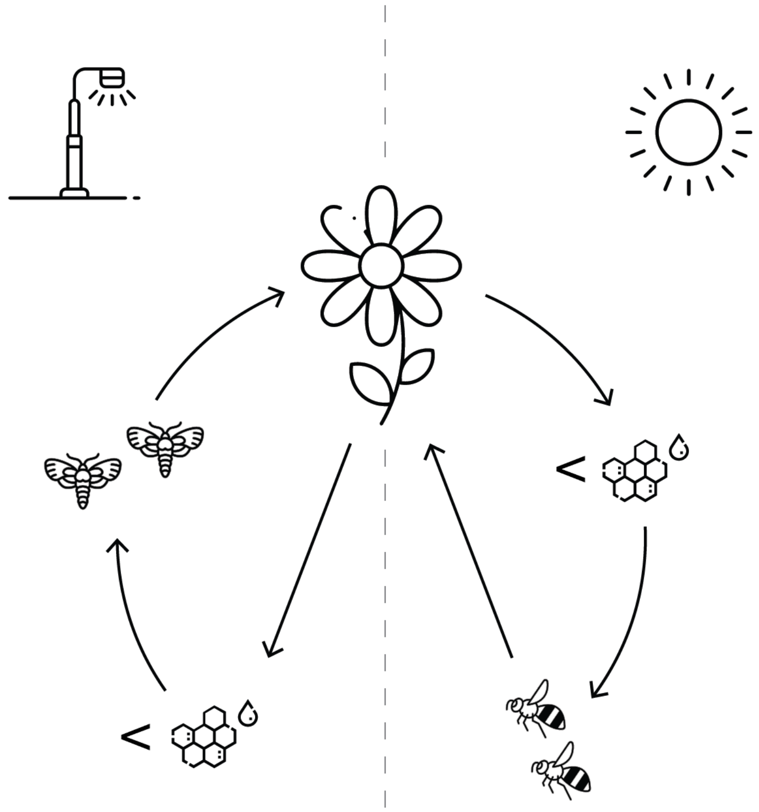


Figure 18: Diagram showing light's effect on plant reproduction and diurnal pollinator communities. Light at night repels nocturnal pollinators, reducing the fruit set of plants, thus affecting diurnal pollinators negatively.

SUSTAINABILITY

One of the main concerns for the future of our cities, as illustrated by professionals in the world of lighting and international institutions such as the UN, is light pollution. Electric lighting is omnipresent in every city, and for many years there has been a quantity over quality mentality to lighting approach, leading to many fixtures being poorly designed. In many instances, lighting fixtures spill light in different directions with only a portion effectively illuminating the desired area. This contributes to the skyglow effect which is one of the main factors that are negatively impacting the experience of a true night sky (Bogard, 2013).

In addition, there is also a desire to reduce the energy that lighting consumes every year. In the US alone, it is estimated that approximately 30% of outdoor lighting is wasted and that equates to almost 66 million metric tons of CO_2 at a cost of circa $7 billion dollars annually (Stone, 2018). Many major cities around the world are paying more attention to the issue of light pollution and skyglow. Cities like Paris, Copenhagen and Amsterdam for example have approached the issue from an energy saving standpoint at first, but are now understanding that the quality of a lighting plan can both save energy and the night sky (Bogard, 2013).

Light pollution is not only a matter of emissions however, it also impacts our daily living and the lives of other animals and plants, of whose ecosystem we are disrupting everyday (Stone, 2018). The International Dark-Sky Association (IDA), since its conception in 1988, has been the front runner in informing the public of the risks of light pollution, advocating for better quality lighting that would not disrupt the experience of the night sky.

IDA has, in cooperation with the Illuminating Engineering Society (IES) issued a press-release containing five principles for responsible outdoor lighting which they have both unanimously adopted in their organisations (Illuminating Engineering Society, 2020). These principles are labelled for 'light to protect the night' and are all an effort to reduce light pollution. The principles are principles of light and are as follows:

- Useful

Lighting should be useful and only utilised where it is needed and serves a clear purpose. One should consider how the use of light will impact the area, wildlife and environment.

- Targeted

Light trespass should be eliminated, and lighting should be directed and targeted at where it is needed to prevent unnecessary illumination.

- Low light levels

Lighting should never be brighter than strictly necessary for the task or objective they serve to aid with and surface reflection should be considered to alleviate light being reflected to the sky.

- Controlled

Controls such as motion detectors or timers should be utilised in such a way that light is available when needed, but only then.

- Color

Designers should be mindful of the spectral distribution of light and avoid short wavelengths of the visible spectrum (blue-violet) if possible.

The five principles are meant to promote sustainable lighting and are provisional guidelines for any and all lighting designers to follow. The elements described share traits with a lot of the same elements that affect wildlife and thus biodiversity. Many of these, if not all, can be translated directly to reducing the impact on plant and animal life in lit areas.

Plant and animal life on land has been greatly affected by the industrialization and expansion of cities in the last two centuries which are causing desertification around the globe and affecting biodiversity everywhere. World population is increasing and the UN estimates that by the year 2030 people living in cities will reach 5 billion, which means that urban parks will have to be preserved with extra care in order to provide city dwellers with access to nature's benefits (United Nations, n.d.).

As described in the previous sections, a healthy ecosystem consists of a lively and mixed biodiversity. In combination with a strong community, a park can become the basis for a more livable and enjoyable experience within the hectic rhythms of ever-growing cities. For a park to help develop community bonds, it must be attractive to the visitors and suggest a welcoming atmosphere. In the case of this thesis, we are primarily focusing on the atmosphere at night which is directly linked to the subsistence of biodiversity in harmony with the human population.

By using goals 11 and 15 (sustainable cities and communities, and life on land respectively) as main inspirators, corroborated or positively influenced by the principles put forth by IDA and IES, we can lay new groundwork to develop a circular framework that benefits itself by constant positive reinforcement.

Figure 19: Seclected UN Sustainable Development Goals

SYNTHESIS OF THE ANALYTICAL FRAMEWORK

In the analytical framework we have reviewed and sifted through theories and research regarding the topics of light relating to human physiology and psychology, biodiversity, atmosphere and sustainability. These subjects have been explored in isolation from each other and this synthesis aims to extrapolate the knowledge of variable parameters affecting each subject and establishing the commonalities and differences in responses thereof.

Artificial light is created for the benefit of humans and this synthesis thus springs from the human as the centrepiece of the equation. Furthermore, the atmosphere is intrinsically linked to the human condition and how we subjectively perceive and experience space. It is our personal understanding of our surroundings and drawing a set of design criteria to define its role in lighting design is difficult, as the subject is rather ambiguous in nature. However, atmosphere is still a reasonably malleable construct and one can influence and provoke moods and feelings through the use of various components, including light. Humans respond pleasantly to light of various colour temperatures depending on the objective at hand. Cold light of short wavelengths stimulates our attention and is preferred for working environments. This is a psychological response in the sense that we perceive cold white light as brighter, yet also a physiological response if the light has a significant portion of its spectral distribution in the wavelengths between 460 nm and 480 nm. Light in this spectrum blocks the production of our melatonin, and the same holds true for many species of animal. It affects our day/night cycle, however, short wavelength radiation seems to have a greater effect on animals, as more of their behaviour depends on light. Artificial light at night should thus be designed in such a way that it does not block the secretion of melatonin.

Parks are commonly places for retreating away from the bustle and hustle of the city and work. Warm white light contrastingly has a relaxing and calming effect on our moods and has less of the spectral power distribution (SPD) in the particular wavelengths we are susceptible to. CCT, however, is only truly relevant for establishing the psychological effect it may have on us and the atmosphere, as CCT is not directly correlated with the spectral power distribution. The physiological effects of not blocking the melatonin secretion is mandated on avoiding the 460 - 480 nm wavelengths, and light with primary distributions in the long wavelengths (Amber, yellow-green, approximately 580 - 640 nm) has also shown to be least impactful on wildlife. Using light with long wavelength electromagnetic radiation is thus recommended for night-time light both for human and wildlife.

Our eyesight adapts according to changes in luminance and the balance and interplay of various intensities is important. A high contrast of brightness and intensity can lead to areas being perceived as less welcoming or secure as the difference in brightness can alter the visibility greatly and can exaggerate surrounding darkness. Heightened intensity can also create maladaptive response in animals and even prohibit some species from habiting an area. Lessening the harshness of contrast between light and darkness can make environments more comfortable and secure for us whilst having a lessened effect on wildlife as well. Additionally, it can also help our adaptation to darkness. The same can be said for luminaires where the source of light is visible when walking by. This creates glare, which disorients and creates discomfort and can appear almost blinding. The attributes can become visual barriers that are contrary to the objective of light, namely creating safe atmospheres for people.

Lighting trespass does not particularly benefit us as humans, although it can potentially lessen the contrast between dark and light. However, as light in general is not a positive element for animals, limiting the distribution of light to where it is strictly necessary can help alleviate the negative impacts we have on biodiversity. The distribution of light should also incorporate dark passages or gaps to allow the wildlife freedom of movement in darkness.

Lastly, limiting the duration of light to when humans are not in the vicinity can alleviate some potential adverse effects of light for animals. However, the time we commonly utilise electric light is in the early evening hours where the effect is most impactful for the sleep/wake cycle and seasonal aspects of animal life.

The sustainability goals offer an ethical foundation in pursuing new knowledge in an interdisciplinary matter and push us to think outside the box and look for new unexplored avenues to follow. The guidelines proposed by IDA and IES for reducing light pollution are harmonious with efforts to reduce light's effect on biodiversity. The criteria for reducing the impact on wildlife are somewhat stricter, however, these do not interfere or oppose the parameters for reducing light pollution, making the guideline a step in the right direction concerning our coexistence with nature.

THEORETICAL CRITERIA

From the analytical framework we have extracted a set of theoretical criteria which we have summarised in the following table (figure 20), that work as guidelines to be further refined in the design section. Some of these criteria partially overlap but they are analysed from different perspectives. These criteria are expansions on the three original success criteria:

Facilitate darkness
Limit impact on biodiversity
Inspire nocturnal use of parks

FACILITATE ADAPTATION	Low intensity Low contrast Low S/P ratio	Lay out fixtures in a way that allow for users to adapt to lower illumination levels, avoiding harsh contrasts and glare. Utilise dimmed fixtures with a low S/P ratio which can falcilitate the eye's adaptation.
COMFORTABLE ATMOSPHERE	Low CCT Encourage curiosity No glare	Use warmer colour temperature lighting to make the environment more welcoming, stimulate curiousity and exploration.
REQUALIFICATION OF DARKNESS	Through experience Light to facilitate darkness	Use light purposefully allowing for the experience of darkness. Use warmer colour temperature lighting to make the environment more welcoming, stimulate curiousity and exploration.
LIMIT IMPACT ON BIODIVERSITY	Low intensity Limit certain wavelengths (SPD) Limit light trespass Distribution, dark passages	Limit the use of wavelengths that have a negative impact on biodiversity. Allow for dark passages that animals can utilise to traverse, and limit unnecessary spillage of light where it is not needed.
SUSTAINABILITY	Limit light trespass Duration of light Usefulness Reduction of skyglow	Light should only be used where and when useful, therefore promote quality over quantity. Use aimable fixtures that do not contribute to skyglow.

Figure 20: Theoretical criteria

STATE OF THE ART

The following brief section illustrates examples of successful lighting designs in urban green areas that tackled at least one issue related to our thesis, inspiring us to pursue a solution to our problem statement.

THE HIGH LINE (2009-2019)

The High Line project in Manhattan, New York (USA) is a successful example of an urban park that has managed to have a strong identity in a city of landmarks whilst driving one's attention outwards, to the scenery and the sky. This project was commissioned by the Friends of the High Line, an organisation dedicated to saving this piece of New York history from being torn down. The lighting design was made by L'Observatoire International, a lighting design consultant firm guided by French designer Hervè Descottes (Descottes and Ramos, 2011).

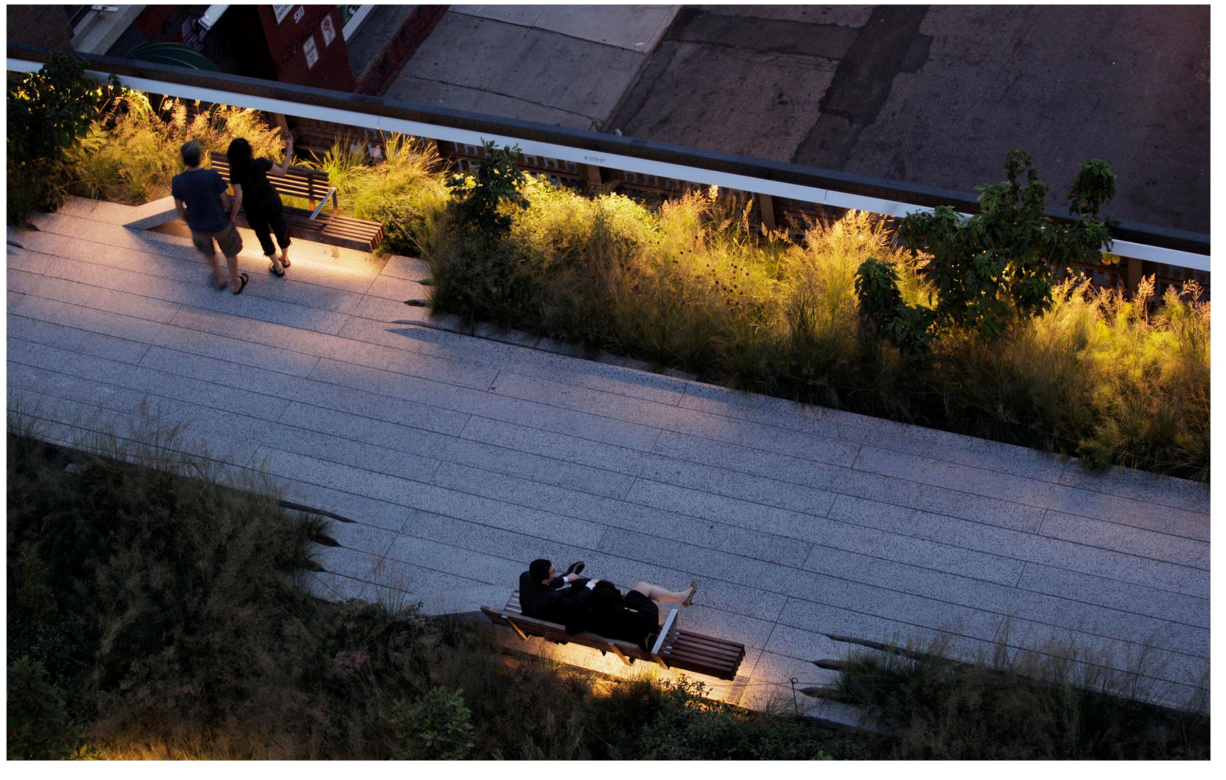


Figure 21: The High Line (isometric view)

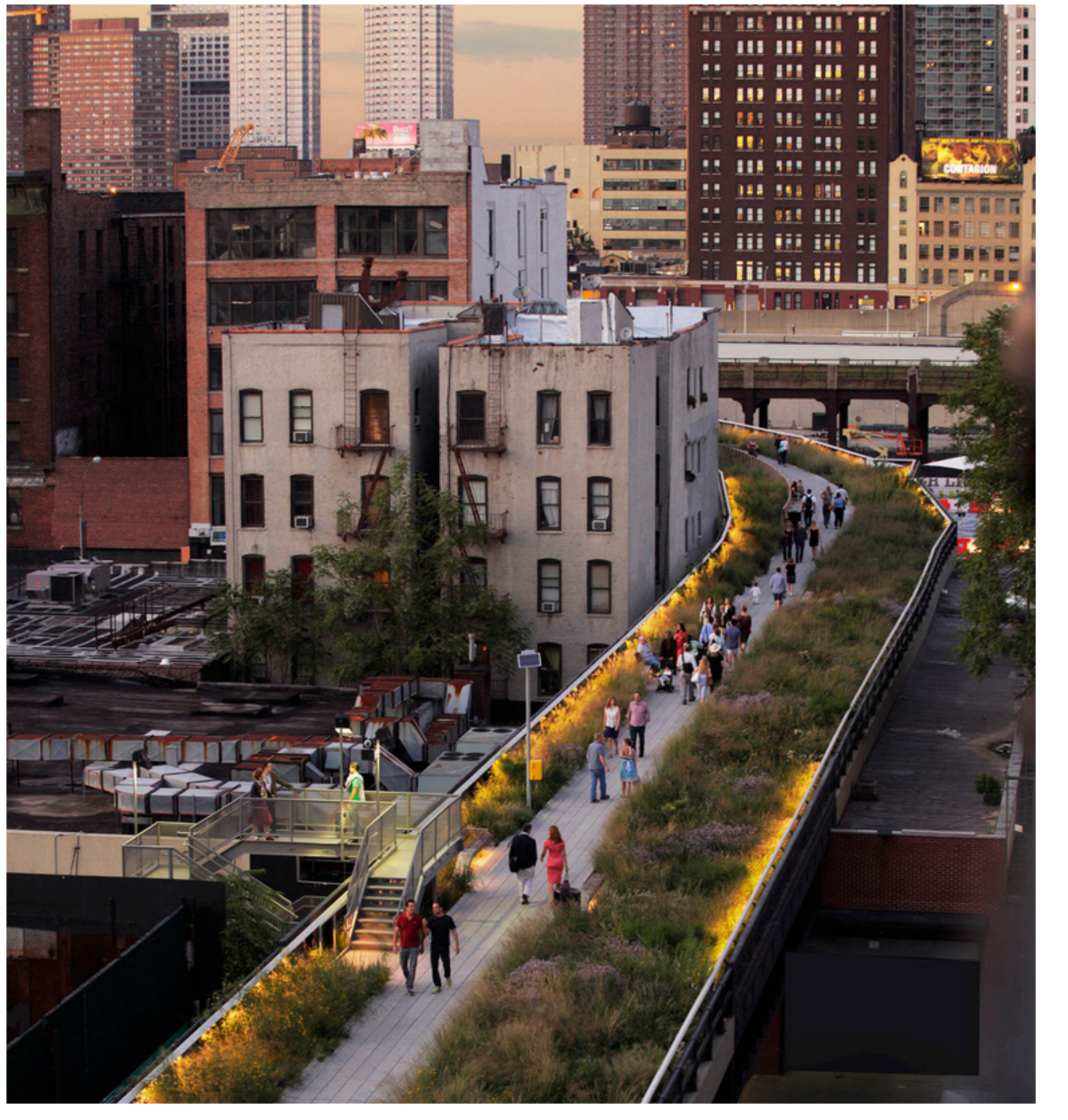


Figure 22: The High Line (perspective view)

One of the High Line lighting's greatest features is its unobtrusive nature. All lighting fixtures are integrated within the urban furniture such as benches and seating areas, as well as in the handrails keeping the sources hidden to the viewer. This allows for people to navigate the space carefree while admiring the view that the elevated park has to offer. With the light sources hidden away there is no risk for glare while the paths are illuminated adequately to provide wayfinding. This design choice offers a low contrast solution that does not distract from the overall atmosphere, letting the user immerse themselves into the nature and simple enjoyment of an evening stroll.

