A Design for Darkness strategy for Amsterdam Noord

"We need darkness to feed our spirit, protect our health and protect the health of our planet. Light at night may be a sign of life on Earth, but the darkness will proclaim our true intelligence" (Bogard, 2020).

Thesis for the Master's Metropolitan Analysis, Design and Engineering

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ABSTRACT

This thesis addresses the problem of light pollution in cities, caused by public lighting. Currently, 99% of American and European citizens live under light-polluted skies (Falchi et al, 2016). Light pollution has measurable negative effects, as it increases energy consumption, disrupts ecosystems and wildlife and harms human health (IDA, 2013).

This research aims to reduce the amount of light pollution in Amsterdam Noord, a district in Amsterdam, the Netherlands, in the form of a case study. A Design for Darkness strategy, that helps reintroducing darkness into our urban nightscapes (Stone, 2019), is applied to structure this thesis. With the help of a literature review, interviews and observations of the research area, a short term Design for Darkness strategy for Amsterdam Noord can be developed.

The outcomes of this research suggest that the lighting in the green structure in Noord can be turned off, that experiments with lower light levels in residential areas should be conducted, that light nuisance in the form of glare and light trespass should be diminished, and that more lighting plans should focus on a qualitative, perception-based lighting approach, instead of only designing with a quantitative basis. Furthermore, the results indicate that dimming the lighting would be beneficial for the reduction of light pollution, but the lighting system in Amsterdam Noord is currently not fit to apply dimming regimes, and more budget is needed before this system can be applied.

Based on the insights from the Design for Darkness strategy, a list of policy recommendations for Amsterdam Noord is drawn up, and these measures express the need to set up regulations to minimize the causes of light pollution, and to educate people in the public and private sector about ways to preserve darkness.

Keywords: *Public lighting, light pollution, darkness, lighting planning, design*

TABLE OF CONTENTS

1.INTRODUCTION

1.1 HISTORICAL CONTEXT OF PUBLIC LIGHTING

In ancient times, people used fire and torches, and later candles to lighten up their nights, and the stars and the moon were used for navigation (Trembley, 2015). Around 1000 AD, streets were lit up by oil lamps, and at the end of the 17th century, gas lamps were put in use(Trembley, 2015). At the same time, people began organizing public lighting systems, but most of the nights were still completely dark, as streetlights would only work for a couple of hours (Stone, 2019). While our cities grew, its lighting system simultaneously grew with it (Schlör, 1998). The first electric streetlight in Paris in 1878, and the production of the first incandescent light bulbs a year later led to a shift in urban nighttime illumination; lights were brighter than before, and could now lengthen the day and turn the night into day (Stone, 2018). Eventually, "artificial illumination became the expectation of urban nights" (Stone, 2018, p. 612). At the same time, the adverse effects of artificial lighting at night, also known as light pollution (IDA, 2013), started to become a problem (Smith & Layden, 2008).

1.2. PROBLEM DEFINITION AND MOTIVATION

More than 80% of the people on earth are impaired to discover the universe, and live under light-polluted skies (Falchi et al., 2016). The International Dark Sky Association (IDA), a leading authority that strives to protect our night skies against light pollution, warns us that "the inappropriate or excessive use of artificial light – known as light pollution – can have serious environmental consequences for humans, wildlife, and our climate" (IDA, 2013). Light pollution increases energy consumption, disrupts ecosystems and wildlife and harms human health (IDA, 2013). It is clear that we need to change the way we illuminate our cities and take light pollution more seriously, to prevent more damage being done to our world. However, "any attempts to reduce light pollution run up against positive connotations of lighting, which are deeply ingrained in modern societies. Culturally, light is a symbol of enlightenment, modernity, urbanity and security" (Hölker et al., 2010, p. 5).

As our current public lighting system is still aimed at providing more light and lacks a focus on darkness, light pollution has increased with at least 49% between 1992 and 2017 (University of Exeter, 2021). The discussion about light pollution still focuses too much on what is bad about artificial lighting, and not on what is good about darkness, and how to reintroduce darkness into our urban nightscapes (Stone, 2018). "More knowledge is needed about the usefulness and necessity of darkness. People now feel like you're taking something away from them" (Interview 4). The only sources that are available are an advice on how to minimize light pollution (IDA, 2013), a directive to prevent light nuisance (NSVV, 2020), and guidelines and a code of conduct to make lighting plans (NSVV, 2018, 2019). A knowledge gap can be identified here, as there is no uniform strategy nor are there any regulations to reintroduce more darkness into our urban nightscapes, and to decrease light pollution caused by public lighting in the short term.

To fill this knowledge gap, this thesis will investigate the possibilities to create a Design for Darkness strategy and a corresponding policy for Amsterdam Noord that can help decreasing light pollution in the short term. This approach will be based on the Design for Darkness framework, created by Stone (2018). With his value-based approach, Stone focuses on what is good about darkness at night "with the practical goal of informing future decision-making about urban nighttime lighting" (Stone, 2018, p. 607).

Amsterdam-Noord is chosen as research location in this study, as it sets the scene for "In lichtjaren heeft niemand haast" by Van Heemstra (2019). This book describes the writer's search for more connectedness between humans, the earth and the cosmos. The book ends with Marjolijn setting up the project "De Nacht-Wacht" (The Night's watch), in which she starts organising night walks with groups to collectively discover the value of night and darkness in a city with too much light. During one of her first night walks, she discovers a population of fireflies in "Het Vliegenbos", the oldest urban forest in Amsterdam, located in Amsterdam-Noord. The intriguing discovery of this species in such an urbanized space inspired me to investigate the actual situation of lighting and darkness in this area of Amsterdam.

The research problem of this thesis is described as follows: the present way of illuminating our cities with public lighting causes light pollution, which has multiple negative side-effects on the earth and all its living beings, including humans (IDA, 2013). In the context of Amsterdam-Noord, the future decision-making about public nighttime lighting should switch from planning for light to designing for darkness, to reduce light pollution. Therefore, the focus of this thesis is to develop a Design for Darkness approach for Amsterdam Noord, with the aim to mitigate the negative effects of light pollution in this area in the short term.

1.3. Research objectives and questions

The main research question of this thesis is as follows:

- What public lighting plans are currently used to illuminate Amsterdam-Noord, and which elements can be applied to a Design for Darkness strategy to reduce light pollution in the short term?

To answer this research question, several sub-research questions are formulated, that help shaping the context of this research, and that help answering the main question. These questions are subdivided into three elements: the theoretical, empirical and analytical contexts. The theoretical context of this research contains the questions that can be answered with theory; the empirical context includes questions that cannot be answered by theory, but that need personal observation and experience of the researcher; and the analytical context, which describes questions that "identify causes, reasons, and motives for action"(Political Science guide, 2018).

The sub-research questions are posed in the following order:

Theoretical context:

- What is the historical context of public lighting?
- Why is public lighting necessary and what do we use it for?
- What are the causes and effects of light pollution?

Empirical context:

- Who are the stakeholders in Amsterdam Noord and how do they interact with public lighting?
- What is the current state of light pollution in Amsterdam Noord?
- What is the current situation of public lighting in Amsterdam Noord?
- What is the focus of the current public lighting plans in Amsterdam Noord?
- Why do the public lighting plans currently have this focus?

Analytical context:

- What elements in the lighting plans can be used in or changed into a Design for Darkness strategy to reduce light pollution in the short term?
- How can the Design for Darkness strategy be applied in the context of Amsterdam Noord?
- What Design for Darkness policy measures can be developed for Amsterdam Noord?

2. Conceptual framework

For the conceptual framework, two different kinds of concepts will be discussed, namely substantive concepts and second-order concepts. First, the substantive concepts are outlined, which describe the substance, or content knowledge within the subject of this thesis. These concepts help to understand the context in which this thesis is situated. Then, the second-order concepts are highlighted, which are used to organise the substantive knowledge and sharpen the research questions. These concepts also help clarifying the boundaries of this research (Cambridge Assessment International Education, n.d.).

2.1 Substantive concepts

The concepts that are discussed in this paragraph form the body of this thesis. They give a better understanding of what light is, and clarify other key concepts that need to be understood in the context of this thesis.

2.1.1. Light

Light is “a form of energy manifesting itself as electromagnetic radiation.” (Philips, 2008, p.10). This radiation has different wavelengths. For the human eye, the visible part of the electromagnetic spectrum is formed by wavelengths between 380 – 780 nanometres. These different wavelengths are what we as humans interpret as colours, ranging from red in the lower part, to violet in the higher part of the spectrum (Philips, 2008).

Light can behave in different ways; when it strikes a surface, it can be reflected, absorbed or transmitted, and often a combination of these effects occur (Philips, 2008). “The amount of reflected light depends on the type of surface, angle of incidence and spectral composition of the light “...” The way the light is reflected also depends on the smoothness of the surface” (Philips, 2008, p.12). Light can also be absorbed by a material, which depends on its angle of incidence and wavelength. Light that is not reflected, can also be transmitted, which mainly happens through transparent materials

(Philips, 2008). Light can also be refracted or interfered, but these effects won't be discussed in this thesis.

Colour temperature is an important aspect in lighting applications. There is warmer light, which has a higher proportion of longer wavelengths (more "yellowish" or "reddish"), and cooler light, which has a higher proportion of shorter wavelengths (more "blueish"). The colour temperature can be related to the temperature of thermal radiators that are used for lighting applications: when an incandescent lamp or iron bar would be heated up to 1000K, its colour would appear red, between 2000-3000K yellow white, at 4000K neutral white and above 5000K blueish. The colour temperature can influence the ambience in an area (Philips, 2008).

Light also has an influence on how we see colours, by both "the spectral composition of the light itself, the spectral reflectance of the illuminated surface as well as the perception of the observer" (Philips, 2008, p. 14).

2.1.2. Human visual system

The retina is the part of the human eye that is sensitive to light. It contains rods, that are sensitive to movement and light intensity, but that are not capable of distinguishing colour; and cones, which are sensitive to long, middle and short parts of the radiation spectrum, and give our perception of colour. Both cones as rods are sensitive to different spectral wavelengths(see figure 1). The retina also contains light sensitive ganglion cells, that influence the body's biological clock (Philips, 2008).

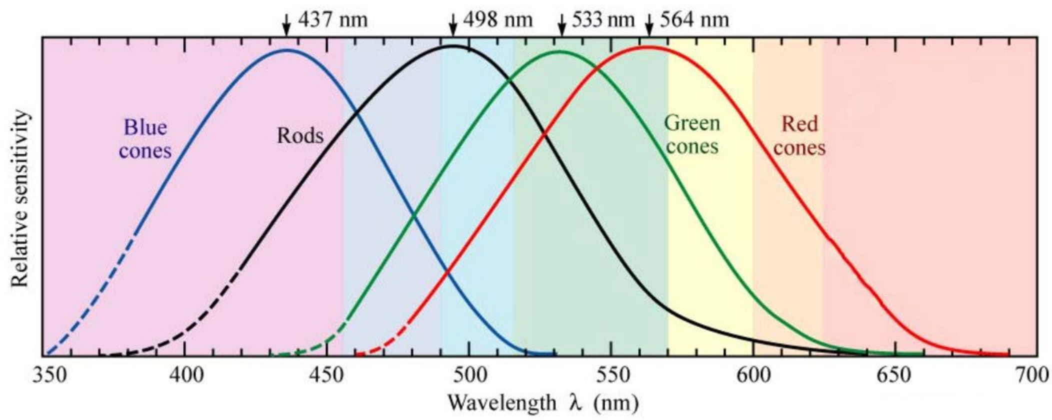


Figure 1: Normalized spectral sensitivity of cone cells in the human eye (adopted from Dowling, 1987 and Schubert, 2006). (Image by Milin et al., in "Keeping it simple: Implementation and performance of the proto-principle of adaptation and learning in the language sciences" (2020)).

Luminance

Our eyes can see a wide range of light intensities, from starlight to a bright sunny day. This is the so-called luminance range of the human eye, which spans from 10^{-6} to 10^{8} cd/m^2 (Forchhammer et al., 2018). Several mechanisms in the eye contribute to the broadening of the luminance range for vision, by responding to a change in the ambient level of illumination, which "allow the visual system to obtain maximal visual information at each luminance level (University of Sydney, 2018).

One of these mechanisms is the visual adaption of the eye, which is an alteration in the gain of the visual system. The gain is the ratio of the output signal (neural responses) to the input signal (light), which increases under dim conditions and decreases under bright conditions. Retinal and higher visual centre mechanisms influence this system(University of Sydney, 2018).

The visual mechanism is involved in the light and dark adaption of the eye. Light adaption is a fast process of a few seconds, and allows the visual system to make “complex discriminations such as contour detection, fine spatial resolution, movement, and colour perception” (University of Sydney, 2018). Where more exposure to light means a decrease in sensitivity, more exposure to darkness, when the dark adaption of the eye is triggered, means that the visual system can recover its sensitivity. Dark adaption is a slower process, and can take up to 30 minutes (Philips, 2008). Figure 2 shows this duplex visual system in the retina of the eye: the switch from the photopic system (cones) to the scotopic system (rods) during longer periods in the dark. After the rod-cone break, the cones have reached their maximum sensitivity, but the sensitivity of the rods still increases until the maximum rod sensitivity is reached, which lies around 30 minutes in the dark (Dark Adaptation, n.a).