BELYSNINGSMASTERPLAN FOR KØBENHAVN (2014)

In the masterplan for lighting in Copenhagen Municipality a section on gentle lighting for nature is located, outlining a proposal on how to light areas with a focus on conserving biodiversity. Amager Fælled park is used as an example of how such lighting could be. In this project, the focus lies not on the people as the park is a protected natural reserve. Only the paths crossing through the paths are proposed illuminated with low bollards utilizing light that specifically avoids short wavelengths. Furthermore, they propose shielding to limit the light pollution that may distract or impact birds, bats and insects that fly above the fixtures. The lighting design is limited strictly to its practical use, as to eliminate as much of the adverse impact it has on the surrounding natural areas. It is a strong project that has yet to be realized and the recommendations for technical specifications regarding light in protected natural reserves are corroborated by our findings in literature. In the following section, they address park lighting specified for parks for the people. Here, ideas of creating dark corridors to ensure the free movement of animals and lighting to encourage human activities is shown using Fælledparken as an example. There is no mention of spectral distribution and the considerations mostly accommodate people.

It is interesting how these two ways of thinking about lighting for parks and nature are not further combined, as the city parks could benefit greatly from introducing elements from the proposal for natural reserves. Only the basic idea of creating dark corridors for animals and a reduction of illumination when human presence is absent are considered in the inner-city parks.

Figure 23: Amager Fælled (above), Fælledparken (below)

CHAPTER 3

THE SITE

The material in the following sections was gathered by first hand observation with the aid of the information found on the Ministry of Culture's website (Slots og Kulturstyrelsen, n.d.).

OVERVIEW

Søndermarken is located in the heart of Copenhagen, within the municipality of Frederiksberg. The park is approximately 32 hectares in size and it is rather hilly, with a lot of sloping paths and areas for people to hang out. The park was made into a romantic landscape garden in the late seventeen hundredths, with the romanticism's fascination with the foreign and dramatic (figure 25). These elements are represented by features such as a Norwegian cottage, a Chinese pavilion, a temple, Pantheon inspired grottos etc. The park was partly destroyed by Scottish soldiers using the park as an encampment during the English occupation of Copenhagen in 1807 (Danmarks Naturfredningsforening, n.d.). In the 1850s three large cisterns were constructed as a water reservoir for the city and its inhabitants.

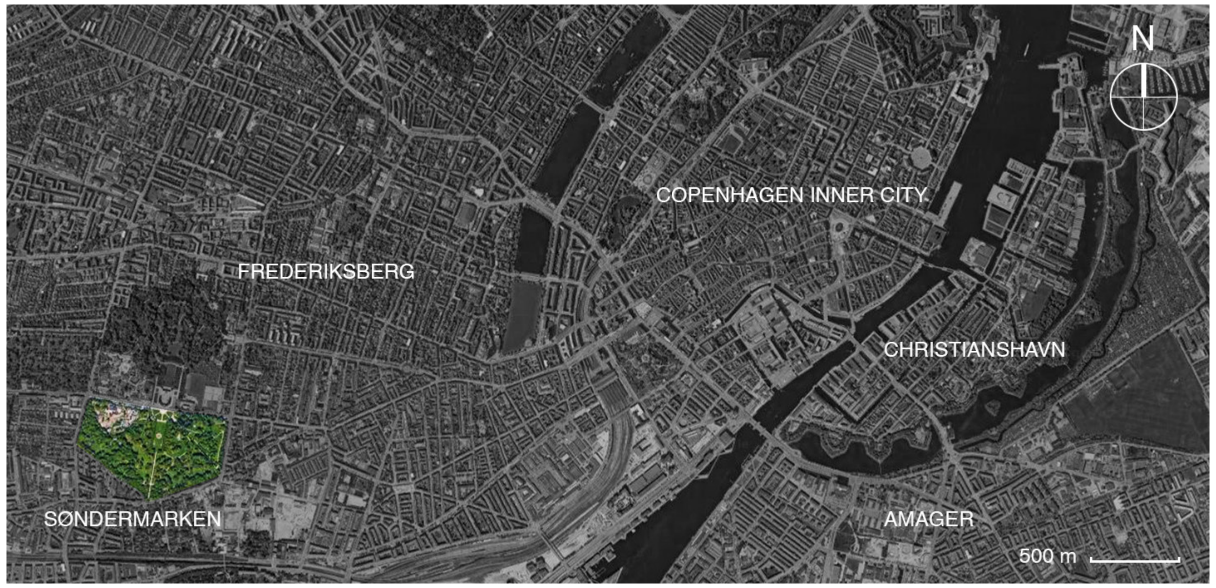


Figure 24: Site location

The municipality has placed a lot of effort on promoting sports and leisure activities in the park and the cisterns provide a chance to experience interesting artistic and cultural exhibitions. The cisterns were previously functioning water reservoirs used to provide clean water to the city dwellers, but were turned into an art gallery exhibition space in the mid 1990s by the municipality of Frederiksberg, in collaboration with Max Seidenfaden Gallery. Within Søndermarken Park there is also a section of the Copenhagen Zoo, which has its main area on the other side of Roskildevej. This smaller zoological space is primarily dedicated to the African savannah and amongst others, people are able to see giraffes, impalas and rhinos.

In 2011, Slots- og Ejendomsstyrelsen commissioned GHB landscape architects to re-imagine the lighting of the park. GHB, in their project Liv og Lys, created an interactive layer in the historical gardens to inspire new uses whilst keeping the historical integrity intact (GHB Landskabsarkitekter, n.d). The design was developed by Morten Weeke Borup and Jakob Fischer in collaboration with Philips Lighting for a total of 12 million Danish kroner.

Figure 25: Archive image of Søndermarken

The main use of the park is for people to stroll around in nature and for others to exercise. For the more relaxed activities, such as walking around or hanging out with friends, the park offers many walkable paths as well as small local landmarks that are scattered within its borders, maintaining an organic feel of the whole site. Some of these landmarks are made for gatherings such as "The Seat" or the small stage area, whilst other ones act like small monuments to local figures, such as the statue of Nikolaj Bøgh. Additionally, the 'Norwegian House' offers information about the local flora and fauna and there are a couple of playgrounds for children.

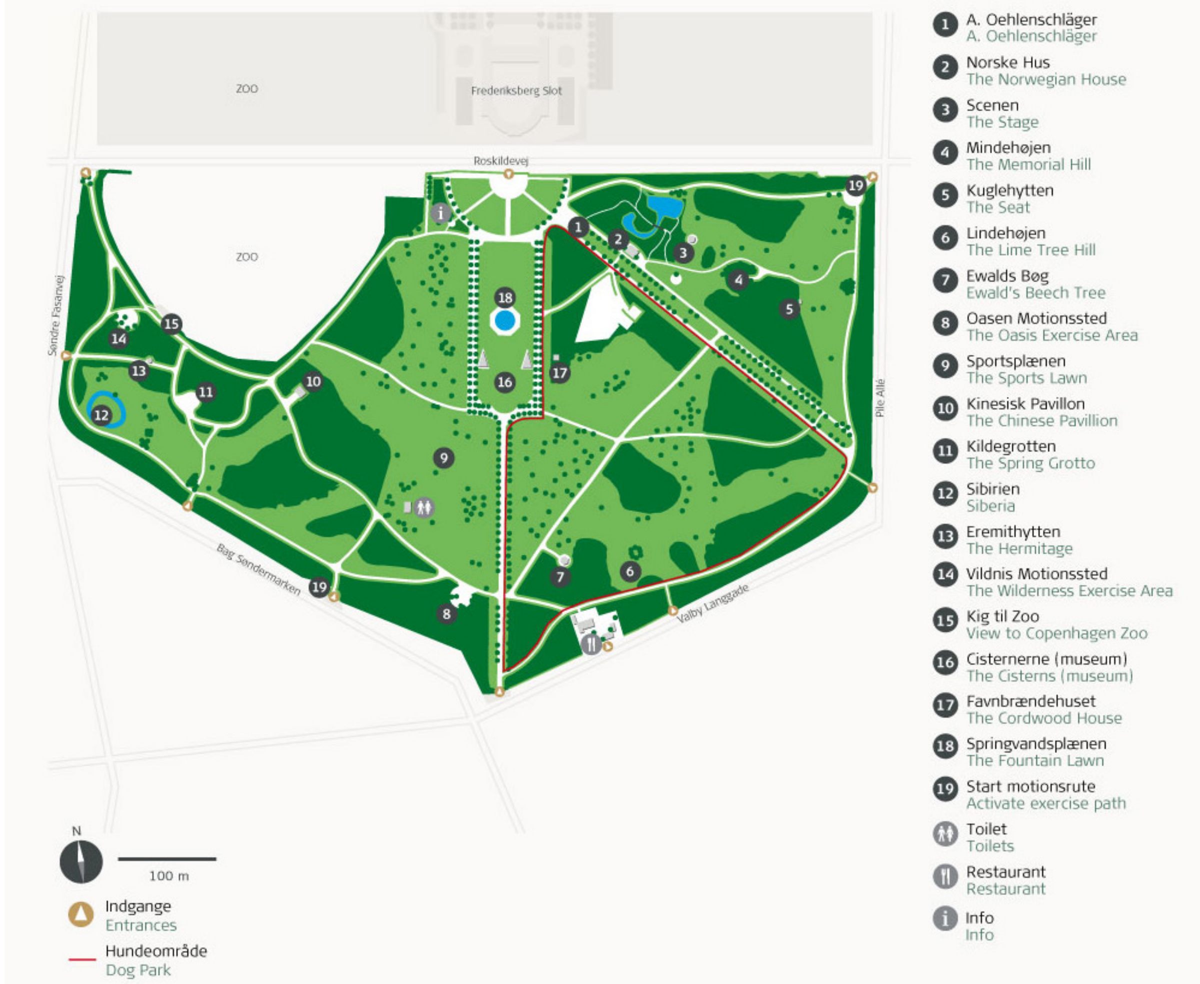


Figure 26: Overview of Søndermarken (Slots- og Kulturstyrelsen, n.d.)

Apart from the leisure activities, the park is primarily used for people to exercise, and the municipality invested in the previously mentioned interactive lighting path for runners. This path stretches around the perimeter of the park and is the primary source of illumination during the night. The interactive lighting consists of a “chase light” that can be activated from the corner between Roskildevej and Pile Allé (figure 27). Runners can choose between five prefixed speeds, which then translate to a coloured light on the side of each bollard that is activated from one to the next according to the chosen velocity. More recently, a company called Go Monkey created a small area dedicated to climbing and zip lining. This climbing park takes advantage of the many tall trees and allows users to book sessions to climb on various trees and go from one to the other using mobile bridges, zip lines, ladders and ropes (figure 28).

Figure 27: Chase Lights (Gestsson, n.d.)

Figure 28: GoMonkey Park (GoMonkey, n.d.)

Figure 29: Photograph of Søndermarken (personal archive)

FAUNA

Søndermaken is a park with variable elevation, water features, thickets and tall trees, allowing for a diverse and broad range of fauna. The following list of animals is based primarily on observations of people reporting to Danmarks Fugle og Natur, a website dedicated to collect and catalogue information on flora and fauna (Naturbasen, n.d.). These observations are supplemented by our own observations.

23 species of birds have been observed, ranging from small birds such as the house sparrow to larger birds such as hooded crows, tawny owls and even whooper swans.

More than 60 insects have been observed, yet it is likely that there are more species found in and around the soils. Anything from bugs, beetles and crickets, bees, butterflies, moths etc. have been observed. Of small creatures, there is also a subset of arachnids and snails found in the park.

8 species of mammals have been observed in Søndermarken:
Common noctule (bat)
Soprano pipistrelle (bat)
Serotine bat
Nathusius’ pipistrelle (bat)
Red squirrel
European hedgehog
Yellow-necked mouse

Due to the water features, a couple of amphibian species have also been observed in the park. The common toad and the smooth newt (or common newt) are the only ones that have been observed in the marshlands (figure 30).

Figure 30: Photograph of local toads (personal archive)

OBSERVATIONAL ANALYSIS

To analyse the site of Søndermarken we used different methodologies. For general knowledge pertaining to the current use of the area, its users and experience we conducted observations, specifically descriptive observations following a protocol based on work by James P. Spradley (1980). Descriptive observations begin with an informant, in this case we treat ourselves as the informants. The work was purely descriptive yet should also describe in detail feelings elicited by observed actions and happenings. We conducted what Spradley refers to as a grand tour, a broad view of actions and spaces that does not question why a thing is, how it is or indeed how it came to be - yet describes how it is and/or feels. Spradley created a matrix of possible descriptive questions for a grand tour and a mini tour (a more specified line of questioning for a smaller area) organized along his proposed dimensions of social situations.

The dimensions are situated in the first row and column and the corresponding questions in the diagonal line represent grand tour questions to keep in mind when conducting the observations. This is to establish the mindset of taking in every detail possible in all areas that may be relevant for further exploration in a mini tour, however, our work to establish a baseline of what the park is and is used for, included only the grand tour line of descriptive observations. Other parts of the analysis of the site were gathered throughout multiple visits to the park via spot-observations, including site measurements of the illuminance levels of the existing lighting features around the edge of the park, further observations of park-uses and state of the installed features of the park.

Figure 31: Current lighting of Adam Oehlenschläger's Statue

Figures 32-34: Current lighting situation of main boulevards (top) and running paths (mid and bottom)

PURPOSE OF SITE EVALUATION

In order to develop a design that is consistent with our interdisciplinary approach we visited Søndermarken various times and did several photo registrations, autoethnographic investigations and observed the users' behaviour and activities. This was particularly insightful to identify the purpose and use of the many landmarks present in the park and how the lighting was designed for them. Most of the registrations were taken during the months of March and April, during late afternoon hours and early evening. The observations revealed a quite diversified population of users: during the day the park is primarily inhabited by casual walkers of all ages and many parents with their children in strollers, whilst during the late afternoon and evening hours the main users are runners and fitness groups.

Figures 35-36: Photographs of landmark (left) and running path (right) (personal archive)

DARKNESS OBSERVATION

Throughout the period of writing, we went on numerous excursions to Søndermarken in the nighttime as well. These excursions were done primarily to collect notes on the atmosphere, on the area in general and the lighting as personal accounts of our experiences throughout the nightscape. We travelled through the entirety of the park, on various paths and crossing, on the lit surrounding path to the unlit inner-most paths and places. These observations also serve as base knowledge of the surroundings in the dark, as a precursor for our test. Our account of what we perceived, based on notes, has been written into a coherent text as follows:

Entering the park after dusk, you are presented with a brightly lit entrance followed by the outer trail of lights surrounding the park's exterior. Although you can spot small instances of light from the local landmarks, you are met with a wall of darkness. The innermost parts of the park, from the perspective of one in the lit path, are a black abyss where anything that enters quickly goes out of view and blends with the dark backdrop. On the path you are greeted by the passersby, the runners and strollers. The intermittent gaps between the fixtures create instances of darkness, and people sitting on the benches in those gaps are difficult to perceive from a distance. During the lockdown, temporary signs have been put up to make the runners and walkers to go in the same direction to try and combat the spread of the Covid-19. We see a small detail of policemen strolling the park trying to enforce this and are promptly advised to alter direction.

Figure 37: Photograph of main boulevard (personal archive)

We all follow the same path down the lit avenues of the park. You feel part of a slow-moving wave of people, connected, yet distant. The park in its central area near the Cisterns is surprisingly densely populated. Our thoughts are outwards bound, towards the people and the current conditions. Moving into the darkness, our eyes start the process of adapting to the light levels. We begin to see. The atmosphere is much quieter than the lit pathways and further distanced from the still-busy city streets. These unlit paths are almost completely void of people. We do come across the occasional small group of people sitting in the darkness having a drink or a smoke, however, the paths remain empty. Some of these people utilize their phones and almost appear as bright beacons, posing the question of our dependence on phones. Questions as these, and opportunities for reflection are brought forth in the darkness. There is less visual and audible clutter allowing us to exercise different thoughts and perspectives in the calm and quiet. Our thoughts are turned towards ourselves and our immediate surroundings. Sounds in the inner-most areas of the park are brought to our attention. The sound of our footsteps, the quiet bustle of birds and other critters in the thickets. You feel less alone in your stroll, knowing and perceiving the surrounding animals, although invisible to the naked eye.

Near the pond, however, we see multitude toads on the dark path, frolicking and looking for mates. Life is now brought to our immediate and visual attention as time passes whilst observing the toads. There seems to be an abundance of them in the unlit path near the pond, all virtually motionless. A wholly different and tranquil reality from the scarcity of toads on the lit path and their movement.

Figure 38: Photograph of the stage (personal archive)

As we stroll further in the dark-zone, a bright light hits us as we approach "The Stage", an unusual wooden stage with a big three-armed luminaire. When approaching, the adaptation our eyes went through is entirely reset, and we are met with bright glaring spots and an even larger contrast to the surroundings. Visibility is severely limited at this point, only the stage is visible. The many landmarks scattered throughout the park, such as "The Stage" are inconsistent in lighting, some having a smidgeon of light, others unlit and some feel as if contrasting figures to the dark of night. Moving to the lit paths again, our thoughts are projected outwards again and the stroll ends with the experience of the now reappeared dark wall.

Exiting the park towards Frederiksberg Slot (north side) we look back at the park. We see the ideas that went into the creation of the current lighting situations and commend these from a distance. We see a certain quality in the layout but cannot help but to remind ourselves again of the discomfort felt when strolling through. The spotlights that shone upon us throughout, enhanced the limitless contrast and stirred a sense of vulnerability.

QUANTITATIVE MEASUREMENTS

All of the quantitative measurements were gathered on a night with an intermediate sky, partly cloudy, partly clear, with the moon shining lightly. Data sheets of the current luminaires can be found in appendix 1.

LUMINAIRES

On separate occasions to the darkness observations we performed various measurements to objectively gauge the current lighting situation in the park. To gather the necessary data from the luminaires and surroundings, the following tools were used (figure 39):

Figure 39: Equipment

Luminance Meter:	Konica Minolta, LS-150
Digital Luxmeter:	Hagner, Model EC1
Spectrometer:	Asensetek, Lighting Passport Standard, Model: ALP-01
DSLR camera:	Nikon D3400, 18 – 55 mm lens

To begin the assessment, we first needed to get an overview of the light in Søndermarken. We identified the main path in the perimeter of the park lit by the bollards. Following that, we located the taller luminaires on poles placed on the boulevard-like straight paths tangential to the cisterns and cutting through the park. We subsequently noted the locations of the independent light features utilising the same luminaires as in the boulevard poles, a crossroads and "The Stage". We plotted these light situations on an aerial masterplan along with the two lit landmarks, the Chinese pavilion and the statue of Adam Oehlenschläger (figure 40).

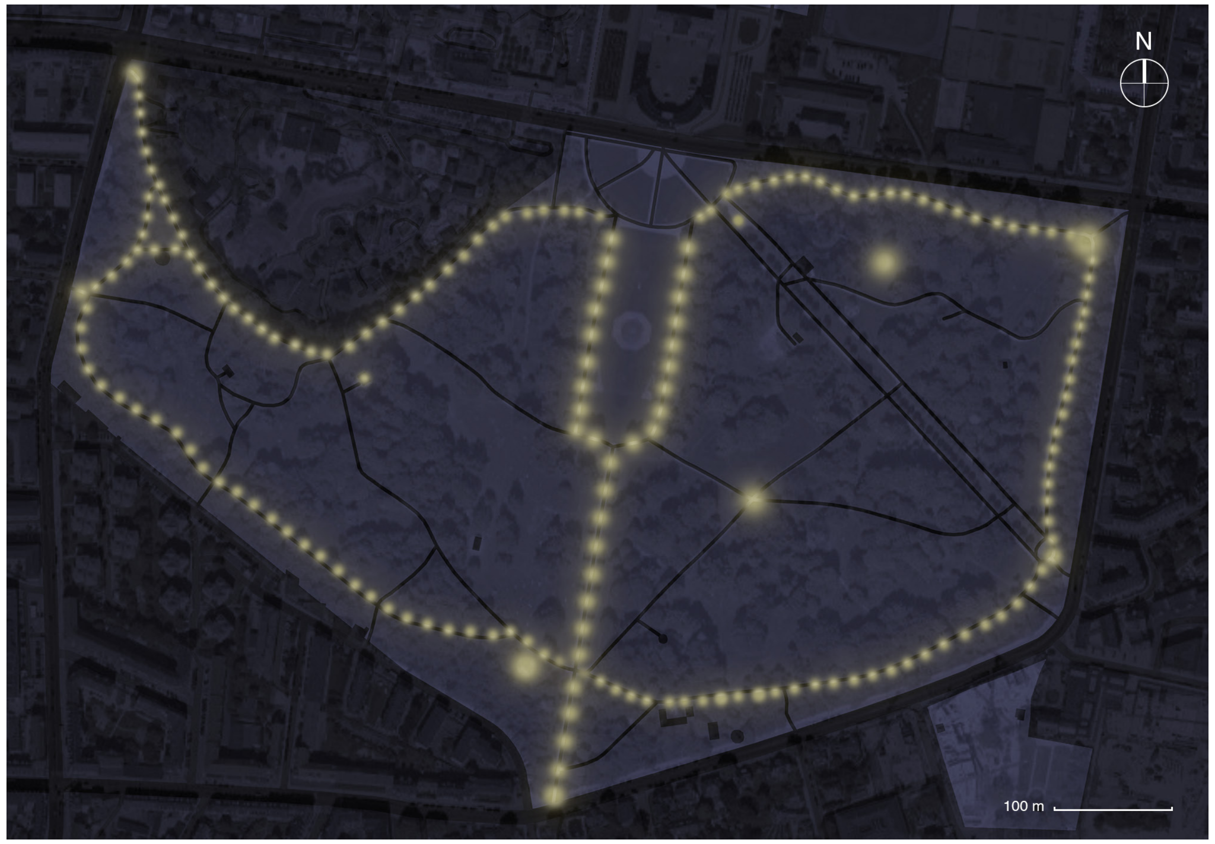


Figure 40: Current night plan

The masterplan gave us a birds-eye view to figure out what to further investigate. The most prominent luminaires utilised in the park are the CitySwan Bollards, the tall pole-mounted CitySwan LED luminaires and the similar three-pronged pole-mounted CitySwan LED luminaires used at the cross and "The Stage".

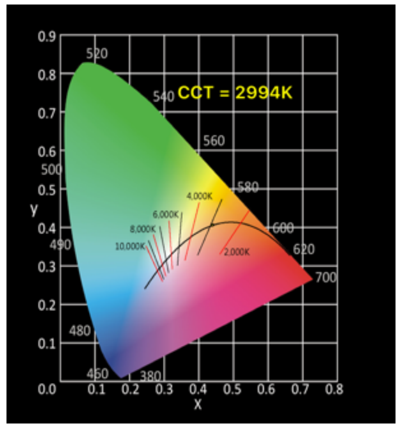
The CitySwan family of luminaires is designed by the Danish architects Bjarne Schläger and Morten Weeke Borup and produced by Philips. The product family is widely used in Copenhagen and Frederiksberg alike and comes in various editions for wall-mounting, pole-mounting and a bollard.

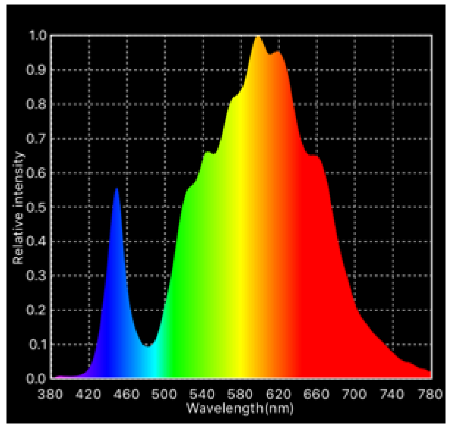
CITYSWAN BOLLARD

Figures 41-42: CitySwan Bollard (left) and photograph of regisrtation (right)

Measured values are displayed normally and the data-sheet value is seen in brackets where applicable.

System power:	(7) W
Luminous flux:	(380) lm
Colour Rendering Index (CRI):	81 (84)
Correlated Colour Temperature (CCT):	2994 K (3000K)





Figures 43-44: Measured CCT (left) and SPD (right)

Above is the measured Spectral Power Distribution (SPD) of a CitySwan bollard with a peak in the short wavelengths, which gives it a measured scotopic/photopic (S/P) ratio of 1.3 (figure 43-44).

DISTRIBUTION

We spot-measured one of the luminaires' illuminance in a two-dimensional space to show how the light distribution is for the path and beyond (figure 45). The bollards primarily contain their light directly in front of the fixture, thus measurements behind the fixture would be superfluous.

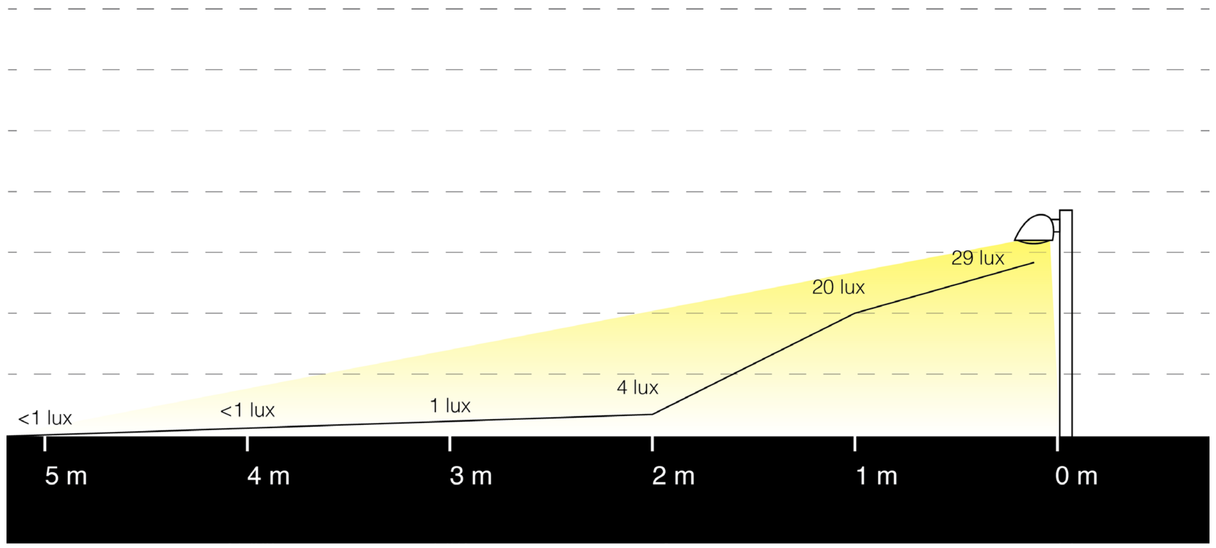


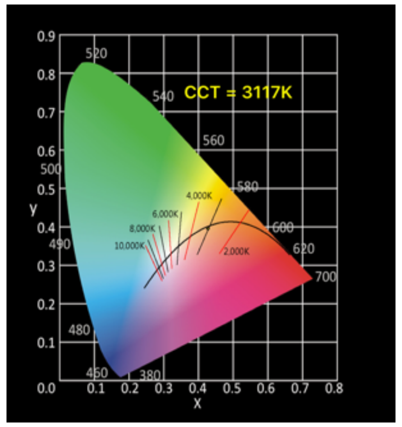
Figure 45: Light fade diagram

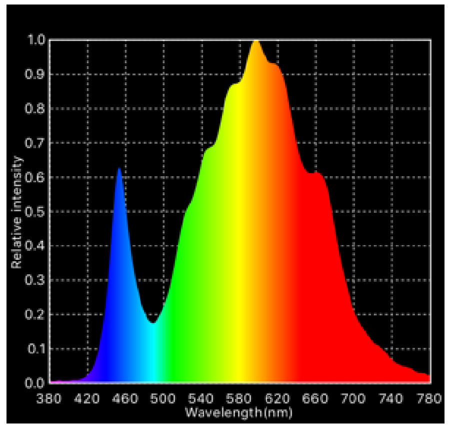
CITYSWAN POLE MOUNTED LUMINAIRE SINGLE

Figures 46-47: CitySwan Pole (left) and photograph of regisrtation (right)

Measured values are displayed normally and the data-sheet value is seen in brackets where applicable.

System power:	(18-108) W
Luminous flux:	(1600-7808) lm
Colour Rendering Index (CRI):	81 (84)
Correlated Colour Temperature (CCT):	3117 K (3000K)





Figures 48-49: Measured CCT (left) and SPD (right)

Above is the measured SPD of a CitySwan single pole-mounted luminaire with a peak in the short wavelengths, which gives it a measured S/P ratio of 1.3 (figure 48-49).

DISTRIBUTION

We spot-measured one of the luminaires' illuminance in a two-dimensional space to show how the light distribution is for the path and beyond (figure 50). The single pole-mounted luminaire has a wide distribution of light, also behind the pole, warranting measurements both covering the path and the back.