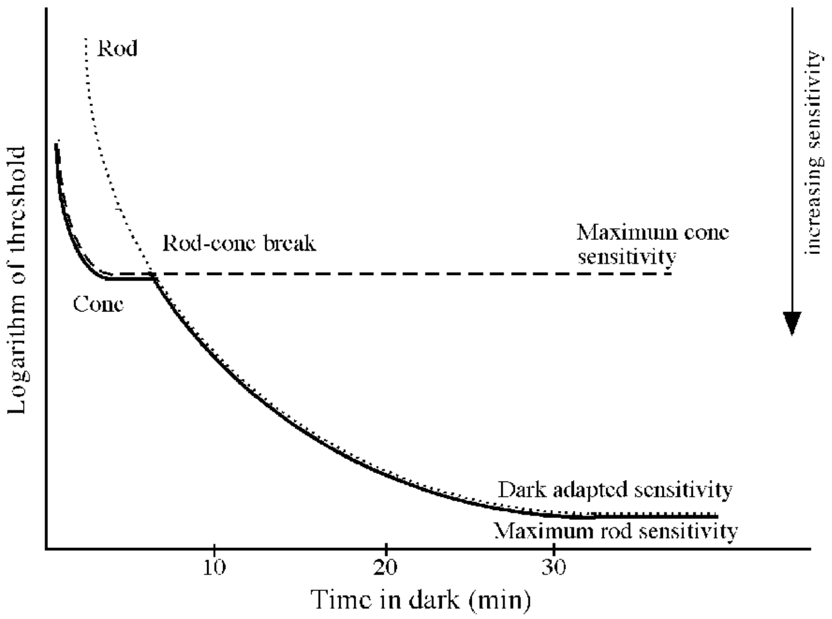


Figure 2: Dark adaptation curve. Published in Dark Adaptation 1: the Basic Curve. Retrieved from: https://api.semanticscholar.org/CorpusID:14806598

Next to these two mechanisms, our pupil also reacts to changes in light and dark. The pupil size enlarges in the dark to 8 mm and constricts in light conditions to 2.5 mm, and the area for light entry into the eye can become 16 times higher after this change (University of Sydney, 2018). When people become older, their eyesight deteriorates: the accommodation ability and contrast sensitivity of the eye reduces, next to the overall sensitivity and visual acuity. Older people need more light to perform the same visual task compared to younger people (Philips, 2008).

“Luminance and contrast are central to the function of the visual system. Without light (luminance = 0) there can be no vision, and without contrast we can see no spatial or temporal patterns. The ability to respond to luminance is an essential first step in seeing, which makes possible all other visual processes. However, what is really important for making sense of the visual world is not the absolute, steady-state luminance level, but rather its temporal and spatial derivatives, namely, contrast” (Kaplan, 2008, p. 31).

Luminance contrasts

Luminance contrasts are not simply a difference in the colour contrast, but the difference in the light reflective properties of each colour (Equal Access, n.d.). Luminance and luminance contrasts play a major role in lighting design: "Most of the visual tasks and objects that lighting designers illuminate have variable material and form properties such as reflectance patterns, textures and different surface normal orientations. Their prominent characteristics can be defined as desirable visual features that need to provide visual impact through illumination. Visual impact can be translated into a luminance contrast between two different, representative surface elements of the object. On the basis of the desired luminance contrast and specific material characteristics, luminaire locations can be computed such that the desired luminance values are achieved" (Moeck, 2000, p.55)). Our eyes are also able to detect simultaneous luminance contrasts, which can for example be found when looking at a tunnel when standing in daylight: the tunnel may appear darker than it actually is.

2.1.3. Lighting (artificial)

Lighting is "an artificial supply of light or the apparatus providing it, also: illumination" (Merriam Webster, n.d.). In the context of our city nightscapes, artificial lighting can also be understood as artificial nighttime lighting, which "has close associations to – and at times is even understood as synonymous with – values such as safety and security, civic order, nightlife, prosperity, and progress (Stone, 2018, p.4). Lighting can be applied in indoor and outdoor environments. In this thesis, the focus is on outdoor lighting in the public domain.

2.1.3.1. Public lighting

The term public lighting mostly refers to streetlights, which "constitute the primary source of nighttime illumination, making them fundamental to any strategies addressing light pollution and incorporating the positive aspects of darkness into urban nightscapes" (Stone, 2019, p.91). As a key service, public authorities facilitate public lighting at night at the local and municipal level (Buck, n.d.). "With public lighting, the lighting installations are meant that illuminate the public road. All roads fall under this description, from highways to footpaths through parks. Also squares and back roads are illuminated by public lighting if they are freely accessible and part of the public space" (NSVV, 2020, p.10).

2.1.3.2. Lighting planning

Lighting planning can both have a practical as a functional purpose. Practical planning focuses on the materials that need to be used to make a lighting plan, functional planning outlines what function the lighting should fulfil in a space.

-Practical:

"Decisions regarding the lamps and luminaires to be used, the arrangement and installation of the luminaires, their control gear and the lighting control equipment required."(Ganslandt & Hofmann, 1992). In this thesis, the term 'lighting layout' is used to describe the practical lighting planning.

-Functional:

"The planning of our visual environment. Aims to create perceptual conditions which allow us to work effectively and orient ourselves safely while promoting a feeling of well-being in a particular environment. At the same time it enhances the environment in an aesthetic sense "…"Eventually, "the value of good lighting can only be grasped by personal observation and real experience" (Philips, 2008, p. 7). The different functional approaches to lighting planning are described in the following two paragraphs.

2.1.4. Quantitative lighting design

Quantitative lighting design focuses on the visual needs of the user. The quantitative lighting aspects that play a role in lighting design and planning are the luminous flux, luminous intensity, illuminance, luminance, which are visualised in figure 3. Moreover, other concepts that should be taken into account in a lighting plan are luminance contrasts, spatial distribution of the light, colour rendering and efficiency. Luminance and luminance contrasts were already described in chapter 2.1.2.

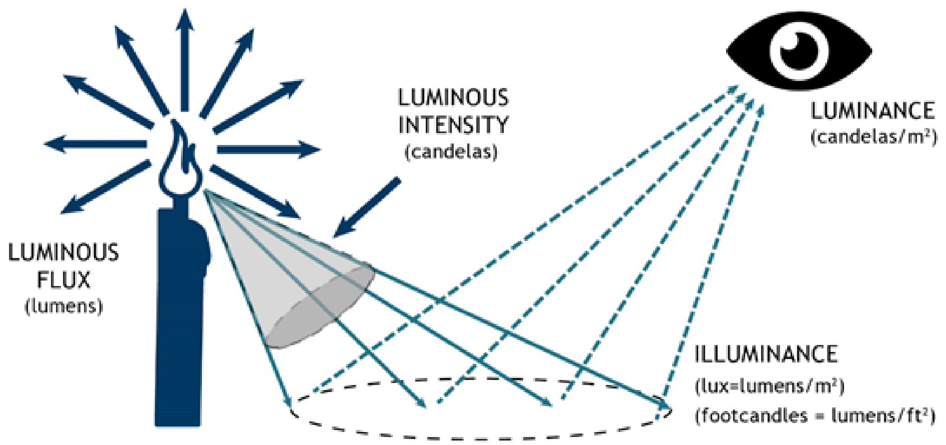


Figure 3: Illustration of luminous flux, luminous intensity, illuminance and luminance. (Image by Yi-Ying Lai (2022), Retrieved from: https://luminusdevices.zendesk.com/hc/en-us/articles/4403668356109-What-s-the-Difference-Luminance-Luminous-Flux-Illuminance-Luminous-Intensity-Lux-Lumens).

Luminous flux and intensity

The luminous flux is the total amount of light that is emitted by a light source per second, and it is measured in lumens (lm) (Philips, 2008). The luminous intensity is the amount of flux of light that is emitted in a certain direction and its unit is in candela (cd) (Philips, 2008).

Illuminance

The illuminance refers to "the amount of light that shines onto a surface, measured in lumens per square meter (lm/m2), also called lux" (Lai, 2022). The lighting level (illuminance) should be high enough so that people can perform specific visual tasks, which is also related to people's age and visual abilities. Generally, we need higher lighting levels when visual information is presented on a higher speed. When visual requirements are less demanding, lower illuminances can be sufficient (Philips, 2008). This is also a part of the most recent Dutch guideline public lighting (NPR-13201), which advises lighting planners on the illuminance levels of the lighting in the public space in both the horizontal as the vertical plane (NSVV, 2018).

Glare

When the goal is to provide high quality lighting, the amount of glare, coming from a light source, should be limited. Glare is “the sensation produced by brightness levels within the visual field that are considerably greater than the brightness to which the eyes are adapted”(Philips, 2008, p. 37). There is direct glare, that comes directly from a light source, and reflected glare, that comes from a reflected surface. Discomfort glare makes seeing uncomfortable, and disability glare prevents vision. Glare can cause errors, fatigue or accidents, and should be prevented (Philips, 2008). In the Dutch guideline public lighting (NPR), a maximum for the amount of disability glare is given (NSVV, 2018). Also, the reflection of road surfaces, the reflected glare, is taken into account in the last version of the NPR.

Spatial distribution

The spatial distribution of the light is also an important criterion in quantitative lighting planning. “Light sources can be spread fairly evenly using a system of so-called diffuse general lighting, it can be concentrated in certain areas using directional lighting, or it can be distributed throughout the space but with local accents” (Philips, 2008, p.38). In the Dutch guideline public lighting (NPR), the uniformity for the public lighting is specified.

Colour rendering

An important aspect in artificial lighting is the colour rendering of the light. Artificial light can have different blends of wavelengths, which are reflected by surfaces in a different manner; we can have two seemingly similar light beams, but their wavelength can have a different effect on surfaces, and the appearance of colour on these surfaces will not be the same (Philips, 2008). “In some situations colours should be represented as naturally as possible as under daylight conditions, yet in other cases lighting should highlight individual colours or create a specific ambience. However, there are also various lighting situations where it is not so much a precise natural colour rendering that matters most, but where illumination level and efficacy are of greater importance” (Philips, 2008, p. 16). The latter is for example the case in road lighting.

Efficiency

Next to the photometric concepts that describe the quality and quantity of light, the electrical and fixture efficiency also play an important role during the installation of lighting, and help making cost calculations. The electrical efficiency determines how well the lighting system transforms electrical power, in Watt (W), to useful light, and the fixture efficiency determines how much light leaves the fixture. The coefficient of utilization (CU) is used to compare different fixture efficiencies (Inter.light, 2022). The efficiency of the lighting is not further discussed in this thesis.

2.1.5. Qualitative lighting design

Where the previous chapter focuses on the quantitative aspects of lighting design, this chapter dives deeper into qualitative lighting design, which is perception orientated. This approach doesn't only take into account the quantitative terms of light, like the luminance and illuminance levels and distribution, but also the psychology behind the perception of light, how people perceive structures and how lighting can also convey an aesthetic effect. This newer approach to lighting no longer considers "man and his needs as a mere recipient of his visual surroundings but as an active factor in the perception process"(ERCO, 2012, p. 6). It "centres on vertical illuminance and accentuation, as well as glare control. Glare-free surroundings with consistent luminance levels are easier on the eye, eliminating the need to adapt constantly to changing lighting conditions. This enables the designer to produce an energy-efficient solution based on lower illuminance levels and subtle contrasts" (ERCO, 2022). 80% of our visual perception is formed by vertical surfaces, and light on the vertical plane is therefore more important for the subjective impression of brightness than on the horizontal plane, and is therefore a core aspect of qualitative lighting design (ERCO, 2022).

Richard Kelly, a pioneer in qualitative lighting design, was the first lighting designer who articulated lighting design concepts: he made a distinction between three basic functions of light to express the qualities of light: ambient luminescence, focal glow and play of brilliants (ERCO, 2012). These concepts are still used by lighting designers and architects to create a qualitative lighting plan (Donoff, 2016).

Ambient luminescence

"The element of light that provides general illumination of the surroundings; it ensures that the surrounding space, its objects and the people there are visible. This form of lighting facilitates general orientation and activity. Its universal and uniform orientation means that it largely follows along the same lines as quantitative lighting design, except that ambient luminescence is not the final objective but just the foundation for a more comprehensive lighting design"(ERCO, 2012, p.8).

Focal glow

"This is where light is first given the express task of actively helping to convey information. The fact that brightly lit areas automatically draw our attention now comes into consideration. By using a suitable brightness distribution it is possible to order the wealth of information contained in an environment. Areas containing essential information can be emphasised by accented lighting, whereas secondary or distracting information can be toned down by applying a lower lighting level"(ERCO, 2012, p.8).

Play of brilliants

This form of light results from the insight that "light not only draws our attention to information, but can also represent information in and of itself. This applies above all to the specular effects that point light sources can produce on reflective or refractive materials. Furthermore, the light source itself can also be considered to be brilliant. This 'play of brilliants' can add life and ambiance, especially to prestigious venues"(ERCO, 2012, p.8).

Additionally to these three concepts, William Lam introduced a list of criteria (1970), or rather "a systematic, context-orientated vocabulary for describing the requirements placed on a lighting system"(ERCO, 2012, p.12). These criteria are divided over two groups; for activity needs and for biological needs:

Activity needs

When we perform certain activities within a visual environment, we have 'activity needs'. "The characteristics of the visual task at hand are the crucial factor for these needs. The analysis of the activity needs is therefore largely identical with the criteria for quantitative lighting. There is also considerable agreement for this area when it comes to the objectives of lighting design. The aim is to arrive at functional lighting that will provide the optimum visual conditions for the activity in question – be it work, leisure activities or simply moving through the space. In contrast to the proponents of quantitative lighting design, Lam objects to a uniform lighting that is simply designed to suit whatever is the most difficult visual task. Instead, he proposes a differentiated analysis of all the visual tasks that arise, an analysis conducted according to location, type and frequency (ERCO, 2012, p. 13).