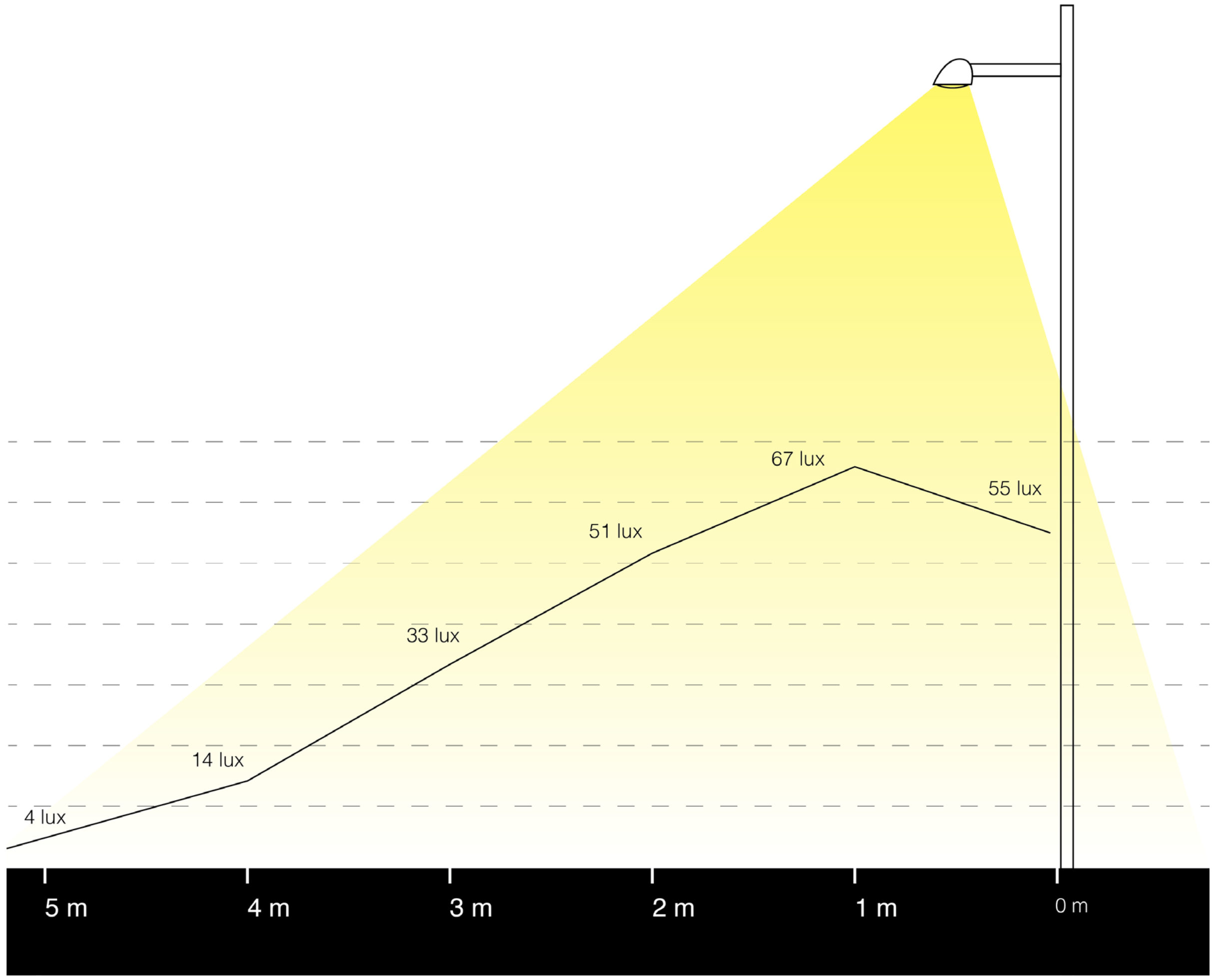


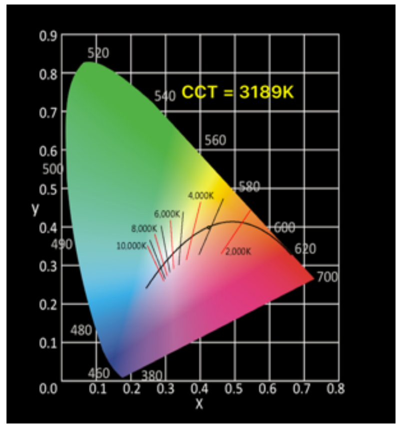
Figure 50: Light fade diagram

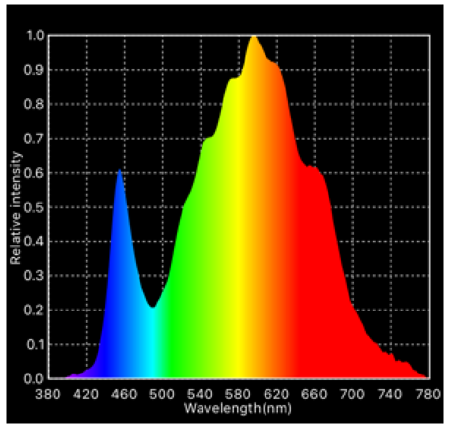
CITYSWAN POLE MOUNTED LUMINAIRE THREE ARMED

Figures 51-52: CitySwan 3 armed pole (left) and photograph of regisrtation (right)

Measured values are displayed normally and the data-sheet value is seen in brackets where applicable.

System power:	(18-108) W (x3)
Luminous flux:	(1600-7808) lm (x3)
Colour Rendering Index (CRI):	81 (84)
Correlated Colour Temperature (CCT):	3189 K (3000K)





Figures 53-54: Measured CCT (left) and SPD (right)

The three-pronged CitySwan fixture is composed of three luminaires identical to the single pole-mounted one described prior. However, a significantly smaller amount of the source's LEDs was functioning or turned on at the time the measurements were taken.

The measured SPD of one of the CitySwan's single luminaires in the three-pronged pole can be seen in figures 53-54, with a peak in the short wavelengths, which gives it a measured S/P ratio of 1.4.

DISTRIBUTION

We spot-measured one of the luminaires' illuminance in a two-dimensional space to show how the light distribution is for the path and beyond (figure 55). The three-pronged pole has its three luminaires spread out and provides light in a semi-circular distribution outward and the measurements are from the pole and out consequently.

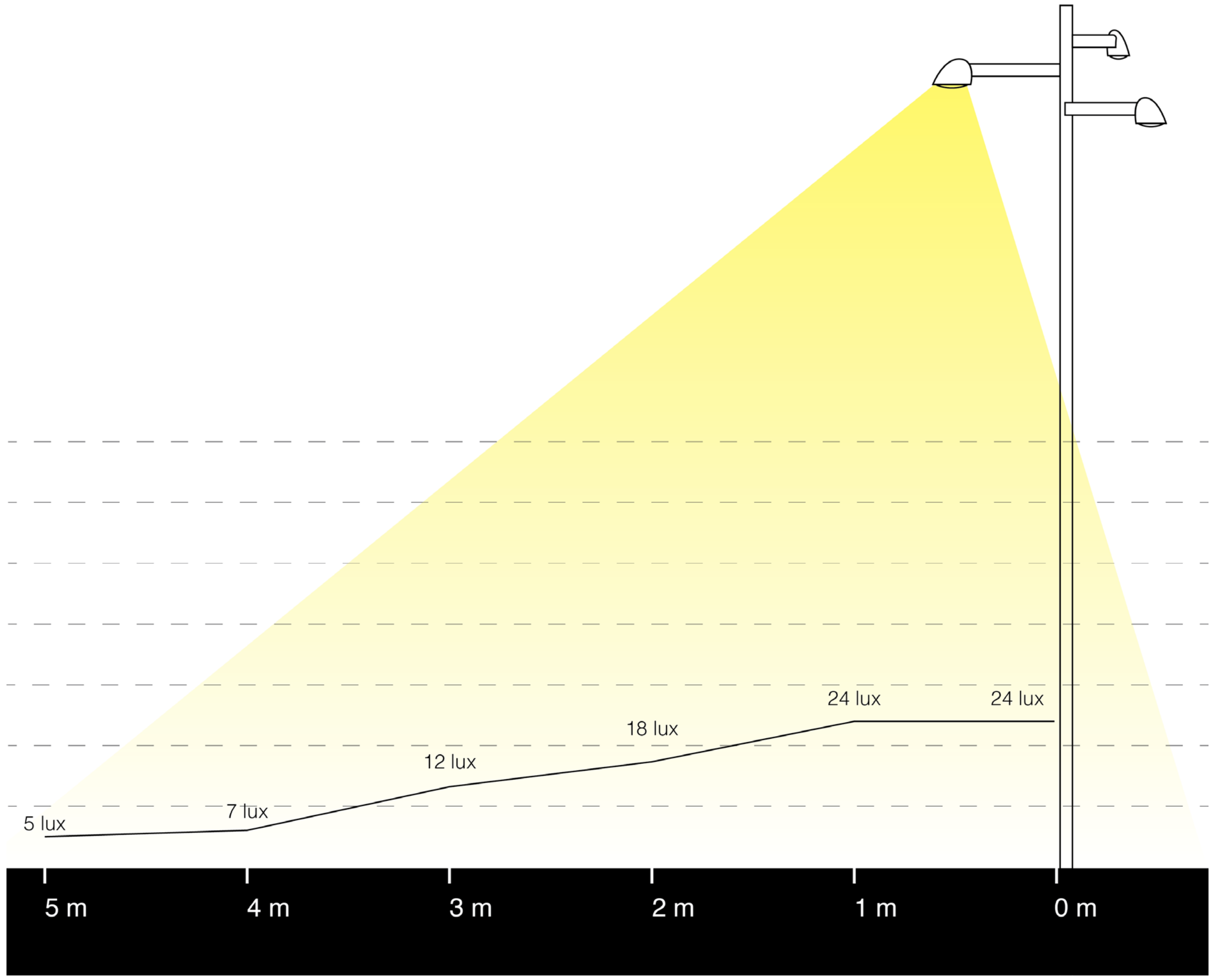


Figure 55: Light fade diagram

LUMINANCE

In conjunction with the data and DiaLux calculations presented later, we also wanted to objectively measure and convey how the luminaires operate regarding the human vision and the contrasts we observed in our experiential study. For this purpose, we created a high dynamic range image (HDRI) for each of the sites used for the above measurements, by creating a composite image of photographs taken with different levels of exposure.

We performed spot-measurements of the luminance in areas of the HDRI scenes and used the data to show the luminance values and thereby the contrast of the scenes in the HDRs as grayscale images of contrast-ratios. Comparisons of the HDRIs and their respective greyscale contrast-ratio images can be found in the following pages (figures 56, 57 and 58).

The images show the great contrast ratios between the luminaires and the background and it is evident how the fixtures are designed in a way that can induce glare and discomfort in the viewer. Especially in the pole mounted luminaires, the light sources are unshielded and their exposure is highly noticeable to a point where it can be blinding. Additionally, the light creates clear boundaries that hide anything that is beyond it, raising issues that will be further described later in this chapter.

The lumen values in the spot-measurements and subsequent false-colour images were measured with a luminance meter adjusted to the V(λ) curve, the photopic luminosity function established by CIE.

Figures 56: Bollard HDRI and greyscale comparison

Figures 57: 3 armed pole HDRI and greyscale comparison

Figures 58: Pole HDRI and greyscale comparison

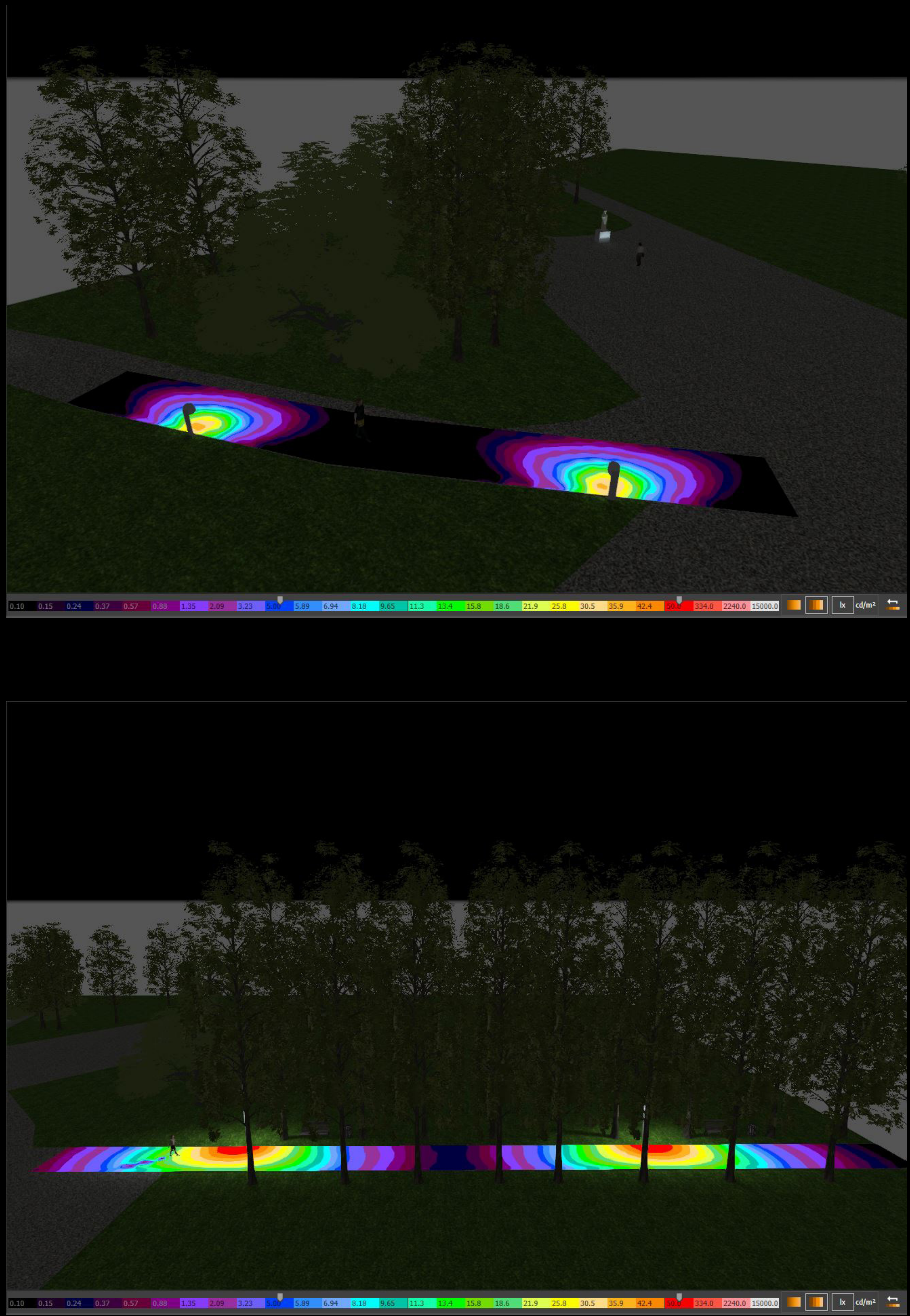
DIALUX SIMULATIONS

We created DiaLux scenes for selected areas of the park to provide context to the various luminaires and their interaction with each other, their distribution and location. The DiaLux scenes visualise the distance of the light-sources, show the discontinuance of light elements and dark areas. It should be taken into account, when viewing the DiaLux images, that DiaLux does not account for ambient skyglow or moonlight, and the calculations therefore do not convey the entire image. However, these images serve as valid indications of where darkness is present and aptly visualise how the distribution is between the luminaires.

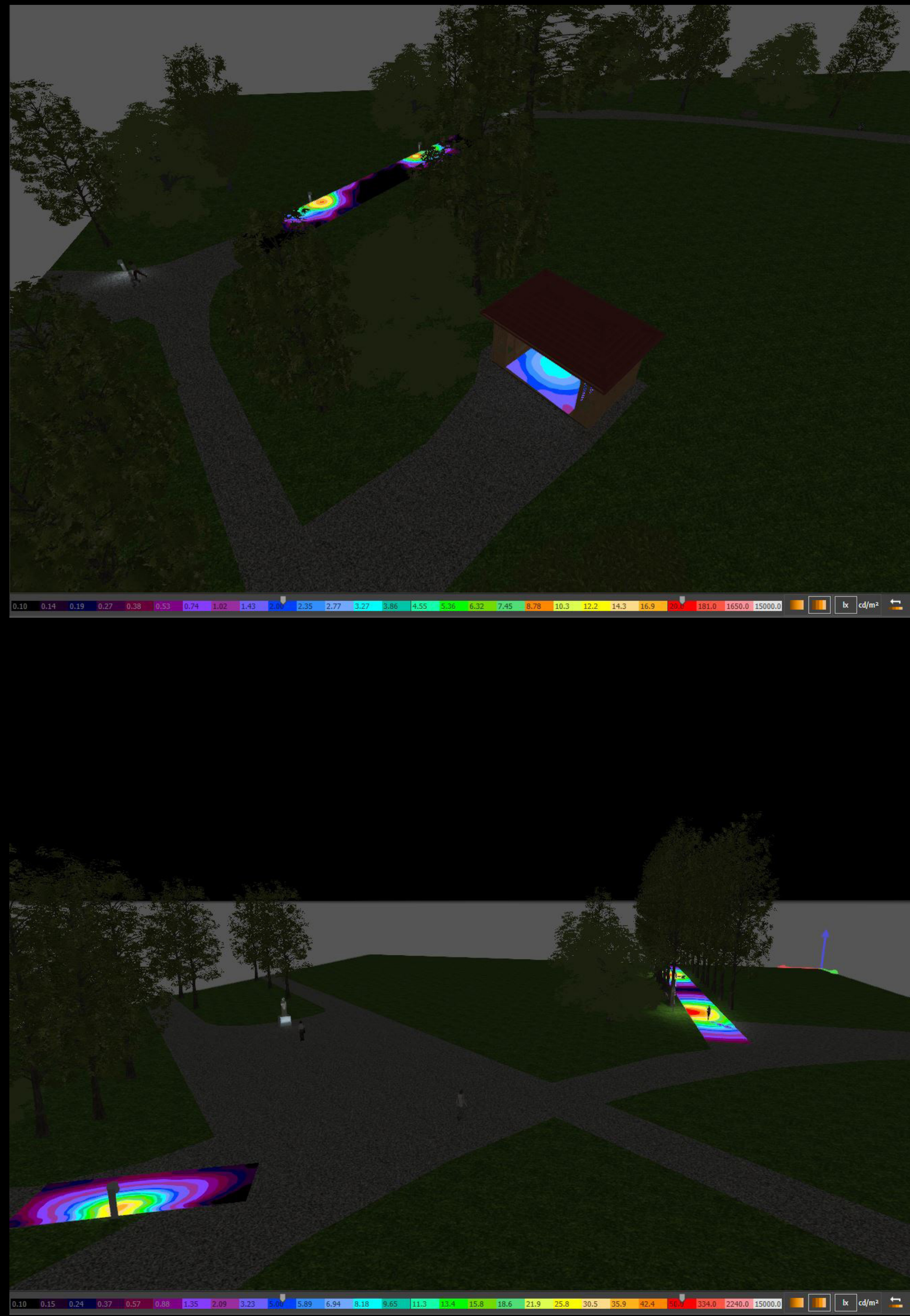
Figure 59 shows the illuminance levels of the bollards in the perimeter path as well as the darkness in between them. This arrangement and distance of the bollards is continuous throughout the lit pathways. The average lux level between poles throughout the paths are around 3-4 lx with a maximum illuminance of 38-40 lx measured directly underneath the light source. Figure 60 visualises the same for the boulevards, however, the illuminance levels are higher and the darkness between fixtures is smaller. The average lux on the boulevards is around 12-14 lx with a measured maximum of 61-63 lx. There is little in terms of dark corridors between the boulevard lighting which cuts through the park.