Biological needs

Lam considers biological needs as more essential than visual needs, as these "sum up the psychological demands that are placed on a visual environment and are applicable in every context" (ERCO, 2012, p. 13). Where activity needs are focused on conscious involvement with the surroundings, biological needs are based on unconscious requirements and the emotional evaluation of a situation and the feeling of wellbeing in a visual environment. "The starting point for Lam's definition is the fact that our attention is only dedicated to one specific visual task in moments of utmost concentration. Our visual attention almost always widens to observe our entire surroundings. This allows changes in the environment to be perceived immediately and behaviour to be adapted to the altered situation without delay. The emotional evaluation of a visual environment depends not least on whether that environment clearly presents the required information or whether it conceals it from the observer"(ERCO, 2012, p.13).

The three psychological demands placed on a visual environment that Lam distinguishes are Orientation in a space, which concerns the discernability of routes and destinations, but also what time of the day it is, or what are the weather conditions; Discernability/Comprehension, which influences our feeling of safety: "Dark corners in subways or in the corridors of large buildings may harbour danger, in the same way as glaringly overlit areas" (ERCO, 2012, p.14). Not everything in an area has to be visible, but the area should be clearly structured, and essential areas should be discernible from the background. "Instead of constituting a confusing and possibly contradictory deluge of information, a space presented in this way will feature a comprehensible number of properties that build into a clearly structured whole. Having a nice view or other points of visual interest, such as a work of art, are also important for relaxation" (ERCO, 2012, p. 14). The third psychological demand is Communication: "A given space should facilitate contact with other people, yet at the same time it should also allow private areas to be defined. One such private area could be defined by a patch of light that picks out a group of seats or a conference table from the overall surroundings within a larger room" (ERCO, 2012, p.14).

Innovative lighting designers, like the ones from ERCO (ERCO, 2022) and the TU Delft lighting department (Pont, 2019) look at the entire light field when designing for light, as Pont(2019) explains: "the luminance as a function of spectral energy (wavelength), position, and direction in regions of space free of occluders. The light field as a function of time then also includes temporal variations, if any. In perception research, this concept is known as the plenoptic function (Adelson & Bergen 1991): all optic information available to an observer at any point in space and time" (Pont, 2019, p. 504). This function parametrizes the intensity of a light ray in space with seven dimensions, which includes a position with three dimensions, a visual angle in two dimensions, a wavelength, and a time dimension (Chan, 2014). This function is visualised in Figure 4 (the wavelength and time dimension are not shown in this image). This thesis highlights this function to demonstrate the complexity of light and the light field. Not all the seven dimensions will be further elaborated in this thesis, but this function shows what dimensions should be taken into account when making an extensive lighting plan with the plenoptic function as a basis.

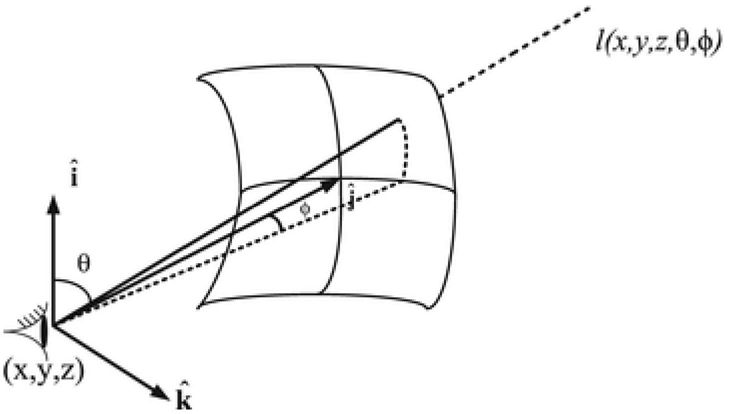


Figure 4: The plenoptic function, with x, y, z as positional dimensions and theta and phi as visual dimensions. The wavelength and time dimension are not shown. (Image by Shing Chow Chan, in "Computer Vision" (2016)).

To close off this chapter, a final note is given about good lighting design, as formulated by ERCO (2012, p. 15): "Good lighting design aims to create perceptual conditions which allow us to work effectively and orient ourselves safely while promoting a feeling of well-being in a particular environment. At the same time it enhances the environment in an aesthetic sense. The physical qualities of a lighting situation can be calculated and measured. Ultimately, it is the actual effect the lighting has on the user of a space and his subjective perception, that decides whether a lighting concept is successful or not."

2.1.6. Light pollution

According to Eisenbeis and Hänel (2009), light pollution is caused by "…the excessive growth of artificial lighting in the environment. It is related primarily to the general population growth, industrial development and increasing economic prosperity, but there has also occurred a significant technical improvement by applying lamps with higher and higher luminous efficiency "…" there is still another component that contributes significantly to light pollution which is the excessive and, at times, careless use of artificial outdoor lighting by humans, as well as the use of poorly designed fixtures..." (p. 243).

Since 1988, the International Dark Sky Association (IDA) has led a movement that strives for dark skies and the reduction of light pollution (IDA, 2013). There is still a long way to go, as global light pollution has increased with at least 49% between 1992 and 2017(University of Exeter, 2021), and 99% of American and European citizens currently live under light-polluted skies (Falchi et al, 2016).

The IDA defines light pollution as “the inappropriate or excessive use of artificial light” (IDA, 2013), “which not only impairs our view of the universe, but also negatively affects our environment, safety, energy consumption and health” (IDA, 2013).

The IDA distinguishes four different components of light pollution, namely:

- “Glare – excessive brightness that causes visual discomfort;
- Skyglow – brightening of the night sky over inhabited areas;
- Light trespass – light falling where it is not intended or needed;
- Clutter – bright, confusing and excessive groupings of light sources” (IDA, 2013).

Figure 5 shows the aforementioned components in a visual, together with the area that actually should be lit by the street light; the useful light.

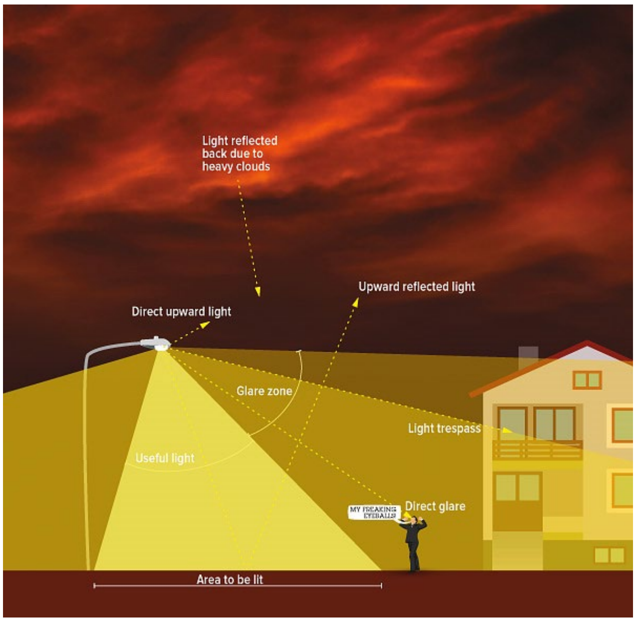


Figure 5: The different components of light pollution. (Image by Anezka Gocova, in “The Night Issue”, Alternatives Journal 39:5 (2013)).

The different components of light pollution can be divided into three groups:

- Direct light nuisance, which is caused by direct glare or light trespass;
- Horizon pollution, which is the visual pollution of the horizon, visible by clutter;
- Brightness of our skies, visible as skyglow, which is caused by direct upward light or upward reflected light that impairs us to see stars (Sotto le Stelle, 2020).

It is possible to measure light pollution in a city, namely with light meters that can be placed on the ground (Interview 11). The impact of sky brightness is mapped by airplanes or satellites, for example the Suomi-NPP satellite, which takes a picture of the earth surface each night (Sotto le Stelle, 2020). These pictures are then processed into light pollution maps.

Light meters in satellites measure the Zenith Radiance, which is the sky brightness, or the diffuse artificial luminance of the night sky, in the astronomical magnitude system $mag_V/arcsec^2$, or less frequently in cd/m^2 (Hänel et al, 2018). Often, the Bortle scale is used to define how bright the sky is. This scale, created by John E. Bortle, is a nine-level scale that helps observers judge the true darkness of an area (Bortle, 2006). A Bortle scale 1 sky is an excellent, truly dark sky, while a Bortle scale 9 sky is a highly polluted inner city sky, in which stars are hardly visible (See Appendix A for the explanation of the scales). Maps that show sky brightness often include a Bortle scale in combination with the Zenith Radiance with a colour code that represents the brightness of the sky.

2.1.7. Darkness

Darkness is defined as "the total or near total absence of light" (Merriam Webster, n.d.). The concept of light and darkness can be understood as relational, and the interplay between light and dark shape our world during day and nighttime (Shaw, 2018). Darkness is often associated with negative emotional experiences, like fear or depression (Persich et al., 2019). People generally feel less safe during the night, and can be afraid of the dark. "This nightly fear stems from an evolutionary response of foreboding anxiety, which our ancestors needed to stay safe during the night" (Tarantola, 2013). People's preference for light instead of dark is also noticeable in metaphors, where light topics are pleasant, and dark topics often foresee a bad omen (Persich et al., 2019). Although many have negative associations with darkness, our ecosystems, including nature and all its species, need darkness to stay healthy. "We need darkness to feed our spirit, protect our health and protect the health of our planet. Light at night may be a sign of life on Earth, but the darkness will proclaim our true intelligence" (Bogard, 2020).

2.1.8. Night and the night sky

The concepts night and the night sky are closely linked to one another. Night is the period of ambient darkness during each 24-hour day, during which no sunlight is visible, or "the time from dusk to dawn" (Merriam-Webster, n.d.). It is also understood as "the beginning of darkness" (Merriam-Webster, n.d.). Diurnal animals sleep during the night, and need darkness for their circadian rhythm, while nocturnal animals are active during the night, and need the dark to reproduce and find food (Bogard, 2020). During the night, the night sky is visible, and celestial objects like the moon, stars and planets can be seen. An estimated number of 2000 stars could be spotted during an undisturbed dark night, without city lights, moon, clouds or haze (Earthsky, 2021). Also the Milky Way could be visible, but due to light pollution, one third of the world's population is not able to see this anymore (Davis, 2016).

2.2. Second-order concepts

The concepts that are deducted from different theories in relation to light pollution are described in this paragraph. These concepts help underpinning the research questions and organising the content knowledge. Second-order concepts may sound less important, but they take the content of this thesis to a higher level; “they’re shaping the discipline and they tend to go across all different topic areas within a particular subject” (Cambridge Assessment International Education, n.d.). This chapter is arranged as follows: first, three concepts are outlined that can help explaining why light pollution has increased in relation to people’s perception and interaction with lighting. Then, two other concepts are highlighted that explain in what way light pollution can be mitigated. These concepts emphasise the values of darkness, and explain how those values can be incorporated in a Design for Darkness strategy, that takes into account people’s positive connotations with lighting.

2.2.1. Direct Rebound effect

For this thesis, the Rebound Effect is used, which is explained by Kyba, Hänel and Hölker (2014). The writers place this concept in the context of increased illumination, caused by the excessive use of outdoor lighting, and the adverse effects on our environment: "Improvements in the luminous efficiency of outdoor lamps might not result in energy savings or reductions in greenhouse gas emissions. The reason for this is a rebound effect: when light becomes cheaper, many users will increase illumination, and some previously unlit areas may become lit” (Kyba, Hänel and Hölker, 2014, p. 1). This concept can explain why people keep using more light than needed, which causes an increase in light pollution.

2.2.2. Dynamics of Demand

The growing demand of lighting can be explained in the context of the Dynamics of demand in networked societies, formulated by Shove and Trentmann(2019). The writers explain how the demand and the need for a networked technology, like public lighting, could increase the way it did, by describing its development as “an outcome of complex processes of demand-making and reciprocal influence between supply and demand” (p.14). Suppliers of services, like public lighting, used (and still use) this strategy to make their service “become firmly integrated into the fabric of daily life: being essential to what are seen to be ‘basic needs’, as well as to societal rhythms and expectations, especially in terms of reliability, with substantial implications for the functioning of the networks on which the fulfilment of these needs depends.” (Shove and Trentmann, 2019, p. 16).

2.2.3. Shifting Baseline Syndrome (SBS)

“Shifting baseline syndrome refers to the changing human perceptions of biological systems due to loss of experience of past conditions. Simply put, people may view the current situation as the typical or normal state, even when the ecosystem is considerably degraded compared to earlier states. Lyytimäki (2013, p. e46)

For this thesis, the theory of SBS is based on the work of Lyytimäki (2013), as this researcher places the theory of SBS in the context of light pollution. The theory of SBS consists out of two types, generational and personal amnesia. “In both cases, it causes a shift in perceived baselines, and thus an evaluative shift in accepted norms. Lyytimäki (2013) posits that the loss of the night sky, and experiences of (especially urban) nights, cause of both types of amnesia. ”(Stone, 2018, p. 105). The shifting baseline syndrome can have an effect on how we perceive and understand darkness: “The repercussions of nighttime lighting on our baseline understanding of darkness can be considerable, as living in constant artificial brightness can lead to perceptions of darkness as unnatural or unsafe (Lyytimäki 2013).”

Soga and Gaston (2018) also explain the theory of SBS, but give a clearer explanation of what Lyytimäki (2013) expresses as ‘changing human perceptions of biological systems’: “SBS describes a gradual change in the accepted norms for the condition of the natural environment due to a lack of human experience, memory and/or knowledge of its past condition” (Soga & Gaston, 2018, p.2).

Stone (2018) mentions that we can reverse shifting baselines with a right Design for Darkness approach, as these baselines are not static: “Shifting baselines are where a designing for darkness approach can focus: on seeking to reverse our baselines and re-introduce darker nights, while still maintaining sufficient levels of illumination for nighttime activities” (Stone, 2018, 106).

In this thesis, the theory of SBS helps to understand why people are getting accustomed to a brighter environment, without being aware of the consequences. It also explains our lack of knowledge, memory and/or experience about darkness and starry nights, and why our perception of safety has changed in relation to darkness and light. It is good to keep in mind that these baselines can be reversed with a right Design for Darkness, which is explained in the following paragraphs.

2.2.4. The Value of Darkness

The value of darkness needs first to be understood before we can start designing for darkness. This theory is “a pluralistic, value-sensitive understanding of darkness relevant to contemporary discourse, and a detailed analysis of the ways in which darkness can be valued – and ultimately operationalized – from an environmental perspective” (Stone, 2019, p. 64). Stone distinguishes nine values, which he sets up by reframing the effects of light pollution into valuations of darkness. He then translates these nine environmental values into prima facie obligations, which are called this way, as there is a morally relevant reason to take action and strive for their achievement (Stone, 2019).

The concepts in this theory can be used to check if the 9 environmental values are present in the current public lighting plans in Amsterdam Noord, or that only a few values can be recognized (See table 1). In that case, Stone speaks of a moral overload, which means that there are “conflicting values or obligations that cannot all be satisfied at the same time”(Stone, 2019, p. 83). As an example, the writer gives LED streetlights, and checks whether all the prima facie obligations are met in this case. He concludes that: “the current usage of LEDs runs into the problem of moral overload, only satisfying a narrow interpretation of the value of darkness. While fulfilling the values of efficiency, and perhaps sustainability, they likely have negative effects on the other seven environmental values of darkness.” Stone doesn’t imply that LEDs shouldn’t be used anymore, but indicates that a more value-sensitive approach can improve the strategy to apply LEDs. By looking at the qualities of LEDs, their controllability and efficiency, a wider range of desired goals can be developed that focus on the value of darkness (Stone, 2019). In this thesis, the part of this theory about LEDs can be applied to compare the use of LEDs in Amsterdam Noord, to see if a moral overload can be recognized, or that the wider range of desired qualities of LEDs are used.

Value of darkness	*Prima facie* obligation derived from value
Efficiency	The responsible use of lighting where and when needed; money-saving
Sustainability	The responsible use of lighting where and when needed; energy-saving and preserving non-renewable resources
Ecology	The protection and preservation of species and biodiversity; habitat conservation efforts
Healthiness	Promoting and fostering human health; physiological well-being
Happiness	Promoting and fostering happiness; emotional well-being
Connection to nature	Preserving a connection to the more-than-human world
Stellar visibility	Preserving conditions for access to the firmament
Heritage and tradition	Preserving the cultural heritage of the night sky for future generations
Wonder and beauty	Preserving the aesthetic appeal of the natural night sky

Table 1: The environmental values of darkness articulated as prima facie obligations. Reprinted from: Designing for Darkness: Urban Nighttime Lighting and Environmental Values, By T. Stone, 2019, p. 83. 4TU, Centre for Ethics and Technology.

In the Values of darkness approach, Stone decides to exclude the topic of safety, as it lies outside the scope of this framework. In this thesis, this topic will be discussed.

2.2.5. Design for Darkness strategy

To introduce the Design for Darkness strategy, Stone (2019) first presents an overview of recommendations and policies for mitigating light pollution, proposed by multiple researchers who investigated this topic in recent years(Table 2). This overview can contribute to the policy recommendations that will be written to mitigate light pollution in Amsterdam Noord.

Recommendation(s)	Suggested Policies
Reduce skyglow, light trespass, and glare	• Properly positioned installations – for overhead lights, angled below 70 degrees from the downward vertical • Fully shielded lighting luminaires to further direct light
Eliminate unnecessary lighting	• Switching off or dimming lights when not in use, to both reduce light pollution and save energy consumption and costs
Proper illumination levels	• Establish proper levels of illumination required for safety and visibility. Research suggests only 1-3lx required for facial recognition and visibility (save for roadways with higher speeds); current streetlights have illumination levels of 10-60lx
Proper colour spectra	• Avoid cold white light due to effects on ecosystems, human health, and skyglow; use "warm" or filtered LEDs with a CCT below 3,000K
Ecological sensitivity	• Maintain naturally unlit areas while promoting and enforcing "dark sky reserves" • Harmonize light levels with the needs of local flora and fauna

Table 2: Overview of proposed recommendations and policies for mitigating light pollution. Reprinted from: Designing for Darkness: Urban Nighttime Lighting and Environmental Values, By T. Stone, 2019, p. 104. 4TU, Centre for Ethics and Technology.

Stone argues that existing strategies to minimize light pollution currently only exist in the form of technical recommendations, and proposes to take it a step further by not only mitigating light pollution, but instead “evaluating all nighttime lighting and actively re-imagining our future urban nightscapes, and the relationship between lighting and darkness therein.” (Stone, 2018, p. 103).

He then proposes three possible Design for Darkness scenarios that encompass, and ultimately complement the existing strategies that aim to mitigate light pollution. These three concepts aim to reverse our shifting baselines, and all incorporate the instrumental advantages of LEDs and smart systems in their design. The three Design for Darkness (DfD) concepts are incremental darkening, environmentally responsive lighting, and urban (dark) acupuncture, which are in the following text:

DfD Concept 1: Dark acupuncture. This is a radical, short term approach, that aims to confront people with spaces, or “pricks”, in the urban environment that are explicitly left dark. With this approach, we will be forced to think differently about our unquestioned expectations and perceptions of nighttime lighting, and it will possibly help us in our acceptance towards darker urban nightscapes (Stone, 2019).

DfD Concept 2: Incremental darkening. This is a longer term strategy that aims to generally decrease the brightness of the lighting in cities, with the help of smart LEDs that provide a uniform change in brightness and colour. The brightness of the lighting will be reduced in such a way, that people won’t notice it, and visibility and nighttime activities aren’t disturbed (Stone, 2019).

DfD Concept 3: Environmentally responsive lighting. This also is a longer term strategy that would attune city illumination to the natural rhythm of the environment. With newly developed sensors and smart LED systems, city lighting will be able to react on changing lighting conditions during different seasons or weather conditions. The current street lighting is controlled by a clock, but responsive lighting should be able to respond to natural brightness levels, in such a way that it would be able to reconnect citizens to diurnal and seasonal patterns (Stone, 2019).

Each of these concepts will be analysed to determine which one should be applied to this case study, or that a combination of two or three concepts could be an option. The selected concept(s) will help answering the research question how a Design for Darkness strategy can be applied in Amsterdam Noord.

2.3. Chapter wrap up

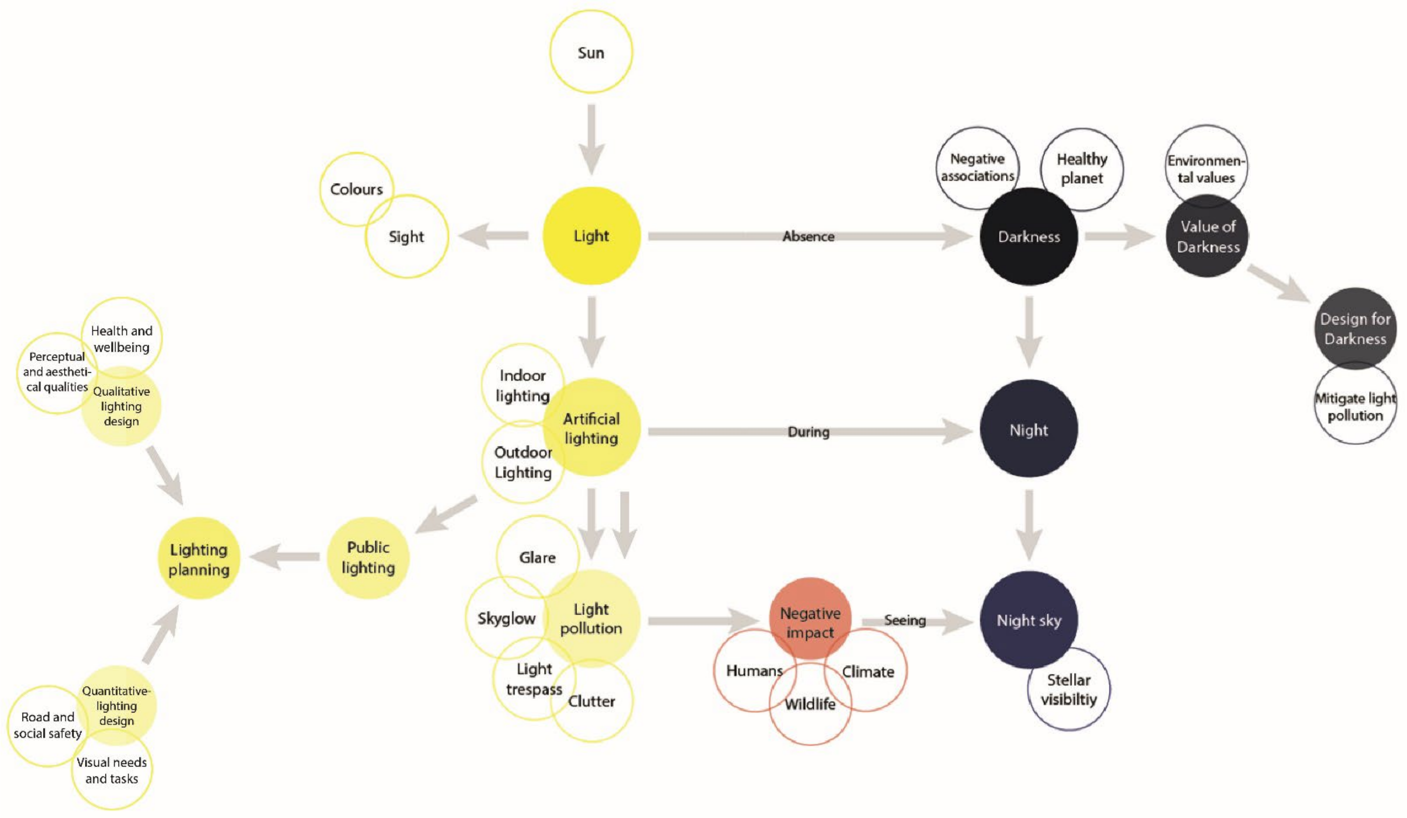


Figure 6. The relation between key concepts in this thesis. Own visualisation.

This chapter discussed the substantive and second-order concepts that will play a role in this thesis. The figure above shows the connection between these concepts. The filled circles in a shade of yellow or dark-blue present the key concepts, the bordered circles that are connected to these filled circles represent the different components of the key concepts. The arrows between the concepts are used to show which concepts can be connected to another. In some arrows, a word is added that clarifies how the concepts influence/affect one another. The concepts of light and darkness are taken as a starting point for this visualisation, from which the rest of the concepts are derived. Some of the second order concepts aren't included in this figure as these don't directly have a relation with light or darkness, but are derived from more general theories.

3. METHODOLOGY

This thesis investigated the problem of light pollution in Amsterdam Noord, caused by public lighting. A qualitative case study about light pollution in the context of Amsterdam-Noord was performed. This approach was taken to understand the phenomenon of light pollution in a comprehensive, holistic manner, and focused on people's subjective knowledge about and experience with public lighting planning and design (Azevedo, L.F. et al, 2011). With a literature review, interviews and observations, the lighting plans that were currently made for an urban area like Amsterdam Noord were analysed. By using different sources of data, triangulation could be ensured. The applied methods, which are outlined in the following paragraphs, contributed to the development of a comprehensive understanding of the current lighting planning in Amsterdam-Noord. Furthermore, with the help of the conceptual framework, the methods helped structuring a Design for Darkness strategy to mitigate light pollution.

3.1. DATA COLLECTION AND ANALYSIS

3.1.1. LITERATURE REVIEW

With the help of a literature review, data about light pollution and public lighting, and relating topics about lighting in the context of Amsterdam Noord were gathered. This was done by searching for keywords on websites offering scientific journals; Google Scholar, Researchgate, Sciencedirect, SpringerLink, SAGE Journals, and the online TUDelft and WUR library. The English keywords that were used to perform this search, represented the first order concepts of this research; "light", "light pollution," "public lighting", "lighting metrics", "lighting planning", "quantitative lighting design", "qualitative lighting design", "darkness", "night" and "night sky", and the second order concepts: "Direct rebound effect", "Dynamics of Demand", "Shifting Baseline Syndrome", "LED paradox", "Invisible infrastructures", and "Design for Darkness". Also, Dutch keywords with the same meaning were used to search for Dutch data, as well as other keywords about Dutch lighting guidelines, policies, and lighting practices in Amsterdam Noord: "beleidskader verlichting", "stadsilluminantie", "lichthinder", "richtlijn openbare verlichting", "Amsterdam Noord" and "LED". These keywords were searched on websites from public and private institutions; the municipality of Amsterdam, Rijkswaterstaat, NSVV, RIVM, and on Dutch newspaper websites from the AD and the NRC to find national, regional and municipal news articles. Also, more local information about Amsterdam Noord was searched on the website from Tolhuistuin and the Geschiedenis van Amsterdam Noord.

Eventually, the data from this literature review were synthesised and processed into an article matrix in Excel (Popenoe, Langius-Eklöf, Stenwall, Jervaeus, 2021). This article matrix consisted out of four rows: in the first row, a summarizing keyword indicated the main subject of the source, the second row contained the link to the source; the third row included the full source in APA style, and in the fourth row, the results/conclusions of each source were described. This matrix offered a literature overview with national and international articles, books, essays, reports, websites and policy documents. This literature overview helped organizing the content, shaping the content knowledge, and answering the research questions. The data from this literature review were also used to support the interviews and observations that were made. The methods that were used for the interviews and observations are explained in the following paragraphs.