The luminaires on the paths and boulevards thus create discernible patterns of light and provide regularity. This regularity is discontinued in the change from path to boulevard as there are no fixtures present in this interim area. The main pathways are in that sense not directly connected and the same was found for the few landmarks that are illuminated in the park. The statue of Adam Oehlenschläger in figure 61, is illuminated but lies in the relatively dark area between the main path and boulevard. The Chinese pavilion as can be seen in figure 62 is equally situated on an unlit path with no connection to the areas most frequented by visitors at night. This obfuscation is increased by the many trees surrounding the pavilion, further removing it from people. The Chinese pavilion’s illumination is also less intense averaging 2 lx with a maximum recording of 4 lx.

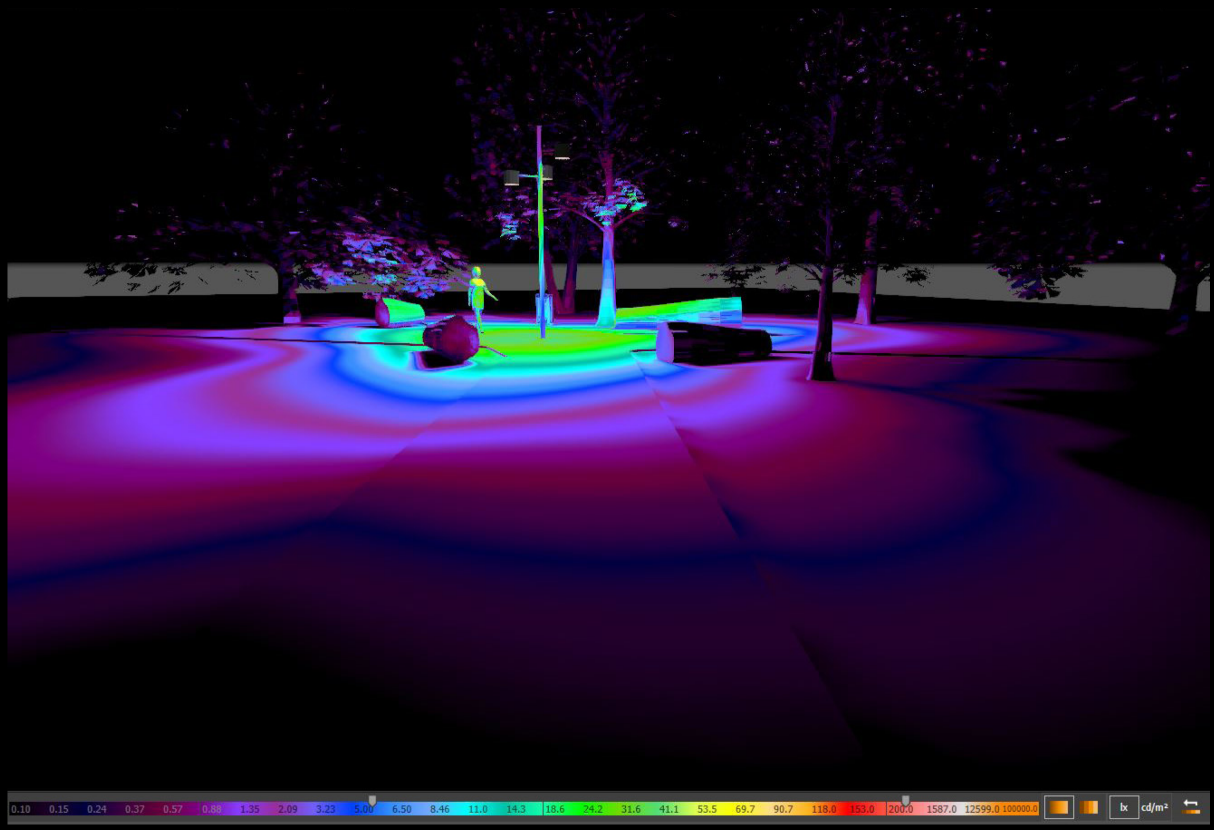
In figures 63-64 images of how the light falls beyond the pathways are shown. These calculations highlight the amount of light that is spilled into the surrounding green areas both in the crossing and from the main boulevards. The illumination of the three-armed fixture from the cross is lower than that of the boulevards, however, the light trespass is increased when combining the three separate luminaires.

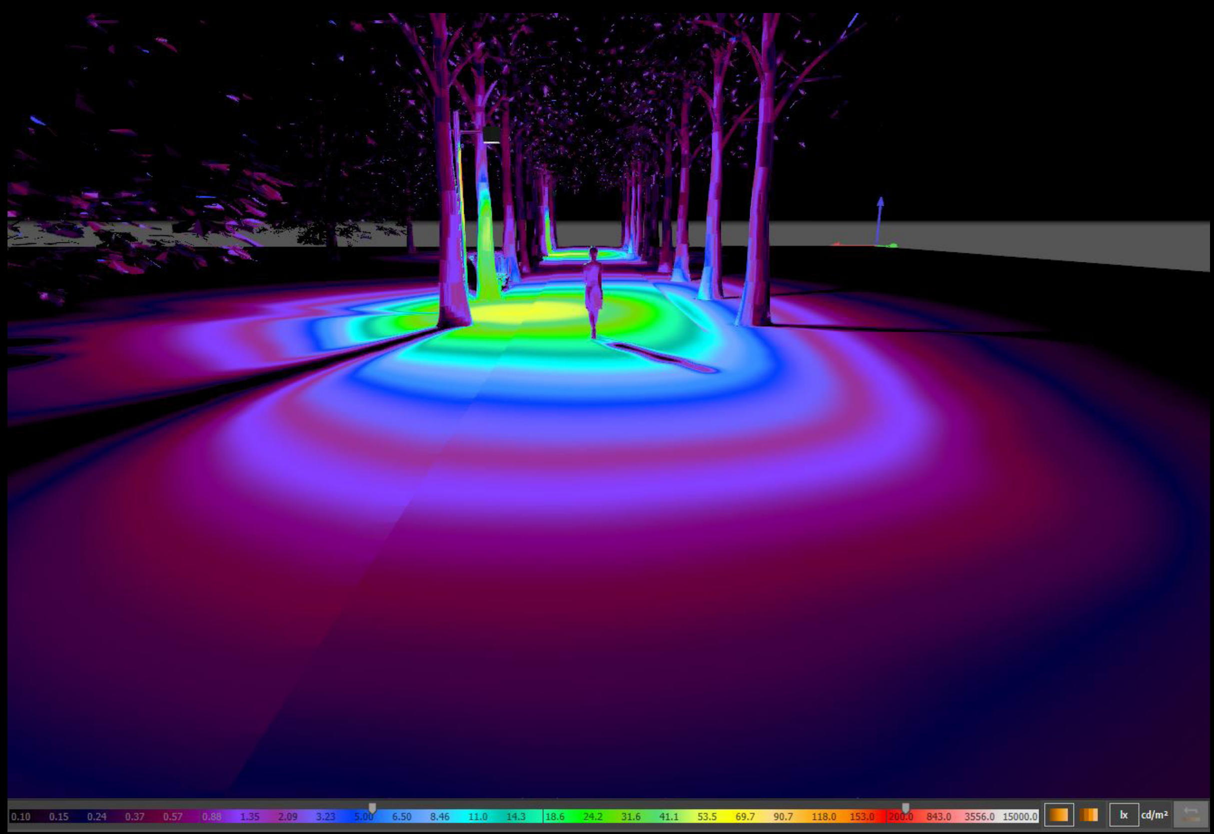


Figures 59-60: Pseudo colour of illuminance distribution. Bollards (above) and poles (below)



Figures 61-62: Pseudo colour of illuminance distribution of distance between elements.





Figures 63-64: Pseudo colour of light trespass. Cross (above) and boulevard (below)

ISSUES IDENTIFICATION - FOR HUMANS

The primary issue with the lighting of the park is that it is almost completely dark at night except for the perimeter path and a few lights on some of the landmarks. This essentially creates an “abyss of darkness” and makes most of the park quite inhospitable at night. The perimeter bollards are approximately a meter high and are evenly spaced throughout their path (~16m apart), being substituted by taller poles on one of the main arteries of the park (~30m apart). The bollards produce an average of 5 lux in the vicinity of the fixture and the output is low due to the lack of maintenance on the optics and lifetime (The lumen output in the measurement-section is for a fixture in optimal condition). Even with this lowered output, the contrast with the rest of the scenery is very high. This is in part due to the spectral composition of the light carrying an S/P ratio around 1.3, increasing the perceived lumen going to the eyes. This creates very sharp distinctions between the path and the central areas of the park, which does not promote exploration of the inner areas of the park during the night.

The tall poles spill a lot of light into the grasslands behind them, a location where the light serves no purpose. They are brighter than the bollards to light a larger area which in turn increases the contrast between the luminaires and the surrounding areas drastically. The source of lighting in the poles is also exposed, creating glare when near or under the fixtures.

Additionally, the landmarks are not consistently lit. The small buildings in the park, such as the Chinese Pavilion and the Norwegian house have poor or no illumination, whilst some of the statues have glare inducing fixtures pointed at them. Certain areas that are meant for gatherings are lit in an impractical way if at all. A prime example of this is the small stage located in the north-east part of the park, which is at the centre of a small natural amphitheatre. The stage is circular in shape but the light that was designed for it consists of a pole with three mounted flood lights positioned at the side of it without any real relationship to the purpose of the space. Furthermore, the paths and surroundings leading to this area are completely dark, leaving it entirely isolated and therefore unused.

Because of these design choices, the park loses most of its vitality during the evening and night. The inner paths that are usually used by people during the day, are almost deserted during the night hours. Certain paths run through some wooden areas whilst other ones are in the middle of the main fields, and regardless of which path one takes at night, they will be in complete darkness. This can be a discomforting atmosphere for many people as in darkness we are not always able to perceive the presence of others (as shown in figures 65-66), which in return can cause us to let our fears overcome us (Edensor, 2013). However, this is also an issue on the lit paths, because of the high contrast generated by the bollards. The way these fixtures are arranged, and because of their distribution, all the benches are in the dark and it is easy to not notice someone sitting on them whilst walking around.

Figures 65-66: Contrast issue visualisations (personal archive)

Ultimately, during our observations we have noticed many small groups of people hanging out in the darker areas of the park, mainly partying. Although this is not an issue in itself we did notice that some litter was left in some of the spots and even if the park is generally well kept, it is worth mentioning as we believe that better lighting could contribute to less littering. Further studies would be required in this regard as it is beyond the scope of this thesis.

ISSUES IDENTIFICATION - FOR FAUNA

The general dark nature of the park is a positive feature for the biodiversity that resides in it, however, the current lighting scheme can still pose potential issues for the animals. The primary fixture, the bollard may only have an illumination level averaging 5 lux, but is in contrast with the otherwise dark park. This contrast is only increased with the taller pole-mounted luminaires. The intensity may discourage or prohibit certain species of animals from utilising the lit areas. This is in part rectified by the large distance between luminaires, allowing for dark passages between them not creating an 'impassable' wall of light. The issue of the intensity is primarily visible in the distribution of light from the poles. They have an elliptical distribution from the source which also covers behind the luminaires, spilling light into areas without any use of it. This increases the intensity in the supposed dark areas surrounding the luminaires.

The luminaires' spectral composition was measured to have a small peak in the short wavelengths (430nm - 460nm) which have been shown to have a large impact on animal behaviour. Short wavelength radiation elicits potentially maladaptive responses in the animals present, shifting balances in otherwise controlled ecosystems. Although the data from our observations in the dark are anecdotal and limited, we saw far greater numbers of toads in the dark path than in the lit, and their behaviour was observed to be of a calmer nature in the darkness. Other animals were observed not visually but audibly, and are assumed to be operating primarily in the dark.

CHAPTER 4

TESTING

Following the site analysis, we turned our focus to find actionable parameters to test and further the project, guided by the knowledge gained from the analysis and theoretical criteria. The high contrast environment with high intensity lumen output creates psychological discomfort and does not facilitate adaptation to the dark. It also produced substantial physical discomfort in the form of glare and the high intensity creates barriers for certain species of animals which is further exacerbated by the observed trespass of light from the pole-mounted luminaires. These elements, coupled with a measured CCT of around 3000 kelvin which we did not perceive as warm or welcoming in the context, did not aid in experiencing the dark and discouraged exploration into the unknown. The test is an exploratory experimentation to gain new perspectives and insights for future evaluation. It is meant as an open-ended exploratory test whose results inform further testing protocol development. The test starts without an overarching hypothesis and all observed phenomena and experiences relating to the test are taken into account.

EXPLORATORY EXPERIMENTATION PROTOCOL

The test is divided in two main sessions: the first one without any equipment and the second one with the use of orange filtered lights. The first session, over the course of a couple of evenings/nights, is dedicated to the observation of people and wildlife. During this session we would focus on how people navigate through the park, which activities are the most usual and how and if wildlife is encountered. In the second session, we would return to the park equipped with filtered lights and position them along a chosen dark path. The filter would eliminate the potentially harmful short wavelengths to limit the impact on biodiversity. The fixtures' locations would be laid out in an alternating pattern to avoid creating a uniform distribution and to allow for nocturnal animals to cross at night. Although biodiversity is not what is being tested, the luminaire arrangement, intensity, filtering and other parameters serve to limit the impact on biodiversity which is a key component of our research. Ideal lighting fixtures for this test would be controllable and possibly inconspicuous in order to not attract the attention of the passersby. In both sessions, the environment would be scrutinized, and our personal experiences would be recorded, through the same observational methods of James P. Spradley (1980). The test is designed to interpret the atmosphere of the park and ultimately, to develop the hypothesis for further testing.

EQUIPMENT

Fixtures:	6 solar powered garden lamps (LED)
	Schou Company - Mr. Solar
Orange tinted filters:	Lee Filters - LEF256 SET
Luminance Meter:	Konica Minolta, LS-150

Figures 67-68: Mr. Solar fixture (left) and modified testing fixtures (right)

ACTUALISATION

The test was set in Søndermarken and spanned across a few weeks, starting in the beginning of April 2020. We spent the first day exploring the park's routes and noting the flow of people, how they interacted with the landmarks and within the open areas. During the subsequent evenings we walked the same paths multiple times and observed the light distribution of the current fixtures, as well as their relationship with the overall surroundings. During the evening/night observations we also noted the change in user usage of the park and how that was affected by the general lighting.

After this first session we drafted a preliminary list of observations about the usage of the park and issues related to the lighting. This led to preliminary design discussions and evaluations to strengthen the overall concept for the thesis.

The following week, we returned to the park with the equipment and chose a path that crosses the 'sports field' from the central area to the western illuminated path (figures 69-70). During the first half of the test we placed the lights along the path covering most of its length by having the fixtures quite far apart. We realised then, that the low output of the luminaires was not enough to create a cohesive pattern that could be determined as intentional. Therefore, we shortened the portion of the path covered by the luminaires, which proved to be a better choice.

Figures 69-70: Photographs of testing (personal archive)

REFLECTIVE OBSERVATIONS

After the second session, we analysed the results and put them against our expectations. This guided us to further design discussions and evaluations for future testing phases.

The most striking result of the test was that during the second session, the park was almost desolated. We encountered only a fraction of the amount of people that we had observed during the first session. Except for the social distancing guidelines we found two other possible explanations for this: 1. The first session was held during a bank holiday period while the second one was not and 2. The temperature had dropped significantly from the previous week, making it less inviting to be outdoors at night. The lack of people coloured our behavioural observations as there were too few subjects to gather any substantial data from.

The temperature drop, we believe, has also impacted the toad population which we had hoped to study more. In the first session we had found toads present on the darker paths in large numbers and almost none during the second session were to be seen.

The test also made us realise that the lamps that we had chosen had too narrow beam angles and low output to create an effective atmosphere. The illuminance they produced right in front of the fixture was around 3-4 lux. Yet, they did mark the path enough to function as guiding beacons, and therefore, lowered the contrast with the nearby surroundings. The existing fixtures, however, were still visible and glary. This made it impossible for our eyes to fully acclimatise to the darkness of the area that we were in. Coming from the currently illuminated path, our test-luminaires practically became invisible to the naked eye. Additionally, we noticed that the skyglow effect is rather substantial and the sky never became completely dark.

ABSTRACT CONCEPTUALISATION

After the results of the exploratory testing phase we have revisited our parameters and focus areas to propose a more specific test protocol that would be ideally tested in future works. As seen from the previous observations, the biggest issue that we have experienced was glare and high luminance levels in contrast to the background of the park. This made us aware that illuminance levels were not the most relevant parameter and that we had to adapt our protocol to test adaptation.

Additionally, the exploratory test was inconclusive when testing curiosity and exploration, therefore, we had to include a qualitative data gathering section in our new protocol. Similar to the exploratory test, the new experiment would take into consideration the preferred spectral power distribution of the luminaires, that are least impactful on animal life. The SPD would be chosen from existing theories whilst the distribution would be sporadic and allow for dark corridors that the animals can use to move unaffected.

HYPOTHESIS

After revising the exploratory test results we have refined our scope of inquiry with new perspectives and parameters in mind, which resulted in the following hypothesis:

A low-contrast environment, aligned to the ideal of nocturnal urbanism, in city parks at night stimulates exploration whilst providing a pleasant atmosphere.

This hypothesis was formulated for the sole purpose of the new testing protocol, as a tool to help answer the greater question posed by the problem statement.

The following figure (71) shows the iterative process from the first exploratory test developing the hypothesis, and lastly, the newly revised test protocol.

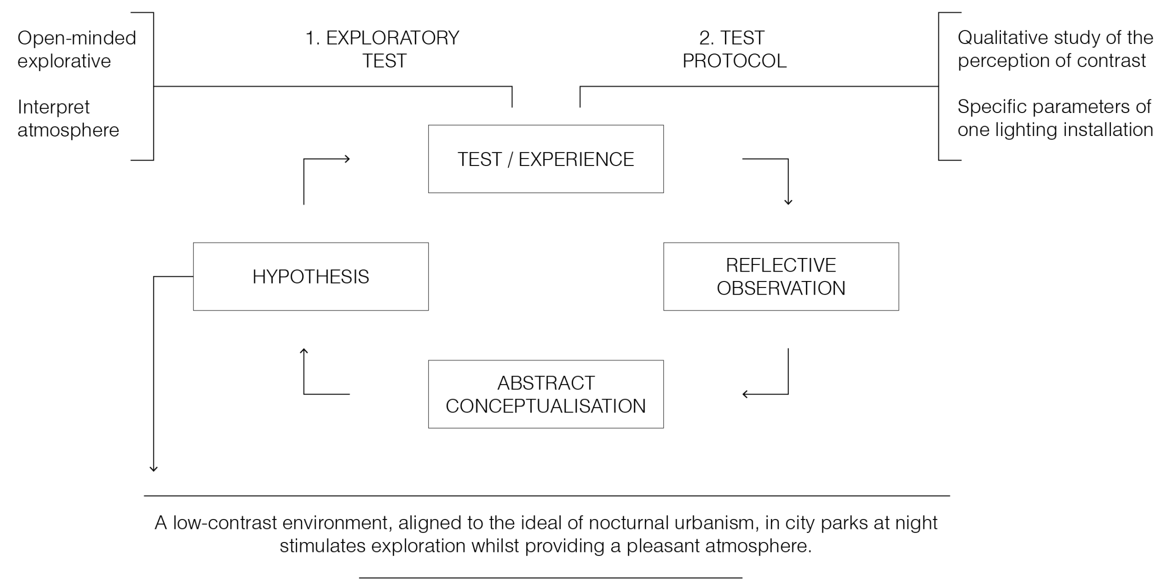


Figure 71: Iterative cycle in practice

REVISED TEST PROTOCOL

The newly proposed test protocol is the culmination of the previous site observations and exploratory test results. Although, due to the guidelines and restrictions that were put in place by the Danish government concerning the pandemic of Covid-19 we were unable to conduct qualitative examinations with participating subjects. The following protocol is a proposal that we assume will yield results that would be able to confirm our hypothesis.

Additionally, as the overall goal is primarily concerned with creating lighting for humans we are focusing the core of the test on behaviour and experience, as well as contrast ratios and perception. However, as previously stated, we root our base parameters of SPD and distribution in the theory of affecting qualities on biodiversity.

EXPERIMENT SETUP

The new experiment will be set in on a chosen path within the park that is currently unaffected by the existing illumination (figure 72). This particular path offers varying levels of vegetation thickness and view to the open areas of the park, as well as differing degrees of sloping walkways.

Figure 72: Highlighted path for testing

The lights are to be placed along the path according to its topography, allowing for enough wayfinding illumination but avoiding uniformity. The layout must allow for dark corridors which can be exploited by animals at night whilst traversing the area. Additionally, the spectral power distribution of the lights must be the least impactful on biodiversity, based on the proposed theory, which suggests utilising narrow spectrum amber (approximately between 580 and 640 nm). The SPD of these lights will be fixed for the entire duration of the test.

The luminaires used should all be the same model to keep parameters and deviations to a minimum. The luminaire should have an inconspicuous design in order to not attract attention and distract the test subject.

The only changing variable for this test is the intensity of the chosen luminaire, which would be predetermined to 3 different output levels. Each night of testing will have assigned one of the three levels of intensity chosen, and it would not be changed during the course of the same night.

ACTUALISATION OF THE EXPERIMENT

On three separate nights, possibly with clear weather and comfortable temperatures, test participants would be asked to walk on the chosen path, alone. For this part of the test the participants will not be given any specific instruction about the lights nor the environment, but simply to walk as they normally would, were they to be in the park on a regular evening. Each night, the participants would be asked to repeat the same task, but each night will have a different luminance level setup.

At the end of the path, one of the researchers would greet them and begin a semi-structured interview. During this interview we would have prepared a set of questions to guide the conversation, but allowing the participants to deviate and elaborate their own thoughts and perceptions and develop further questions from that new perspective. An outline of how such interviews would be conducted has been created including questions in Appendix 2. The overall structure was created according to the paper ‘In-depth Interviews’ by Legard, Keegan and Ward (2003).

This qualitative method, we believe, is useful to gather information of subjective nature, as it allows for a more discursive results which can be subsequently analysed and interpreted through the lens of aesthetics, perception and atmosphere.

ASSUMPTION OF RESULTS

Our assumptions of the results are based on the studied theories and our personal observations. With this test setup we assume that the participants will ultimately feel more comfortable and enjoy walking in the park in a lower contrast environment. We hope that the participants would feel more aware of their surroundings in a positive way and be more inspired to wander. Additionally, with less contrast in their field of view, we believe that they will more likely take notice of the night sky and appreciate the nature around them.

CHAPTER 5

DESIGN

After analysing the site and testing our new hypothesis we can start designing a new framework that can pave the way for new standards when designing lighting in urban green areas. The strength of this framework lies in its interdisciplinary approach, particularly because it combines fields of study that are not usually connected directly. The combination of the aesthetic approach for atmosphere and the foundation of sustainable lighting for animals offers a new perspective for the intent of this framework which is the requalification of darkness. Combining criteria involving both animals and humans in a perfect unison of ideals, that will enrich the experience of urban green areas.

FRAMEWORK

After analysing the site, testing and through utilising the theoretical criteria we have devised a condensed list of practical success criteria, which constitute our proposed framework for lighting in urban parks:

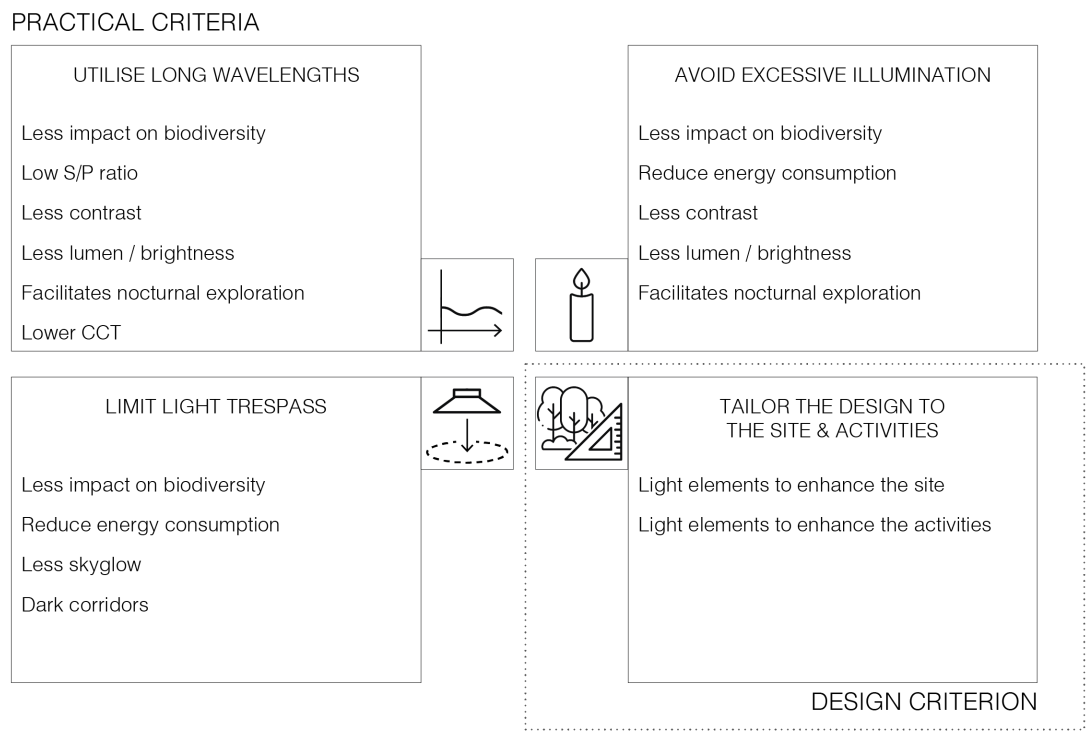


Figure 73: Design framework

These criteria carry a set of positive consequences that encapsulate a wider scope. Making light sustainable for animals signifies avoiding shorter wavelengths which also affects the S/P ratio by making humans perceive less lumen than the actual output of the luminaire. Ultimately this helps reduce the overall brightness contrast which, as we have illustrated before, promotes a comfortable atmosphere and inspires nocturnal exploration. Limiting the intensity of illumination also helps the previous point, as it also lowers the contrast, facilitating the appreciation of darkness in a comfortable environment. Lower intensity lighting is less obtrusive, providing less contrast and allows the user to gaze over the park freely, and appreciate the night. This criterion also shares commonalities with limiting trespass and smart distribution, as light should only be where it is useful, creating points of interest rather than contrasting walls of light. This, in return, avoids creating glare for humans and can help limit skyglow altogether, allowing for dark corridors which the local fauna can use during the night undisturbed.

The design criterion is not directly focused on the qualities of light themselves, but directs attention to the characteristics of the site to tailor solutions to the context. By enhancing the pre-existing strengths and features of the park in question, as well as promoting the user activities. This criterion is variable depending on the site but maintains the same aim throughout the framework.

CONCEPT DESIGN

After analysing the site of Søndermarken, testing various iterations, and ultimately reaching the practical and design criteria, we found ourselves on-site conducting a brainstorming session for our design proposal for the park. The brainstorm rests on the back of the knowledge we have gained thus far in the process of the thesis. The brainstorm is guided by the original problem statement which is as follows:

"How can we through an emphasis on darkness and atmosphere minimize the adverse effects light has on biodiversity whilst creating nocturnal experiences for the urban population."

The practical criteria should ensure that the lighting design proposal ends up impacting biodiversity minimally whilst the design criteria serve as a solid foundation for a lighting design in the specific urban park. The design concept brainstorm generated multitude ideas and philosophies for the lighting design, ultimately ending in the following string of conceptual definitions for the proposal:

Our emphasis is to use light in a sparse fashion, without contrasting the dark backdrop, to facilitate the exploration of darkness. We want the design to give access to darkness for darkness to be re-evaluated as a positive. Through this, we wish to create a space for reflection and contemplation, to reduce people's pace and slow down the rhythm. This desire of slowing down is meant as a catalyst for directing attention elsewhere than the bustle of the everyday and the online. Outwards, to the sudden loudness of our footsteps, our connection to the world and the sounds of nocturnally active animals out of vision. Attention turning inwards, allowing for reflection and differing perspectives. These are qualities that can be found in the cradle of darkness, and darkness also provides a different way of exploring nature as opposed to the very visually dominated way we are used to.

Our design concept is inspired by the art installation "H" by the Danish artist Ingvar Cronhammar, a comprehensive installation located in the heart of Søndermarken, the cisterns, throughout the 2015 opening days (cisternerne, 2015). His installation encapsulates the explorative nature of darkness we wish to pursue. The simplicity of his work and the pools of light amidst the dark elicits metaphors of the subconscious and encourages reflection. His philosophy of the piece is to bring down the speed and take a break from the fast-paced world. To create a sanctuary for reflection and contemplation. The waters on the murky surfaces constitute the unknown and the instances of light make them intriguing, reflecting the surroundings.

Another artwork that inspired us is by the Australian artist James Tapscott and his artwork Arc Zero - Nimbus (Studio JT, 2017). The circular arrangement encased in fog acts like a portal to another world, away from what one came from. In the dark it acts as an intriguing piece and feels very approachable. It encourages the passersby to get closer and to explore the mystical nature it exudes. It has an ephemeral quality that brings a certain sense of mystique and wonder.

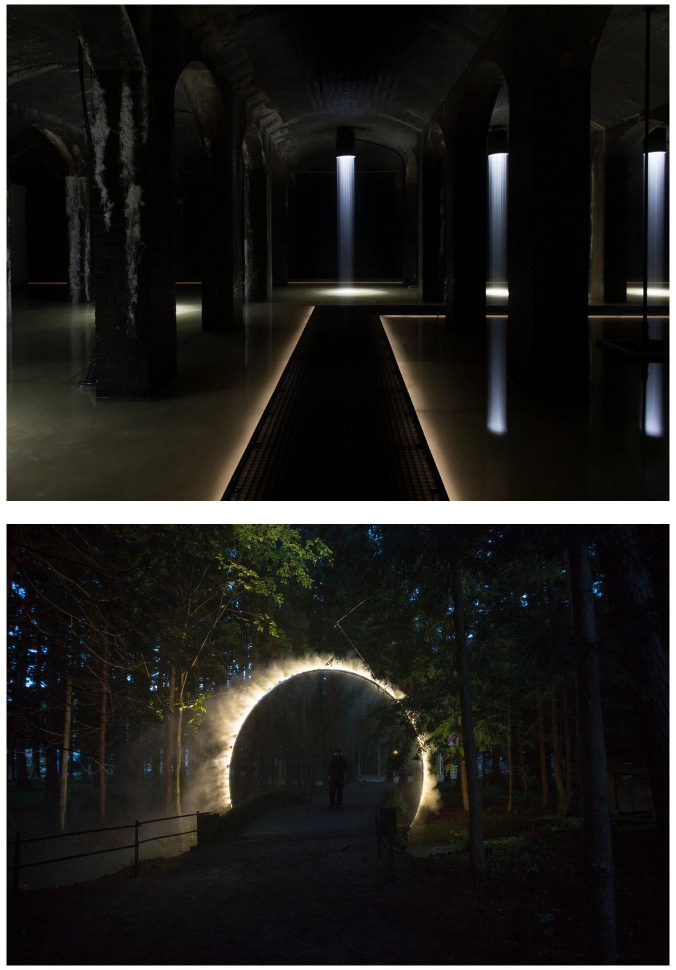


Figure 74-75: Cronhammar's H. (above) and Tapscott's Arc Zero - Nimbus (below)

The lighting design should then be mostly unobtrusive yet invite and encourage exploration. Simplicity is thus encouraged to alleviate potential visual clutter and obstructions. It should create passable paths to the various landmarks and string them together, not in any particular order, but allow for divergent paths to cross and intermingle. The design should accommodate the traversal from light to dark and the current emphasis and abundance of runners in the park should not be neglected but could be integrated into the gradual change of illumination.

It is intrinsically a park for the people but in our vision not about the people. It is about turning the attention outwards to trigger inwards reflection and contemplation. The points for outwards attention is facilitated by a flourishing ecosystem built on great biodiversity.