3.1.2. Interviews

3.1.2.1. Interviewees

The aim of the interviews, conducted for this thesis, was to find between 10-20 people in the public lighting industry who were responsible for the planning or the design of the public lighting for Amsterdam Noord, or for a similar urban area. To find people from this sample group, the exponential non-discriminative snowball sampling technique was used (See figure 7). This method, based on the idea of a snowball effect, starts with one event that initiates multiple other similar events. The snowball sampling technique starts with one subject in the sample group, who refers to multiple new subjects, who in their case again suggest multiple other interviewees, until a sufficient amount of data is collected (Dudovskiy, 2022). In the case of this thesis, the snowball method was initiated by one of my two supervisors, Sylvia Pont, who knew multiple people in the lighting industry.

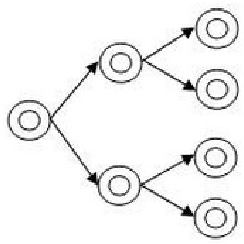


Figure 7: Visualisation of the exponential non-discriminative snowball sampling. Reprinted from: Snowball Sampling, By J. Dudovskiy, 2022. Retrieved from: https://research-methodology.net/sampling-in-primary-data-collection/snowball-sampling/ .

The snowball sampling technique was selected as the sampling method for this thesis, as it provided a fast and easy way to reach multiple interviewees in the same industry in a short amount of time (Dudovskiy, 2022). However, there were limitations to this approach, namely that it could not guarantee that the respondents were representative for the entire industry, and that it could lead to bias, as the respondents could refer to other respondents who shared the same characteristics or ideas, which could skew the validity of the results. To prevent this, a variety in the initial set of interviewees had to be ensured (Etikan, Akassim, Abubakar, 2015). This was done by both contacting lighting designers, lighting planners and lighting engineers, who worked nationally or internationally, for municipalities or private companies, or who had their own independent design agency. Also, people who were promoting the guideline light nuisance were contacted via the same snowball sampling method. This was decided to not only speak to people who applied the guidelines, but also get a broader view of the people behind these guidelines.

However, during this snowball sampling stage, data was missing about the specific lighting plans for Amsterdam Noord, and the stakeholders involved in these plans, like the residents in Amsterdam Noord. Therefore, separate people were contacted to ensure that enough data could be gathered for the case study about the lighting plans in Amsterdam Noord. Eventually, multiple small conversations, in the form of open interviews, were organised with three active residents, who were involved in the mitigation of light pollution in Noord, and who also knew how other residents in Noord thought about this subject (Interview 18). For this thesis, more residents in Amsterdam Noord could not be interviewed about the mitigating of light pollution, but this would be a valuable direction for further research. An overview of all the interviews with specifications can be found in Appendix B. Eventually, 19 interviews were conducted for this research. All the interviews were semi-structured, using the interview setup described in the next paragraph, except for interview 18 and 19. The reason for this, was that interview 18 consisted out of short conversations with residents, and the list of interview questions, which is discussed in the next paragraph, was not developed for residents, but for lighting designers and engineers. Interview 19, with the lighting planner of Amsterdam Noord, was conducted really late in the process, in July. In this stage, most of the data was collected and processed already, and only detailed questions about the situation in Amsterdam Noord, and simulations of the lighting in this area were needed. Overall, the data that was collected could be used to support the observations that were made during the transect routes, and, together with the literature review, contributed to answering the main research question, how to mitigate light pollution in Amsterdam Noord with a Design for Darkness strategy.

3.1.2.2. Interview setup

A list of interview questions was prepared that was used during the semi-structured interviews with lighting designers, planners and engineers. These questions revolved around the current public lighting plans that people had made for an urban area like Amsterdam Noord, what people's considerations were when making these plans, and what they considered as the future of public lighting. The questions were structured by the substantive and second order concepts, detailed in the conceptual framework, and by the research question about the current lighting plans in Amsterdam Noord. The sequence of the second-order concepts in chapter 2.2 was used as a basis for the order of the interview questions. Before the interviews could take place, the interviewees were contacted via an email in Dutch or English, in which they were given a short introduction about the research, and in which they were asked if they could contribute to this research with an interview. The example of the English email that was sent to interviewees can be found in Appendix C. If the person agreed to contribute, a date was planned on which the interview would take place. Before this date, a consent form was sent to the interviewee in English or in Dutch, which clarified what they could expect from the interview, and in what way their data would be collected and stored after the interview. An example of the English consent form can be found in Appendix D. The list of interview questions can be found in Appendix E. These questions were posed in English or in Dutch, depending on the preference of the interviewee.

During the interviews, data was recorded, using an audio recorder, and notes were taken. After finishing each interview, the data was translated to English, if the interview was done in Dutch, and then a transcription was made. This transcription was processed in the program Atlas.ti for Windows (Atlas.ti, 2022), which was a helpful tool to structure the data from the interviews, subdivide the data into different topics, and to organise quotes.

3.1.3. Observations

3.1.3.1. Transect routes

During the night of the 28th of March, the 30th of April and the 3rd of May, three transect routes through Amsterdam-Noord were followed, to experience the lighting and the darkness during the night, and to describe the public lighting that was used. As I didn't want to walk the routes on my own as that didn't seem safe, I needed people to experience the lighting with me. Therefore I took several people with me when walking the routes. During transect 1, a lighting designer, who was also interviewed (Interview 4), joined me. During transect 2, my boyfriend came along, and for transect 3, I was joined by three UvA students, who wrote their report about light in Amsterdam for the Tesla Minor (University of Amsterdam, 2022). First, I planned to walk four transect routes, but it took a lot of time to process three routes, and it was hard to find people who wanted to join the fourth route, so it was decided that three routes would already offer enough relevant information. The three transect routes were mapped out in such a way, that they covered the research area as much as possible, and crossed as many different areas as possible, through nature, neighbourhoods, areas with a function, like shops and industry, and along main roads. These three routes are shown in Figure 8.

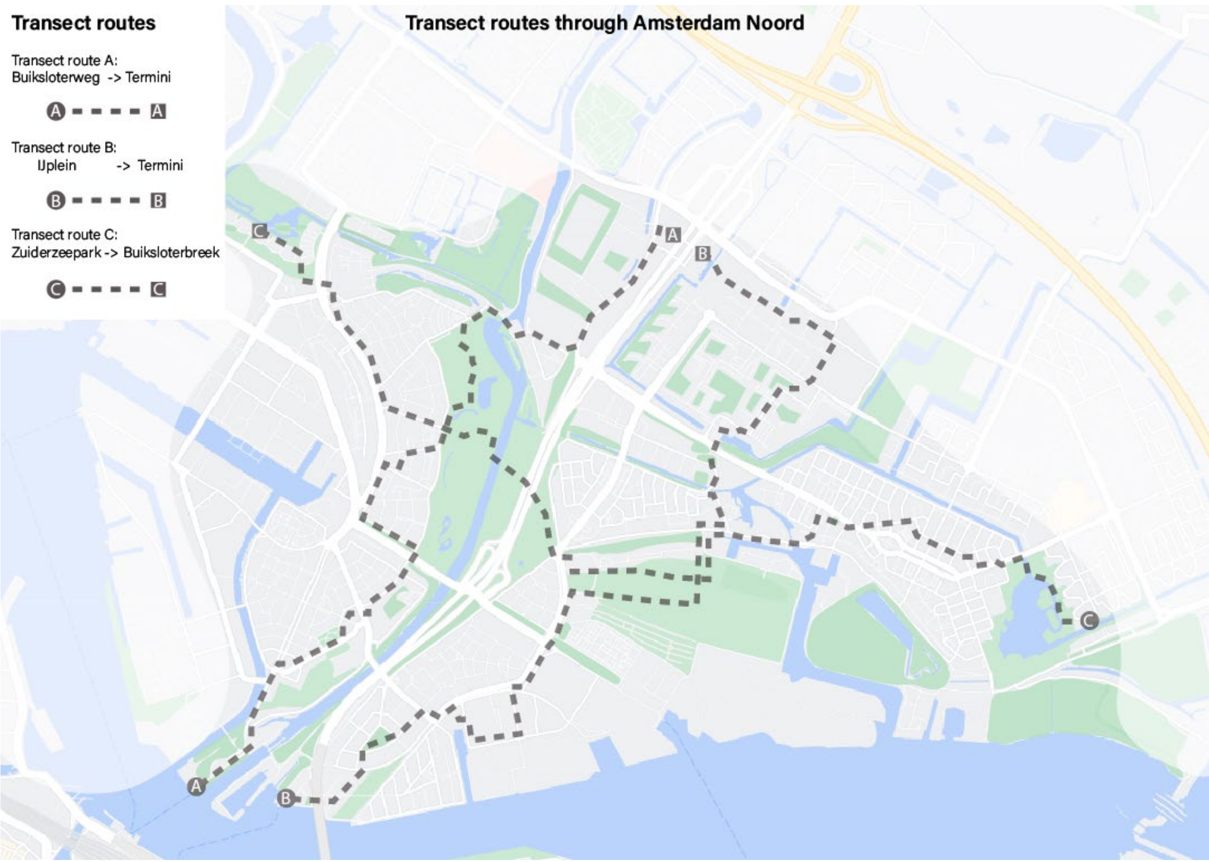


Figure 8: Transect routes through Amsterdam Noord. Own visualisation.

3.1.3.2. Observation setup

The observations that were made of the public lighting during the transect routes were based on three different themes. These themes were deducted from the concepts of lighting planning and lighting quality, described in the conceptual framework, and included the lighting layout, lighting quality and personal observation of the lighting. To communicate the observations, pictures were made during the transect routes, and notes were taken. For the first route, a different camera was used than for the second and third route. The first camera could be borrowed from the Faculty of Industrial Engineering in Delft, but for the routes that followed, this camera was not available. Therefore, a camera from a friend of the researcher, was used. The cameras weren't exactly the same type, so there might be slight differences between the pictures from the first route, and the second and third. This chapter continues with a description of the method that was used to make the observations.

Lighting layout

For the lighting layout, the kind of luminaires, lampposts, lamps, the distance between lampposts and the pole arrangement was analysed (ERCO, 2013) (see chapter 2.1.3.2.) During the transect routes, the luminaires and lampposts were documented and photographed. Afterwards, these observational data were compared to the data from the municipality of Amsterdam, to check what fixtures an poles were observed during the routes. The data from the municipality consisted of an overview of the available lighting elements in Amsterdam with the corresponding names, of which a summary can be seen in Figure 9. The kinds of lampposts that are used in Amsterdam, shown in this figure, are the "Classical pole (1867)", the "Classical pole (1883)", the "Apollomast", the "Modern pole from the 21st century", the "Standard high pole", the "Pole 1924", and the "Conical pole". The height of these masts could be determined, using a document from the municipality about the Puccini Method, "Handboek Rood". This document included all the specifications of the masts and fixtures that were part of the Puccini Method, and their locations in the city (Gemeente Amsterdam, 2021). The lighting elements that are part of the Puccini method are further outlined in Appendix F.

The kinds of luminaires that can be found in Amsterdam, are the "Ritterarmatuur", "Bolarmatuur", "Fixture of the 21st century", "Kroonarmatuur", "Standard fixture", "Holbeinarmatuur" and "Kegelarmatuur". The Kegelarmatuur is also called "Rondstraler" (Interview 6, 9), and this name is used in the rest of this thesis.

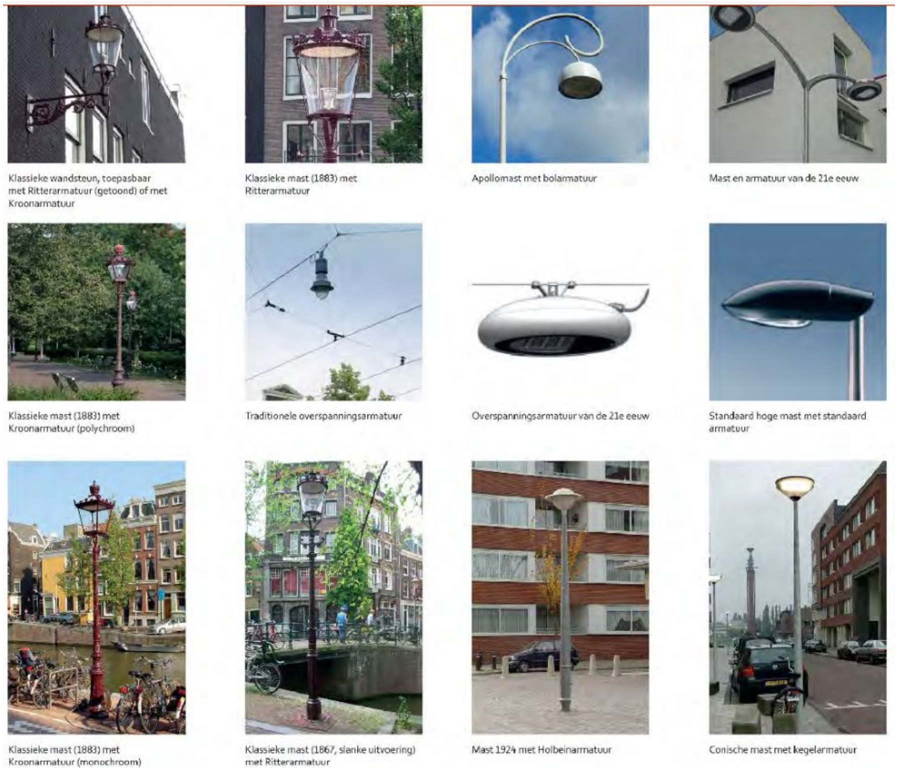


Figure 9: Fixtures and lampposts that are part of the Puccini Method in Amsterdam. (Image by Erna Adam, in "Inspiratie-, informatie- en participatiebijeenkomst Herinrichting Frans Halsbuurt", p. 38, 2019, Gemeente Amsterdam. Retrieved from: https://docplayer.nl/136700097-Inspiratie-informatie-en-participatiebijeenkomst-herinrichting-frans-halsbuurt.html).