Before proceeding to the design development phase we brainstormed a series of ideas conceptualised in the sketches shown in figure 76.

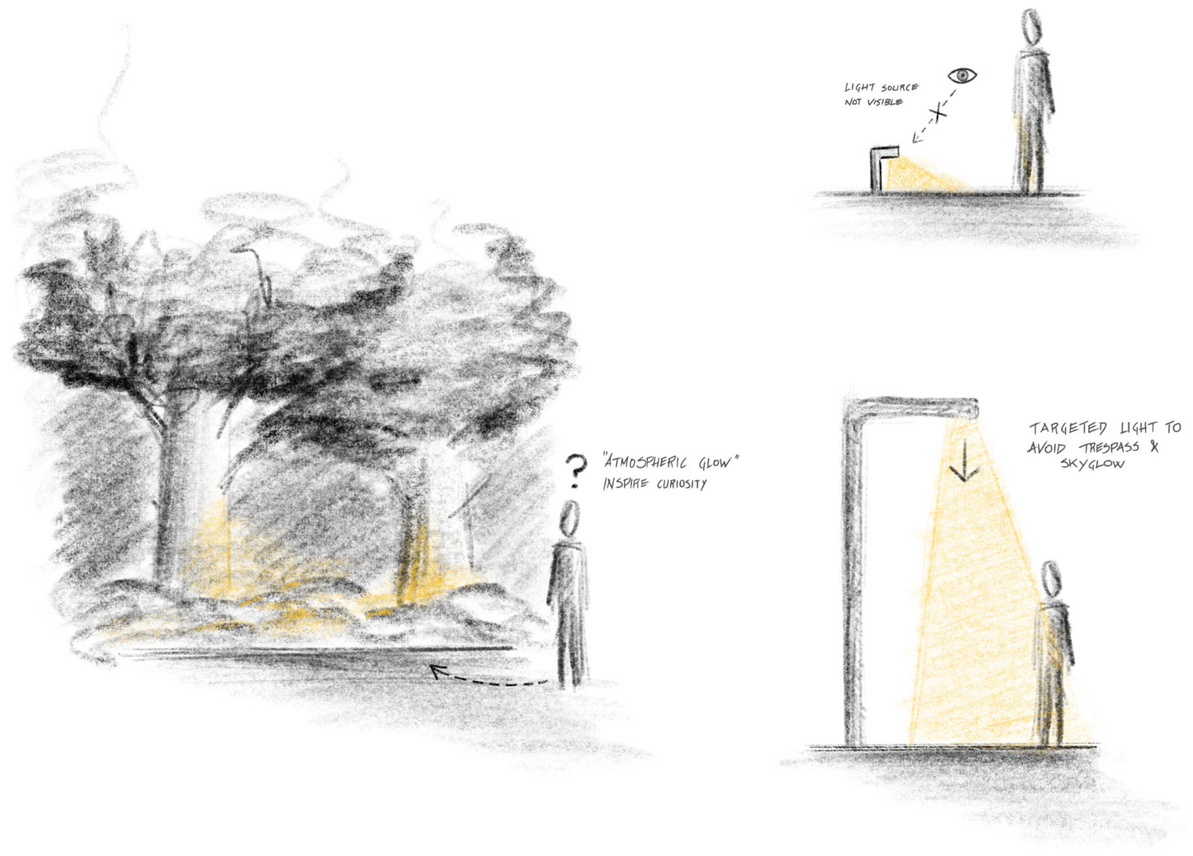


Figure 76: Concept skethes

DESIGN DEVELOPMENT

Drawing from the analysis of the site of Søndermarken, we review the current lighting scheme for the ideas they represent and fulfil. The ideas we perceive form the lighting installation in Søndermarken are valuable to extract as to not divert greatly from the usage of the park.

The path bollards create a perimeter of light for traversal and running and do create some level of transition from light to dark, as their brightness does not rival that of street-lighting. The luminaire distribution, with more than 16 metres between each one, creates ample dark corridors for animals to cross between the fixtures.

The boulevards with pole-mounted luminaires stand out and establish the lighting hierarchy between these central pieces and the perimeter path. The boulevards warrant such grand fixtures to provide the sense of scale and to complement Frederiksberg Slot. The bollards and taller poles create a park that is pleasant on the eyes from a distance.

The bollards' additional light element of a chase light runners can engage with from the main entrance of the park was created for the express purpose of providing the multitude of runners with an interesting tool. This idea serves one of the primary activities in the park and should encourage runners.

The ideas highlighted above are not in opposition to our vision of the site and complements the different areas in various ways, however, there are multiple things to address to achieve the context conscious and exploration accommodating lighting design. The baseline for all luminaires is that short wavelength radiation should be avoided to accommodate biodiversity and lower the contrast, which inherently makes for a warm light of a low CCT. Amber light would be ideal for that task and elicits the minimal response in wildlife.

Bollards lower than the currently placed ones or integrated ones could be used and potentially extended to illuminate the dark areas (figures 77-78). These bollards would be less obtrusive in the curated natural elements of the park and perform their primary purpose; to guide one's steps. Lowering the bollards means energy can be saved in providing a similar illuminance, or lower illuminance. The lumen output of each luminaire would have to be guided by the contrast testing to create the best atmosphere for the various paths. The chase light of the current bollards we believe could still be integrated and updated with new technology. The chase path is currently underutilised and unintuitive which could be changed by making it more immediate to the runners. The chase light could be app-controlled and provide immediate feedback on your current run, based on previous runs. The app creates a ghost-version, recording your previous runs around the park and transmits this data via light signals to the bollards in front of you. The colour of these indicators would change depending on your performance, compared to your previous runs and could also be manipulated to push you further if desired. Letting the interaction be app-based allows for users to immediately engage with the system when entering the park and would not depend on a specific start/end point as it does currently. It would give users the freedom to engage with it where-ever, and would not lead to lights traveling around the perimeter paths without being accompanied by a runner.

Figure 77-78: iGuzzini's Lander (above and Vibia's Break (below)

The bollards provide general illumination and we believe that adding an additional lighting feature would enhance the explorative aspects of the nocturnal scene. Adding in pools of light in strategic points to guide our vision and pique our interest. These pools of light could consist of organically shaped light-elements providing the vicinity with warmth and glow (figures 79-80).

Pole-mounted luminaires as are currently in the boulevards work well in creating hierarchy and we think that a similar approach could be utilised without compromising the vision (figure 81). This could be done by using luminaires with louvres that prevent light from spilling excessively, adjusting the brightness and by eliminating glare by hiding the LEDs higher up into the housing. Hence, increasing the light beam cut-off angle which narrows the overall distribution of the fixture as well.

Figure 79-80: Lichtlauf's Munich Reeds (above) and Catellani and Smith's Syphasera (below)

Figure 81: Bega's LED pole-top luminaires

These three elements should constitute the design of the majority of the park, as too many fixtures would create needless visual clutter and the simplicity would be lost. The idea is to create a compelling atmosphere without compromising the objective, nocturnal exploration of nature. Areas such as “The Stage”, the cross and the few exercise and play areas, illuminated by the three-armed luminaire would have to be reconsidered and re-evaluated and are treated as landmarks. The landmarks and prominent features of the park, including statues, buildings, and burrows, would have to have lighting tailored to their specific needs.

Lighting the landmarks of the park may seem counterintuitive to the vision and questions what “useful light” is. We believe these features of the park have a right in themselves to be discovered during the dark hours. They are markings of a historical and cultural nature and can further contemplation or send thoughts in differing directions. Naturally, the lighting should be sparse, and the landmarks will serve as knots on the strings of paths illuminated for exploration. A landmark would be a resting place, in the sense that it can force one to stop and think, if not physically, then mentally. We believe the landmarks are a vital part of Søndermarken as are the topographically varied natural elements.

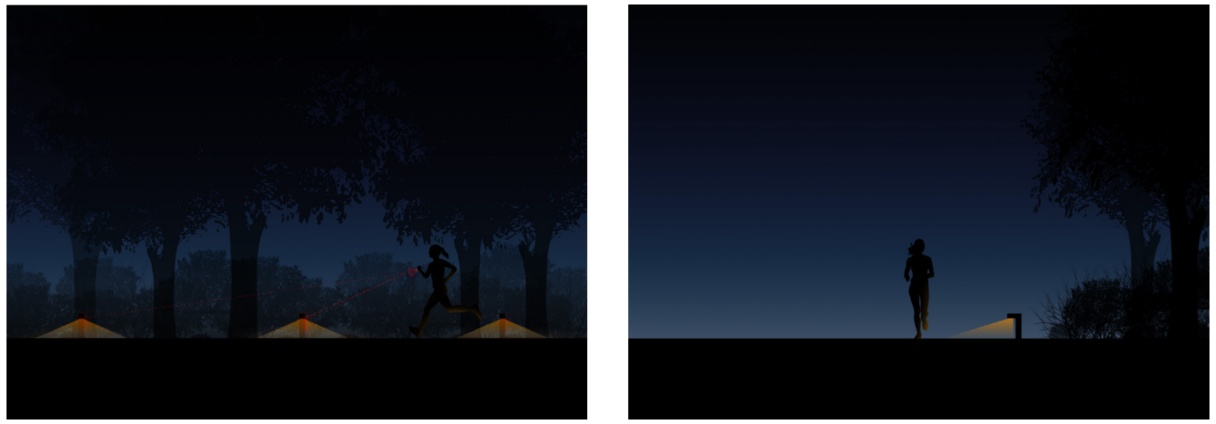
Figure 82: Running path render

PROPOSAL

PERIMETER PATH

The path that runs along the border of the path will be illuminated by low bollards with an even spacing of approximately eight metres between each fixture. This is an increase in terms of quantity from the currently installed bollards, yet still allow for dark corridors for the animals. Each bollard should provide low intensity illumination that allows for safe navigation whilst being non-obtrusive. The light should be composed of long wavelengths, giving it an amber hue which not only will reduce the impact on biodiversity, but also lower the perception of brightness. The light throw is directed down and limited to the path, reducing light trespass and eliminating the potential for glare.

The perimeter path is supplemented with a revision of the current chase light system, which presently is activated from only one location in the park and is often neglected, as well as non-controllable. Our proposal is an app-based system where the user can start the interaction from any point on the path in any direction. The app will allow the runner to set their chosen speed as well as recording their performance. They then subsequently can use their performance data to customize their running experience. Our idea is to provide the option for different lighting colours that the user can associate to a chosen set of parameters. The colours will represent the performance of the runner relative to their previously recorded data and will be different depending on whether the user is ahead, on track or behind. The vision is to provide users with immediate feedback on their jogging encouraging them to challenge themselves. Figure 83 shows how the app could function, interacting with the light.



Figures 83-84: Proposed running path lighting solution

Figure 85: Boulevard render

BOULEVARDS

For the main boulevards that intersect the park, we envision a similar layout to the pre-existing, however, with a fundamental difference in luminaires. Our proposal features shielded luminaires that limit light spillage by focusing the light on the walkable avenues. The fixtures should have an opaque housing to limit the upwards light emission which otherwise may disrupt aerial creatures. The light should conform to the same spectral power distribution of the perimeter bollards, featuring an amber hue that will not disrupt the surrounding ecosystem. Additionally, the pole-mounted fixtures should provide lower illuminance levels to maintain a lower contrast ratio with their surroundings, allowing for easier darkness adaptation. This has the added benefit of reducing the energy consumption overall.

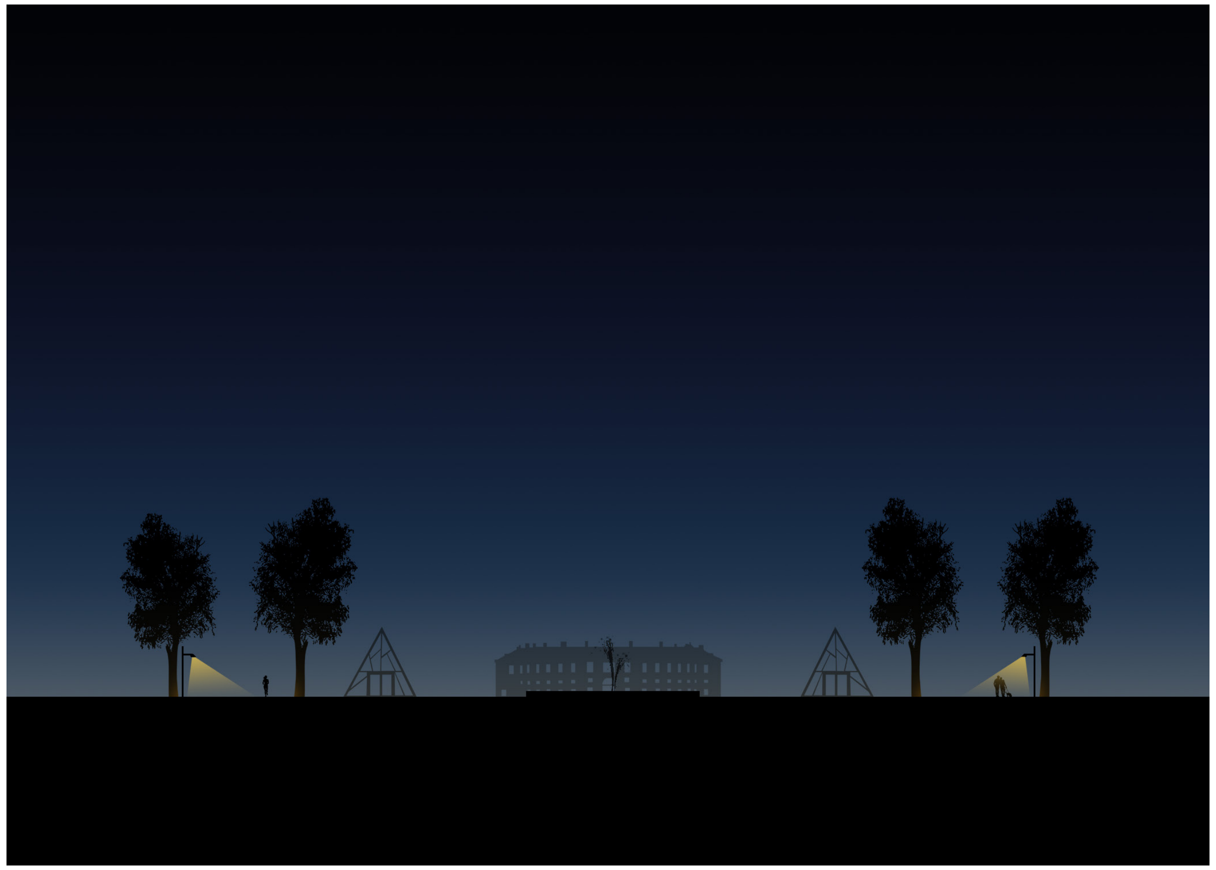


Figure 86: Proposed boulevard lighting solution

Figure 87: Atmospheric lighting render

ATMOSPHERIC LIGHTING

In order to facilitate and encourage curious exploration, our proposal features an atmospheric layer of lighting. This is revealed as an organic layout of pools of light throughout the park in various levels of vegetation. These luminaires should provide subtle illumination to their surroundings, to create points of interest, stimulating curiosity. The proposed fixtures would be similar to the inspiration images in figures 78-79, blending seamlessly into nature with their organic shape whilst allowing for movement with the wind and other natural elements. Since they will be incorporated into nature it is imperative that their spectral distribution is the least impactful possible for their surroundings. Therefore, a narrow spectrum amber is proposed as the ideal Their low illumination and warm light will invite people into the darker areas of the park, allowing them to experience a new connection to darkness in the hopes of altering their perception.