The municipality of Amsterdam has divided its city in different zones. The lighting in these zones is adapted to the image quality of each zone, which is based on the historical character of the zone, ranging from pre-19th century historical to the 21st century modern. In Appendix F, the zonal distribution by the municipality and the corresponding lighting is highlighted. In Amsterdam Noord, the following zones and lighting is applied: in the pre-19th century belt, 4-meter high Classical poles, from the type (1883) or (1867), with Kroon or Ritterarmaturen are applied on smaller roads (max 30km/h), and 8-meter high Apollomasts with Bolarmaturen on wider roads (50km/h). In the 20'-40' belt, the 4-meter high Pole 1924 is often applied with Holbeinarmaturen on smaller roads, and on wider roads the 8-meter high Apollomasts with Bolarmaturen. In the post-war belt, the 4-meter high conical post with Rondstralers (Kegelarmaturen) are applied on the smaller roads, and standard high poles (8 meter) with standard fixtures are used on busier roads. Along the IJ-oever, the most modern lighting is applied, which are the low (8-meter) or high (10 meter) poles from the 21st century with fixtures from the 21st century (Gemeente Amsterdam, 2021).

A comparison between the observational and the municipal data of the lighting elements was made, to see what kind of public lighting was applied in which zone, what the names of the different elements were, and to recognise the differences in lighting applications between the zones. Also, the data was compared to a dataset from January 2022, published by the municipality of Amsterdam (Gemeente Amsterdam, 2022). This was a big Excel file with more than 250.000 lighting objects in Amsterdam, including all the fixtures and lamps in the city. This data was also used to check what lighting elements were seen during the transect routes in Noord. However, sometimes it was hard to determine what kind of lamps were applied, as this dataset wasn't up to date, and data was missing. Therefore, to determine the kind of lamps, data from personal observations was compared to literature about lamp types and interview data, which was gathered during the correspondence with the municipality (Interview 15, 19). The interviewees from the municipality indicated that differences between the lamps could be distinguished, based on the kind of light colour they emitted, which was also confirmed by literature (Van Heusden, 2017). Gold-yellow light turned out to come from QL lamps, which are known for their gold colour (Gemeente Amsterdam, 2022), while orange-yellow light could come from the older Sox or High Pressure Sodium (HPS) lamps, and warm white to blue-white light came from LED bulbs. The interviewees could not indicate what percentage of the lighting in Amsterdam Noord had currently been replaced by LED. Sometimes, assumptions about the lamp types had to be made, based on their light colour, and in other cases, the dataset of the municipality was used.

The distance between the light poles was measured with the help of a GIS file from the municipality of Amsterdam, published in 2019 (Dataplatform, 2019). This GIS file contained point objects of all the lampposts that were available in 2019. This data may be outdated, as it was published 3 years ago, and new light poles could be added or removed, but as a newer GIS file was not available, this file was used. With the measuring tool, the distance between each light pole could be determined (See Figure 10), and these measurements were then rounded to the nearest whole number. The distance between the light poles was measured, to see how and where the lighting was placed, and to recognize differences between zones.

Figure 10: Distance between light poles on the start of Buiksloterweg. ArcGIS, 2022. Full map available on: https://wur-girs.maps.arcgis.com/apps/mapviewer/index.html?webmap=22d74e4532b340839ccb4e78ed068733

Next to the distance between poles, also the pole arrangement was analysed, with the help of the GIS database, and data about four different pole arrangements (Parmar, 2019), which are visualised in figure 11. These pole arrangements are further described in Appendix G. The arrangements were analysed, to see how the light was distributed per location, and to check on what kinds of roads and in what zones each pole arrangement was applied.

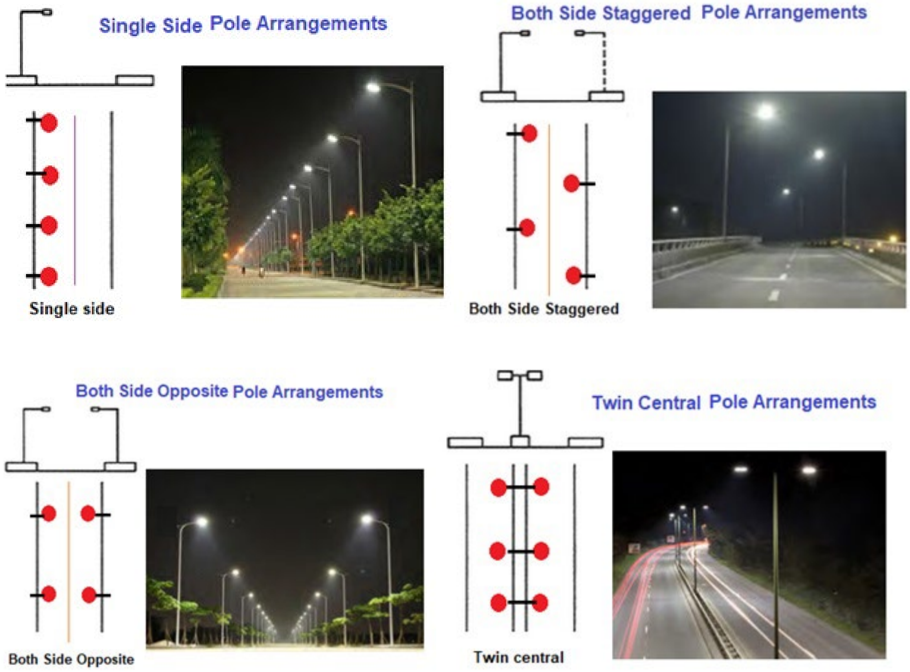


Figure 11. The different light pole arrangements (Images by Parmar, J. in "How to Design efficient Street Lighting – Part 1 B: Street light pole". (2019). Retrieved from: https://electricalnotes.wordpress.com/2019/04/24/how-to-design-efficient-street-lighting-part-1

Lighting quality

The lighting quality includes the lighting level, spatial distribution and colour of the light(Philips, 2008). During the transect routes, the lighting level was measured with a lux meter, which measured the illuminance of the light, the amount of light that shone on a surface. The measurements were made by putting the lux meter on the footpath, in front of a streetlight, underneath a fixture, on a distance of 1,5 meter from the pole (see figure 12). During the transect routes, in almost every street that was crossed, a lux measurement was made of a streetlight, to create a complete overview of the lighting and lighting levels during all the routes. Only the horizontal illuminance was measured during the transect routes in this way, and not the vertical illuminance. The reason for this was that it took too much time to make multiple measurements of all the locations that were passed during the route. For future research, the other dimensions of the lighting should be also taken into account when making measurements, based on the plenoptic function, described in Chapter 2.1.5.

In the figure 12 underneath, a golf ball is visible during a lux measurement, which was photographed during the first transect route to show how the light fell on the surface. This was only done during transect route 1, as after evaluating the pictures of the route, the camera turned out to be unable to make a clear picture of the different lighting conditions, and it was decided to not use the golf ball in the next measurements anymore.

Figure 12: Illuminance measurement with a lux meter during one of the transect routes. Own picture.

During this research, the spatial distribution of the light could not be measured. Only when there were clear contrasts between light and dark in the landscape, this was noted. This could be the case when lighting was missing, and dark shadows in the landscape were visible, or when the lighting was too targeted, and caused stripes on the road surface.

Next to the light distribution, the light colour could not be measured, as there was no spectrometer available. Only when there was a distinctive colour of the light, compared to the rest of the lighting (like orange/yellow/green), this was noted. For the rest of the lighting, it was assumed that the colour was warm white, between 2700-3000K, which is the standard colour the municipality applies to all new LED lighting (Gemeente Amsterdam, 2017).

Personal observation

The personal observations that were made during the transect routes were based on the judgement of the lighting, the feeling of safety in the area and the overall atmosphere, created by the light (Philips, 2008). These observations were solely based on the subjective impression, both of the researcher as well as the person(s) who joined the researcher during the routes.

The feeling of safety in the area was based on how well we could see around us, the visibility of the environment. This was also strongly based on the distribution of the light, and whether there were a lot of dark shadows in the landscape (contrasts). When the lighting was uniform, and contributed to the overview and clarity of the road and its surroundings, we indicated this as good visibility, but when there were a lot of dark contrasts in the landscape, and we were not able to discern other people, or the boundaries of the landscape, the visibility of the area was judged more negatively, and the feeling of safety was also negatively influenced.

Our judgement of the lighting was influenced by our feeling of safety, but also by the brightness of the light, and if light pollution could be recognized in the form of direct light nuisance. This included light trespass and glare (see Chapter 2.1.6). When light not only shone on the roads, but also towards natural areas or into windows of houses, or when a streetlight was almost placed against a window of a house, we indicated this as light trespass (see Figure 13 for an example).

Figure 13: An example of a light pole which is almost placed against a house. Own picture.

Glare was determined by looking towards the light source. If the light blinded us, this could be indicated as glare. When the light was uncomfortable for the eye, it was noted as discomfort glare, and when we wouldn't be able to see because of the glary light, it was noted as disability glare. These kinds of glare are also described in the conceptual framework about a quantitative lighting design, in chapter 2.1.4.

It was planned to also count the number of stars, to see whether walking more north would have an influence on the stellar visibility, which would confirm the results in chapter 4.2. However, during night walk 1 and 3, the sky was too cloudy, and stars were hardly discernible. Therefore, the number of stars isn't further highlighted in the observations.

Lastly, the lighting plan was judged on its consistency: if masts were placed in a logical order, on equal distance from one another, and the design and arrangement of the lighting was consistent, the lighting plan got a positive judgement. When the lighting plan felt chaotic, and streetlights were missing, or there were too many poles in the street, which hindered a good overview of the road, the lighting plan got a more negative judgement.

3.1.3.3. Zoning

To structure the observations that were made of the public lighting in Amsterdam Noord, the method of Functional zoning was used to subdivide the research area into four different zones (Rodrigue, 2020). This method is also applied in urban planning as well as transportation planning to make zonal categories of land use, based on the function of the zones, such as commercial or residential, and the different regulations per zone (Rodrigue, 2020). In the case of Amsterdam Noord, the Hoofdgroenstructuur (Green space), the neighbourhoods, both historical as modern, (Residential area), the functional area (the commercial, industrial, and educational, recreational area), and the road structure were each put in a zone, and separately discussed. In figure 14, the zoning in Amsterdam Noord is visualised, and a water layer was also added tot this map. This layer isn't further discussed in this thesis, but is only added to clarify the orientation of the map. The road structure isn't part of the Functional zoning method as described by Rodrigue (2020), but was added as a separate zone to the map, as the focus of this thesis is to analyse public lighting, and this kind of lighting is frequently placed along main roads. It was decided to use the zoning method, as this offered a clear structure to the observations that were made during the transect routes. Furthermore, the lighting in each zone could be separately discussed, and the lighting characteristics per zone could be compared with one another, to see what differences are visible. Eventually, the findings from the different zones were synthesised and processed in a summarizing table. This table also showed the issues per zone, which included the components of light pollution that were recognized during the routes. Based on the components of light pollution, observed in Noord, a Design for Darkness strategy for Amsterdam Noord could be formulated.

Figure 14: Different zones in Amsterdam Noord and the transect routes crossing these zones. Own visualisation

3.2. CHAPTER WRAP UP

In this chapter, the approach that was used to gather and analyse data was clarified. First, a literature review was conducted to collect relevant data about the main subjects discussed in this thesis. With the help of an article matrix, data could be synthesised and grouped into categories that aligned with the research questions. Secondly, the snowball sampling technique was used to contact multiple people in the lighting industry for an interview. The interview questions that were posed to these people were structured by the substantive and second-order concepts in the conceptual framework, and revolved around the research question what people's current public lighting plans were for (an urban area like) Amsterdam Noord. Lastly, with help of three transect routes, observations were made of the lighting in Amsterdam Noord. These observations were structured with the zoning method, with which the research area in Amsterdam Noord was subdivided into four different zones. The findings from the literature review, interviews and observations were analysed, and the findings could be used to formulate a short term Design for Darkness strategy for Noord.

4. Results

The findings of this research, in the shape of interviews, transect routes and a literature study, are processed and presented in the following four sections. Firstly, in the context of Amsterdam Noord, the stakeholders are described that interact with public lighting. Then, the current state of light pollution in this area is highlighted, by zooming in to the situation in Amsterdam Noord. Thirdly, an overview is given of the current public lighting in Noord. To do so, the research area in Noord is subdivided into four different sections, and for each section, the quality, layout and subjective impression of the lighting is given. This approach is based on the concepts of lighting planning and quantitative and qualitative lighting design in the conceptual framework. Lastly, the focus of the lighting plans, which is deducted from the interviews with lighting designers and engineers, is outlined.

4.1 Stakeholders in Amsterdam Noord

In the context of Amsterdam Noord, the stakeholders that are involved in the current lighting plans, and the stakeholders that are impacted by these plans are identified, and their interaction with each other is explained. These stakeholders include the lighting engineers, lighting designers, lighting suppliers, the Public lighting department of the municipality of Amsterdam, the police in Amsterdam, the residents in Amsterdam Noord, the civil society in Amsterdam Noord and the silent stakeholders in Amsterdam Noord.

Lighting engineers

The street lighting in Amsterdam Noord is planned by a lighting engineer from the Ingenieursbureau Amsterdam, which is led by the municipality. This engineer follows the ROVL, the guideline public lighting, or the NPR, the newer version. Interviewee 17 and 19 indicate that the aim of a lighting engineer is to provide a functional lighting plan in a short amount of time. The plans from lighting engineers are mainly based on a quantitative lighting approach as described in 2.1.4. This plan is conform the lux levels and the uniformity that are advised by the guidelines, and provides social safety and facial recognition, which has become increasingly important over the last years (Interview 19). It is not common for this person to visit the streets he designs lighting for, as there are multiple projects that need to be finished in a short amount of time, and clients don’t appreciate it if a project takes longer than expected. Lighting engineers often use the program Dialux to visualise their ideas, to simulate the impact of lighting on surfaces, and to make calculations with the lighting.

Lighting designers/architects

Apart from functional street lighting, designed by lighting engineers, there is City illumination, which is the uplighting of (monumental) buildings, bridges and artistic objects. This is designed by lighting designers, who are also called lighting architects. These people often visit the place they design lighting for to test their lighting setup on-site, to see what the impact of the lighting is on the environment. The lighting designers that were interviewed for this thesis indicate that they try to play with contrasts in the landscape caused by the lighting that they add, and often try to create enough visibility and safety with as little light as possible. The plans of the interviewed lighting designers are often based on a qualitative, perception based lighting approach, as described in 2.1.5 Some of the interviewed lighting designers (Interview 3, 4) make stakeholder overviews to map out the relationships and interactions between the people and animals living around their lighting design, and to show the impact that the lighting has on these stakeholders. They make such an overview to know who they need to involve in their lighting plans, and to give every stakeholder a voice before the actual lighting is implemented.

Lighting suppliers

The lighting supplier for the municipality of Amsterdam is the Materiaalbureau Amsterdam. This bureau purchases all the material for the public space in the city. The Puccini method (see Appendix F) is applied during these buy-ins, to assure the recognizable image of the city (Materiaalbureau, 2022). The municipality of Amsterdam is aware about the quality that lighting should have, and has set up its own sustainable procurement strategy to regulate the purchase of public goods like lighting. This document outlines what requirements should be met before products like LEDs can be purchased (Gemeente Amsterdam, 2010). For the supply of public material, like public lighting, the Puccini Method is followed (see Appendix F). The process of the supply of public lighting won’t be further discussed in this thesis, but it is mentioned in this paragraph as it is an important aspect of a lighting plan.

The municipality of Amsterdam

At the municipality of Amsterdam, officials from the Public lighting department in the cluster City Management are responsible for the management, maintenance and functioning of the public lighting in the city. These people have taken up the ownership over the public lighting, and have drawn up a Policy Framework Public lighting for its requirements (Interview 15). The department is the client or process owner during the implementation of lighting, and is involved in many chain processes related to lighting, for example overseeing the cable network from Liander, the network operator (Interview 15).

Residents can contact the public lighting department with a complaint about lighting. Right now, the only complaints the municipality gets are from people who find their environment too dark and want more light, because they don’t feel safe (Interviewee 15). The officials from Public lighting work for the residents of Amsterdam, and do what the inhabitants ask. They add more lighting to a street, even when they would prefer to turn off the lighting at 12 pm themselves, as it saves energy and money (Interviewee 15). According to interviewee 7, ”The public lighting department knows that it is a political decision to use more lamps. They know that this is just a symbol, a reassurance to the people that the municipality has done something and that they are safer after that. That's why they do that. The people who are responsible for the lighting also know that it doesn't work that way”.

The police in Amsterdam

The police have an important say in the decision for more lighting, quoting the Asset manager public lighting from the municipality: “Once we wanted to dim the Vondelpark, we could apply less lighting at certain times, well boy, the police went completely crazy, they said: we don't want less light, we want more light! The police are responsible for enforcement and safety, if they can no longer see a thing, it is difficult to perform their task.”(Interviewee 15).

Residents in Amsterdam Noord

The residents in Noord can be subdivided into two different groups: the older residents, who have lived in Noord their whole life, and the newer residents, mainly yuppies (young urban professionals), who often have a higher income, and live in Noord for a maximum of 10 years (Interview 18). Noord went from a small borough with a lot of social cohesion and community feel, to a gentrified area with more anonymity and estrangement, which can cause friction (Van de Kamp, Welschen, 2019). The older residents are more resistant to change than the newer residents, who are more flexible and adventurous (Interview 18). The asset manager public lighting in Amsterdam indicates that he doesn’t know how the residents in Noord feel about darkness. To find out, he supervised a minor project at the University of Amsterdam (UvA) in which students interviewed residents in Noord about a possible reduction in the brightness of the lighting. The report with their findings was published only a month before this thesis research, and the major findings that could be drawn from this research indicated that residents in Noord would be open to a reduction in the brightness of the lighting in their neighbourhood, and that more pilots in Amsterdam Noord are needed to determine how far the lighting could be turned down while still guaranteeing a comfortable environment for its inhabitants (Cramer, Lücker, Osinga, Stojanovic, 2022).

Civil society in Amsterdam Noord

In the civil society in Noord, a countermovement against more lighting is visible. Multiple pro-environmental residents and local organisations are aware of the impact of light pollution, and are in favour of preserving darkness. The voices from local organisations, residents and species in Noord are bundled into the Manifest for Nature reserve Noord. This Manifest is an appeal to declare Noord to be a nature reserve, to preserve natural darkness, and to safeguard the green area they coexist in together with all other living species. More than 50 local, pro-environmental organisations, businesses, initiatives and resident committees in Noord have signed this Manifest, which consists of a wish list of 10 goals to protect the landscape in Noord. One goal is to decrease the amount of light pollution in the area, to conserve plants and animals. (Tolhuistuin, 2021). The parties that signed this Manifest, like Marjolijn van Heemstra with her project the Night Watch, also aim to convince other residents in Noord of the value of nature and darkness. They have created a way of storytelling that incorporates darkness into the positive values of Noord, to show people that a darker environment and a safe Noord can still go hand in hand.

Silent Stakeholders

The silent stakeholders are all the flora and fauna in Noord that are affected by the lighting plans, but that cannot express their opinion about the lighting. The impact of lighting on nocturnal animals is different from that on diurnal animals. For nocturnal animals, like bat and mouse species, lighting disrupts foraging habits and reproduction, while for diurnal animals, like bird species, lighting negatively affects sleeping patterns (NIOO-KNAW, 2019). For plants, like trees that are placed close to a street light, lighting disturbs their growing pattern and defoliation (Bennie; Davies; Cruse; Gaston, 2016). For this thesis, an overview of the species in Noord could not be made, but an important step of a complete lighting plan would be to take ecology into account. This was also expressed by multiple interviewees, who involved an ecologist in the process of lighting planning and design (Interview 1, 3, 8, 13, 15). Next to flora and fauna, the silent stakeholders can also be a group of residents that doesn't express their opinion about lighting. These people may be affected by lighting at night without knowing that it can have a negative impact on their biorhythm and health (IDA, 2013). They are unaware of light nuisance, or they don't know that they can report it.

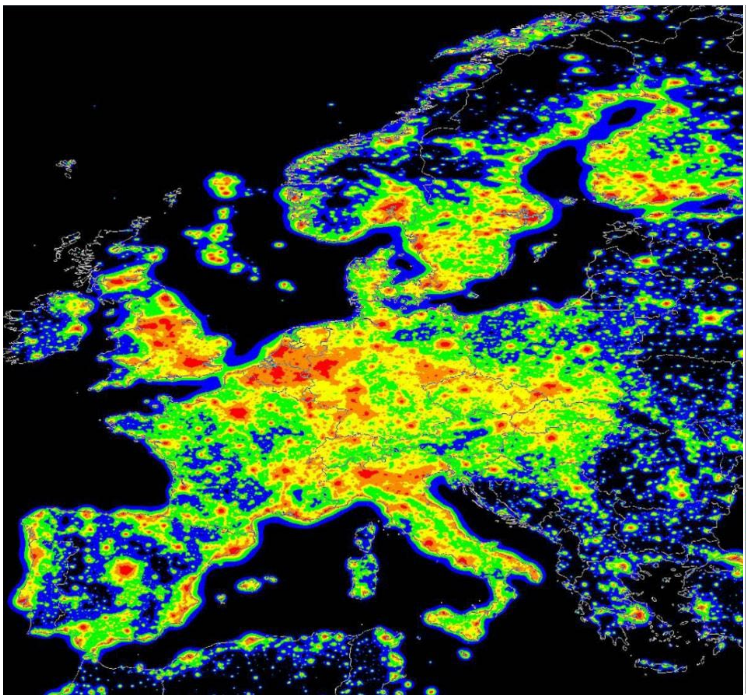
To conclude, the municipality is responsible for the lighting in Noord, and manages lighting engineers and lighting architects, who design street lighting and city illumination, which are two separate disciplines. The Materiaalbureau Amsterdam purchases the lighting equipment for the city. The lighting department in Amsterdam develops the lighting plans in Amsterdam, and is often asked to add more lighting to meet the demands of its inhabitants and the police, who both are in favour of more lighting, as it increases the feeling of safety and improves facial recognition. In Noord, a countermovement in civil society against more lighting has come forward in the form of multiple pro-environmental organisations, residents and resident committees, who signed the Noord Manifest that advocates for more darkness. With storytelling, this movement now tries to convince the rest of the residents in Noord to embrace a darker environment to preserve nature, and to give a voice to the silent stakeholders, the animals in Noord who are impacted by lighting.

4.2. Light pollution, zooming in on Amsterdam Noord

In this paragraph, the causes and effects of light pollution, according to interviewees, are shortly outlined. Then, the current state of light pollution in Europe, the Netherlands, and finally in Amsterdam Noord and the surrounding area is highlighted with the use of maps, showing the sky brightness, Bortle scale and/or number of stars.

According to multiple interviews, light pollution is caused by light sources that are aimed directly into the sky, that radiate to places where it is not needed, or that are still on when it is not needed (Interviewee 2, 3, 7, 8, 13, 14, 16, 17). Overall, people indicate that light pollution is mainly caused by badly designed public lighting with too many lights, too many fixtures with a too high output. Also, billboards were mentioned a couple of times as a newer cause of light pollution in the public space (Interviewee 2, 12, 14). Many interviewees indicate that light pollution has an effect on nature and ecology, but only a few people indicate that lighting also can have an impact on people's health.

The amount of light pollution in Europe is visualised in the figure 15 underneath. It is clearly visible that the Netherlands is one of the most illuminated countries in Europe (AD, 2018).



Conditions at Zenith			
Color	Artificial / Natural Sky Brightness	Sky Brightness mags / sq arcsec V Band	Bortle Scale approx
	< 0.01	22.00 to 21.99	1
	0.01 to 0.06	21.99 to 21.93	2
	0.06 to 0.11	21.93 to 21.89	2
	0.11 to 0.19	21.89 to 21.81	3
	0.19 to 0.33	21.81 to 21.69	3
	0.33 to 0.58	21.69 to 21.51	4
	0.58 to 1.00	21.51 to 21.25	4
	1.00 to 1.73	21.25 to 20.91	4.5
	1.73 to 3.00	20.91 to 20.49	4.5
	3.00 to 5.20	20.49 to 20.02	5
	5.20 to 9.00	20.02 to 19.50	5
	9.00 to 15.59	19.50 to 18.95	6
	15.59 to 27.00	18.95 to 18.38	7
	27.0 to 46.77	18.38 to 17.80	8
	>46.77	>17.80	9

Figure 15: World Atlas of Artificial Night Sky Brightness - Europe.
Retrieved from: https://www.cleardarksky.com/maps/lp/large_light_pollution_map.html

When zooming in on the Netherlands (Figure 16), we can see that the most light pollution stems from the Randstad, in the area around Rotterdam, Delft and The Hague, and going north, also from Amsterdam. In this area, level 8 and 9 on the Bortle scale is reached, which is an inner-city sky that is so brightly lit, that hardly any stars are visible (Bortle, 2006) (See appendix A). The least light pollution can be found in the province of Drenthe, Friesland and Groningen. In Friesland, even two International Dark Sky Parks can be visited, namely in National Park Lauwersoog and on the Waddeneiland Terschelling, De Boschplaat (IDA, 2018). These Dark Sky parks are both certified by the IDA, and got this certification as they both possess “an exceptional or distinguished quality of starry nights and a nocturnal environment that is specifically protected for its scientific, natural, educational, cultural heritage, and/or public enjoyment.” (IDA, 2018).

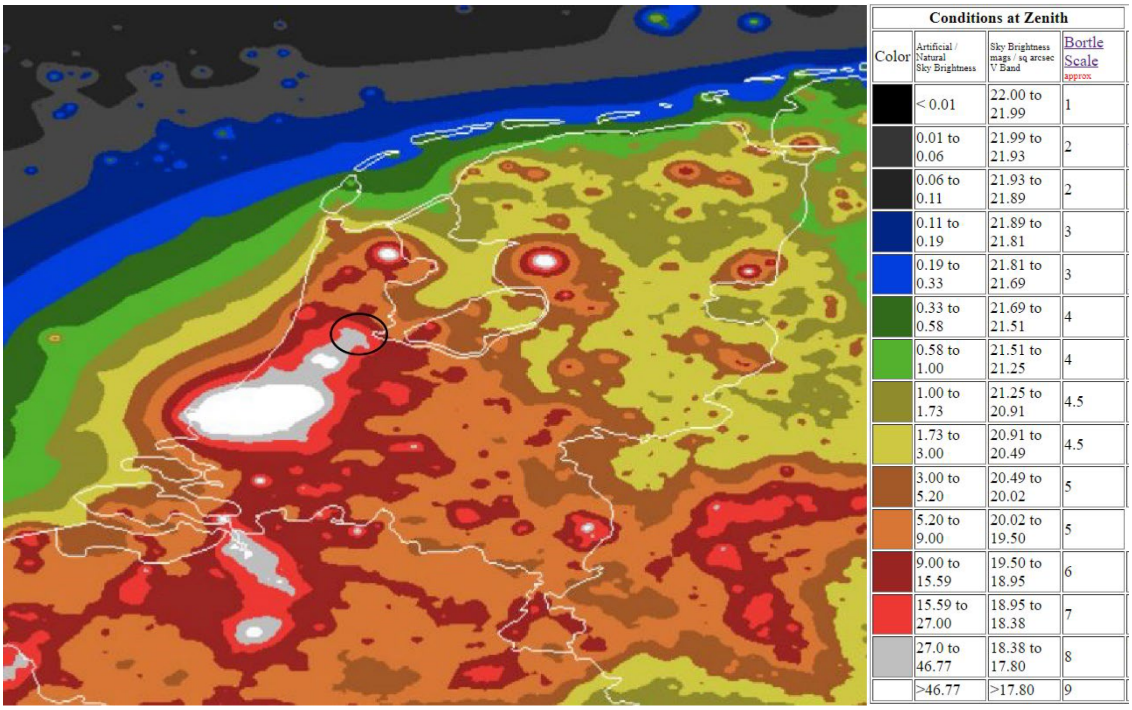


Figure 16: World Atlas of Artificial Night Sky Brightness – the Netherlands.
Retrieved from: https://www.cleardarksky.com/maps/lp/large_light_pollution_map.html

The black encircled area in figure 16 represents the area where Amsterdam is situated. We can see that Bortle scale 8 is reached on the south side of Amsterdam, but moving to the north-east towards the Markermeer, the sky brightness decreases, and only a Bortle scale of around 5 is indicated.