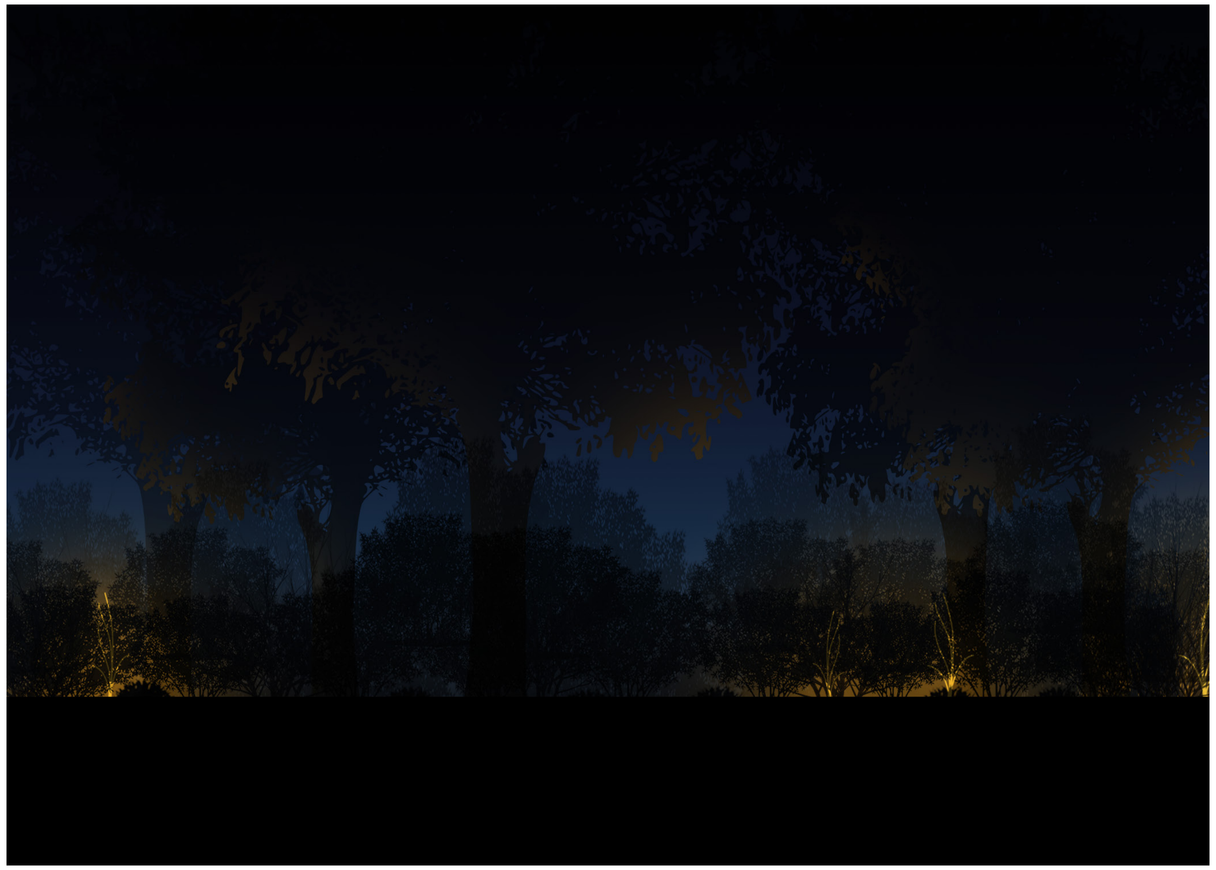


Figure 88: Proposed atmospheric lighting solution

CHAPTER 6

DISCUSSION

In the following chapter we analyse and discuss the criteria from the proposed framework and design solution in relation to the problem statement:

"How can we through an emphasis on darkness and atmosphere minimize the adverse effects that light has on biodiversity whilst creating nocturnal experiences for the urban population."

Furthermore, we will also discuss how the design proposal relates to the philosophy of nocturnal urbanism, a driving force throughout the project. We aim to answer our problem statement by exploring these topics through the lense of the initial success criteria; Facilitate darkness, limit impact on biodiversity and inspire nocturnal use of parks.

The framework was developed to further specify the theoretical criteria and turn them into actionable lighting parameters. We have focused primarily on the non-disruptive aspects both in terms of biodiversity as well as the human experience, whilst allowing for a certain level of aesthetic freedom in designing lighting. The practical criteria of the framework focus on objective benefits as well as the potential aesthetic qualities of the design. We argue that the design framework, if utilised appropriately, can guide the creation of a design that facilitates darkness. We have learned from the analytical framework that darkness has a negative cultural connotation, yet has the capacity for various benefits for both humans and biodiversity. Reconnecting with darkness can make us more aware of our surroundings and inspire reflection, therefore our approach to designing light may need to be re-evaluated by shifting our attention to darkness instead. The framework we have created allows for this shift towards designing with darkness. By insisting on creating a design which attracts the minimum amount of attention to itself we can drive the awareness outwards. By putting strict limitations on the typology of light and its distribution we allow darkness to become the centrepiece, which is at the core of nocturnal urbanism. Through our test-protocol and assumed results we believe that we can give people an opportunity to challenge their preconceptions of darkness and discover something about themselves. We assume that a low-contrast environment stimulates the behaviour of being present and comfortable within darkness. This facilitation of darkness feeds into the ideas of nocturnal urbanism, where the importance of light is balanced by an emphasis on darkness. This elevation of darkness is particularly by the design criterion which is primarily concerned with the specific nature of the site. The practical criteria can only go so far in terms of heightening the importance of darkness whereas the design criterion allows for each lighting design to be unique, regardless of the rigidity of the practical side of the framework. Tailoring the design to the site allows darkness to be emphasized in creative and subtle ways. In the case of Søndermarken, it offers the opportunity to make the dark more inviting by eliminating the current high-contrast barriers. Additionally, the pools of light act as integrated plays of brilliants in the scenery. They complement the varied natural elements present in the park, from the smallest bush to the tallest tree.

Nocturnal urbanism is a valuable philosophy in the field of lighting design and carries positive implications not only for humans, but also for ecosystems in our city parks. During the daytime, the park itself poses no restrictions on the inhabiting fauna, however, the infrastructure is challenged in the night by inconsiderate lighting. Lighting design that considers only the aspect of humans runs the risk of neglecting fundamental aspects of ecosystems, such as the fragmentation of dark areas, adversely affecting wildlife. Hence, the practical criteria put forth in the framework allow for a more holistic and considerate approach, also encompassing the needs of the fauna. In considering this holistic approach it is pertinent to first determine the purpose of the park in question. In the case of Søndermarken, the park is meant for people and their leisure activities whilst a park such as Amager Fælled is a protected natural reserve, requiring an entirely different lighting solution. This highlights the importance of the typology of the park as it determines the role of biodiversity, related to the framework. The practical criteria offer a solid foundation for the safeguard of biodiversity, while the design is tailored to the human users in Søndermarken. For a natural reserve, however, the design would go above and beyond the practical criteria to reinforce the conservation of biodiversity rather than accommodate human activity other than wayfinding. Here, research should solely revolve around the specific fauna and flora to best optimize the lighting solution.

The same amount of scrutiny should be applied when developing a lighting strategy that enhances people's activities, thus involving the atmosphere of the site. In developing our proposal for Søndermarken we took inspiration from theories and reference projects as our opportunity to test was severely limited by the current global situation. This is particularly relevant when discussing the subject of atmosphere as it is an intangible topic requiring the physical experience of space. Although it is possible to digitally recreate part of the experience through means such as virtual reality, it cannot encompass the full-body sensation that is the perception of atmosphere. The state of the art and the analytical framework has delineated how atmospheres can be staged and in combination with ourselves as research subjects, we can extrapolate that our framework has the potential and provides the freedom to create welcoming atmospheres. The use of warm light and low illumination levels, combined with the aesthetic design choices can encourage exploration and ultimately reveals the capacity for a new appreciation of darkness. Consequently, the lighting design resulting from the strict nature of the practical criteria, unveils the surroundings and integrates them into the whole picture.

Conclusively, the proposed framework offers rather strict guidelines whilst allowing for creative freedom for the lighting designer when approaching lighting for urban parks. As shown, the site specificity is key and the overarching criteria should always be used in service of elevating the overall purpose of the park and its requirements. The framework promotes the idea of nocturnal urbanism and tries to make conscious design more accessible, shifting the focus to designing with darkness.

Figure 89: Photograph of Frederiksberg Slot (personal archive)

CHAPTER 7

CONCLUSION

The problem statement poses a rather comprehensive question, which we have broken down in smaller and narrowly focused subjects to better tackle the overall vision of this thesis. By developing the initial process model, adapting it with a more iterative operating methodology we were able to devise a functional testing protocol. Although the test was hindered by the global pandemic of Covid-19, we are confident in our result assumptions based on the literature review and personal experience which helped us formulate a schematic framework for lighting urban green areas. The proposed framework offers the tools to approach conscious lighting design in parks with added perspectives and value, by introducing the concepts of biodiversity and atmosphere. The framework functions as a check-list that ensures a lesser impact on biodiversity which allows the lighting designer to focus on the creative aspects of their design. The nature of the criteria elevates the importance of darkness and its beneficial aspects for both humans as well as biodiversity. This expands the perspective on the simplistic duality of light and darkness, allowing for a more mature and holistic approach to the discipline of lighting design and the betterment of the environment.

FUTURE WORKS

The solutions presented in this thesis are widely applicable and offer great creative flexibility because of their focus and valuation of the site. However, as previously anticipated in the delimitations, there are a variety of additional elements that can be further studied and subsequently strengthen our approach.

Firstly, once the Covid-19 crisis will be over it is worthwhile to actualise the testing protocol in order to gather empirical data that can help solidify the proposed framework. The test could also be expanded to include the local fauna, and with the collaboration of biology experts, the gathered data would be cross referenced in a truly interdisciplinary manner.

Additionally, further research could be conducted about the affective qualities of lighting on flora, expanding the biodiversity sphere of our study to encompass the local ecosystem in its entirety. This will also offer a more comprehensive view on how to engage in discussing sustainability more deeply and further address the United Nations' concerns for the future of our planet.

In order to promote activities in the park we have made a brief proposal for the redesign of the current 'chase' light feature of the bollards, as an app operated 'running buddy' (example of appearance in appendix 3). This should be further developed with the insight of UX designers, to seamlessly integrate the chase light functionality and tailor the user experience. The running buddy would not necessarily have to solely revolve around Søndermarken itself, but function as a running assistant with the additional interactivity in Søndermarken, which could be expanded to other interactive areas.

Lastly, a more in depth study and testing could be made on the local landmarks and how to light them in an innovative, coherent and emotional way. By taking notions from scenography and stage design, it would be beneficial to develop a tailored study focused on how to emphasise the notable sights of Søndermarken. An example for one of the landmarks can be seen in figure 90.

Figure 90: Potential statue lighting solution

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APPENDIX

APPENDIX 1: CURRENT FIXTURES DATA SHEETS

CitySwan Bollard – stylish and discreet

CitySwan Bollard

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

Benefits
- Elegant Danish design
- Energy-efficient

Features
- Provides functional lighting together with a nice design

Application
- Entrances
- Squares
- Sidewalks and bicycle and walking paths

Specifications

Type	BGP444
Light source	LUXEON®
System power	7 W

Correlated Color Temperature	3000 K (Warm white)
	4000 K (Neutral white)

Product family leaflet, 2020, March 17

data subject to change

CitySwan Bollard

Luminous **flux**	Warm white: 380 lm
	Neutral white: 420 lm
Color Rendering Index	84 (3000 K)
	73 (4000 K)
Lumen maintenance at median useful life* 100000 h	min L80
Control gear failure rate at median useful life 100000 h	10%
Performance Ambient Temperature Tq	+25 ºC

Operating temperature range	-20 to +25 ºC
Driver	Built-in (self ballasted LED-module)
Mains voltage	220-240 V / 50-60 Hz
Dimming	1-10 V DC (on request)
Material	Mast: extruded aluminum
	Housing: die-cast aluminum
	Optical cover: polycarbonat, transparent bowl or opal flat
Color	Black Noir 200 Sablé
	Other RAL colors available on request
Installation	Underground length: 800 mm (to be mounted in solid ground)
	Max SCx: 0,09 m^2

Versions

CitySwan Bollard BGP444 luminaire

Approval and Application	
Mech. impact protection code	IK10
Controls and Dimming	
Dimmable	No
General Information	
CE mark	CE mark
Color choice	Black Noir 200 Sablé
Driver included	Yes
Lamp family code	LED-K2
Light source replaceable	No
Product Family Code	BGP444

General Information

Order Code	Full Product Name	Optical cover/lens type
910502610226	BGP444 LED/740 230V II PCC BK-200	Polycarbonate bowl/cover clear
910502610227	BGP444 LED/740 230V II FG BK-200	Flat glass

PHILIPS Lighting

CitySwan LED – distinctive and elegant

CitySwan LED

The beautiful CitySwan LED luminaire was designed by Danish architects Bjarne Schläger, light + architecture and Morten Weeke Borup, GHB Landskabsarkitekter A/S. Its simple shape, minimal materials, clean lines and white opal 'lampshade' make it a discreet yet visible presence in any city environment. At night CitySwan LED illuminates streets and spaces with soft, functional light. It can also be used to create colorful light moods in order to emphasize local identity or give urban spaces an innovative setting. The distinctive and elegant CitySwan LED luminaire is suitable for pole or wall mounting and is also available as a bollard.

Benefits

- Patented glowing lighting technology to provide color-based guidance or communication
- Winner of several design prizes, including a red dot design award, the German Design Prize 2009 and the Danish Design Award 2010
- Future-proof: LED engine and driver serviceable and upgradeable

Features

- LEDGINE inside – state-of-the-art, future-proof LED technology
- Elegant design suits any urban setting
- CitySwan is part of our Urban Styling solutions which are designed for a diversity of uses and lighting scenarios while giving cities a consistent identity. It offers combinations with a range of bollards, wall-mounted and street lighting solutions, including mast and brackets.

CitySwan LED

Application
- Residential streets
- Pedestrian and cycle paths
- Minor roads

Specifications

Type	BRS439 (side entry version)
	BWS439 (version for wall bracket)
Light source	Build-in LED-module
Power (steady state in W, +/- 10%)	18 up to 108 W
Correlated Color Temperature	3000 K (Warm white)
	4000 K (Neutral white)
Luminous **flux**	GreenLine: 1600 up to 7808 lm
	EconomyLine: 2322 up to 11329 lm
Luminaire **efficacy**	Up to 79 lm/W (for 3000 K)
	Up to 104 lm/W (for 4000 K)
Color Rendering Index	84 (3000 K)
	76 (4000 K)
Maintenance of lumen output - L80F10	Green Line 100,000 hours
	Economy Line 70,000 hours
Operating temperature range	-20 ºC to +25 ºC
Driver	Built-in (self ballasted LED-module)
Mains voltage	220-240 V / 50-60 Hz
Inrush current	130 A / 165 μs (50%)
Dimming	LumiStep: 6 and 8 hours
	DynaDimmer
	SDU
	External Dimming 1-10 V and DALI
	StarSense RF
	AmpDim

Optic	Distribution comfort (DC)
	Distribution medium (DM)
	Distribution wide (DW)
	Distribution wet road (DK)
	Distribution pedestrian crossing right (DP-R)
	Asymmetrical (A)
Optical cover	Glass, flat
Material	Housing: PMMA, impact resistant
	Pipe thread: aluminum, extruded
	Heat sink: cast aluminum
	Cover: glass, tempered
Color	Housing standard: opaque
Installation	Delivered with 10.5 m cable (BRS439) and 4,5 m cable (BWS439)
	Recommended mounting height: 4 to 8 m
	Standard tilt angle: 0º
	Max SCx: 0,08 m^2
Accessories	Wall brackets for version BWS439
Remarks	BWS439: order wall bracket separately

General Information	
Driver included	Yes
Product Family Code	BRS639

General Information

Order Code	Full Product Name	Light source color	Lamp family code	Optic type
919008632835	BRS639 GRN20-3S/740 II MDW DDF1 C10K	740 neutral white	GRN20	Metronomis distribution wide
919008632840	BRS639 LW1 GRN16-3S/830 II MDM C10K	830 warm white	GRN16	Metronomis distribution medium

Order Code	Full Product Name	Light source color	Lamp family code	Optic type
919008632845	BRS639 GRN60-3S/740 II MDW CLO-DDF6 C10K	740 neutral white	GRN60	Metronomis distribution wide
919008632871	BRS639 GRN20-3S/830 II MDW CLO C10K FQQ	830 warm white	GRN20	Metronomis distribution wide

APPENDIX 2: SEMI-STRUCTURED INTERVIEW PROTOCOL

Semi-structured interview protocol
LiD 4 Master Thesis: "Park of Darkness"

Interview number:

Structure of interview:

To put the interviewee at ease, start off explaining what the interview will entail and that they can withdraw at any point during.
Introduce briefly what we are researching.
Early interview-stage, before the test on the first night (light questions to build rapport):

Age (note on form):
Occupation / field (note on form):
Do you have any previous experience with the site?
Have any of those experiences been at night?

Main body of the interview (ask follow up questions when the opportunity presents itself):

Can you briefly describe your experience?
Did anything in particular attract your attention? (if yes, can you describe it?)
Can you describe any emotional state that arose during your walk?
How would you describe the visibility of your surroundings?

Announce the interview's end and provide them the possibility to add final comments.
Tell them what will happen with the data and thank them for participating.

Note: After the third night test, we ask an additional summising set of questions:

Did you notice any changes in regards to the light during the three nights?
Do you feel that light has affected your experience in any way, and if so, how?

APPENDIX 3: RUNNING BUDDY APP MOCK-UP

PARK OF DARKNESS
A COMPREHENSIVE DESIGN APPROACH TO LIGHTING URBAN GREEN AREAS

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MSC. LIGHTING DESIGN
SPRING 2020 - AALBORG UNIVERSITY COPENHAGEN

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