In the six years before the year 2018, the Suomi satellite measured an increase in light pollution above the Netherlands. However, in 2018, it measured a small decrease, and Dutch Environmental Federations reported that the Netherlands may have reached a turning point (AD, 2018). Whether this trend will continue, largely depends on businesses, according to these federations: “municipalities, provinces and Rijkswaterstaat are already trying to dim the lighting where possible, but due to the low costs of LED-lighting, some companies and businesses tend to leave lighting and advertising signs on when it is not needed” (AD, 2018).

To visualise the amount of light pollution caused by upward directed lighting in North Holland, the province in which Amsterdam Noord is located, a map of this province, created by Sotto Le Stelle, is analysed. This map below, in Figure 17 shows the sky brightness and the number of visible stars in the province. The Bortle scale isn’t used for this map. The orange encircled area in the close-up map represents the research location in Amsterdam Noord.

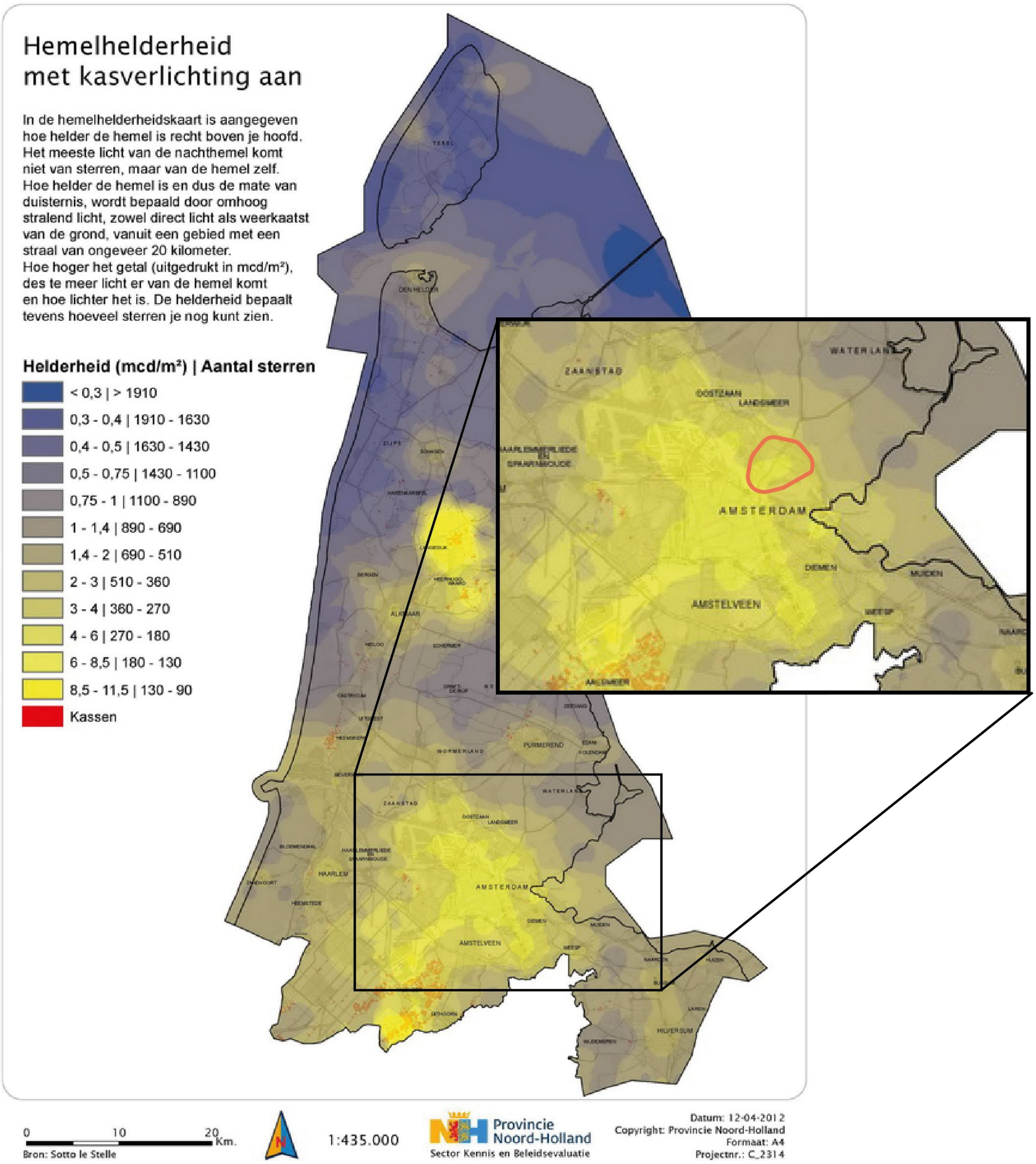


Figure 17: Sky brightness and visible stars in the province of North-Holland. Reprinted from Sotto Le Stelle, Province North-Holland, 2012. The encircled area represents the research location for this thesis.

The map above shows that the sky brightness in Amsterdam is high (between 4 – 11,5 mcd/m^2), and that only between 90 - 270 stars are visible in the city. The number of stars that can be seen on a moonless, cloudless night, without disturbance of city lights, is estimated to be 2000 (Earthsky, 2021), so the visible stars in Amsterdam are just a fraction of this number. However, the map reveals that by moving towards the rural north, the sky brightness reduces and the number of stars increases. A better visualisation of this can be seen in Figure 18, from Atlasleefomgeving (2022). This map shows a slightly different legend from the one from Sotto, by only indicating the number of stars that can be seen. This number can be linked to the sky brightness in Sotto's map.

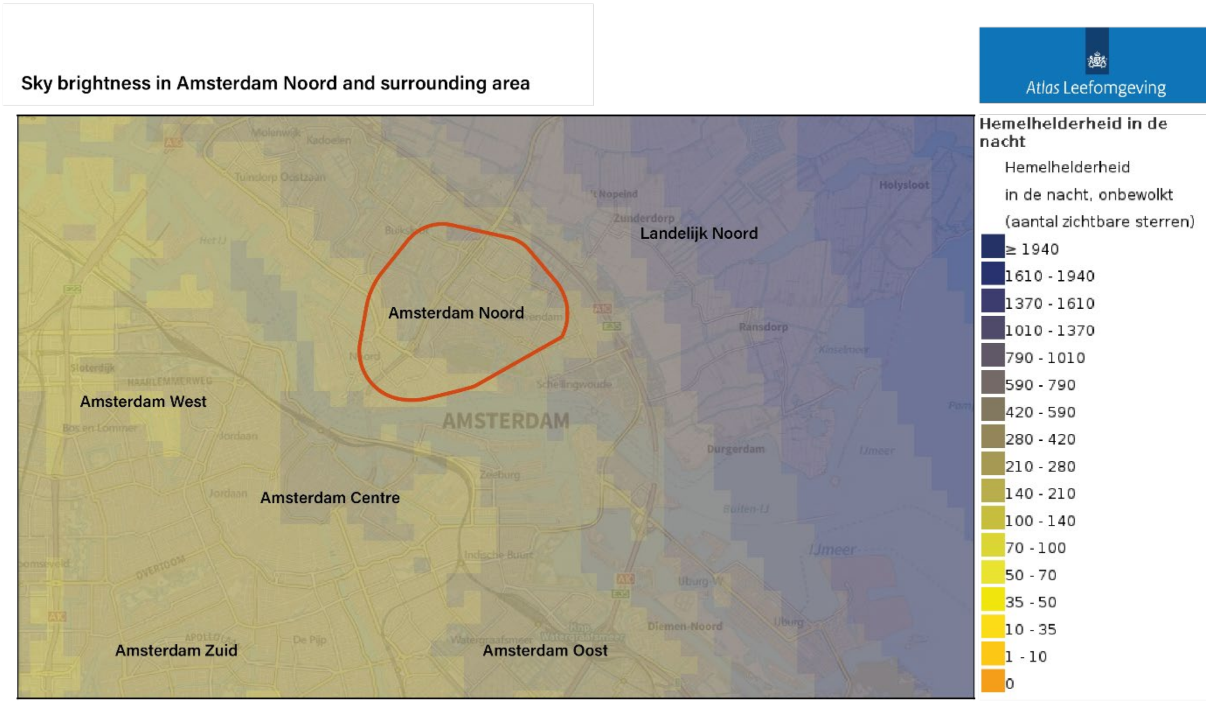


Figure 18: Sky brightness (number of stars) in Amsterdam and surrounding area. Created on Atlasleefomgeving.nl, 2022

Figure 18 shows that Amsterdam Noord lies in between the urbanized Amsterdam and Landelijk Noord (Rural North). The district has seen an increase in illumination in the last couple of decades, due to the gentrification in the area (Interview 18). The environment will probably become brighter, as 50.000 new dwellings will be constructed here in the coming years, at the expense of nature and natural darkness (Interview 18). Where Amsterdam Noord has a sky brightness of around 4 - 6 mcd/m^2, and between 180-270 visible stars, the number of visible stars in Landelijk Noord ranges up to a 1000, and the sky brightness lies around 0,5 - 3 mcd/m^2.

To conclude, the Netherlands is one of the most light polluted countries in Europe, but the overall measured light pollution above the Netherlands saw a decrease in 2018. It is not clear whether this is a trend that will continue. When zooming in on Amsterdam Noord, the maps show that the sky brightness in this area is high, and that a Bortle scale of 8 is applicable in this area. Interviews indicate that illumination in Noord will probably increase in the coming years due to gentrification. There is a significant difference between the sky brightness in Amsterdam Noord and the attached rural area, Landelijk Noord. Data show that in the rural area, around 1000 stars can be seen, while in Noord, this is only around 200.

4.3 Current public lighting in Amsterdam Noord

This paragraph describes the public lighting that was observed during three transect routes. The observations of the lighting were based on three different themes: the lighting layout, lighting quality and the personal observation of the lighting. To organise the findings from the observations, the research area in Noord was broken down in four different zones. The methodology section (3.1.3) elaborates on the approach that was used to collect and process the observations. In Appendix H, the complete overview of the three transect routes is shown in chronological order, supported with pictures, notes and specifications of the lighting.

4.3.1. Zoning in Amsterdam Noord

The research area was subdivided into four different zones to structure the observations (See Figure 19). Specifications of these zones are given in the following paragraph.

Figure 19: Different zones in Amsterdam Noord and the transect routes crossing these zones. Own visualisation.

Hoofdgroenstructuur:

The parks in Noord are part of the main green structure of Amsterdam, the so-called Hoofdgroenstructuur (Gemeente Amsterdam, 2021), which is shown in the green layer in figure 19. Nature in this structure is protected and will be strengthened and expanded in the coming years, following Amsterdams Green city vision for 2050 (Gemeente Amsterdam, 2020). It is remarkable that the Green vision doesn't say anything about lighting, or the impact of light pollution on nature. As Stone mentions, "we can extend ideas of "greening" cities to also include "darkening" city nights as a form of environmentally restorative urban design" (Stone, 2019, p. 102).

Neighbourhoods:

In 1921, Amsterdam annexed Amsterdam Noord. Before that, the landscape in Noord mainly consisted of pre-19th century villages with characteristic wooden houses on old dikes; the Dijkdorpen, which were focused on agriculture and shipping (Rijksdienst voor Cultureel Erfgoed, 2014). During and after its annexation, the residential area in Noord was expanded with the construction of the Tuindorpen and three additional parks. The Dijk- and Tuindorpen and their parks now belong to the cultural heritage of Noord and have the status of protected cityscape (Cultureel Erfgoed Amsterdam, 2014). In figure 19 the Dijk- and Tuindorpen are combined into the yellow layer that indicates the historical neighbourhood structure in Noord, built in the pre-war period (Dijkdorpen), and between 1920-1940 (Tuindorpen) (Geschiedenis van Amsterdam Noord, 2018). The modern neighbourhoods that were crossed during the transect routes are indicated in orange. These neighbourhoods are mainly built in the post-war period, and will be discussed separately from the historical neighbourhoods, as their structure differs significantly.

Functional area:

The functional area both includes the pink layer in Figure 19, which is dedicated for the commercial and industrial area in Noord, and the purple layer, which includes locations meant for education, sport and leisure. Both areas are mainly illuminated by private lighting. This kind of lighting was actually not part of the scope of this research, but as multiple interviewees indicated that this lighting was an important source for light pollution, it was decided to shortly discuss the observations of this lighting as well (Interview 2, 12, 16).

Road structure:

The main roads that connect the different neighbourhoods in Noord are indicated with the brown line in Figure 19. The road structure is set up to transport (heavy) traffic, but in this layer, also bridges and viaducts are included that are used by slower traffic. The lighting on these connecting roads differs from other layers and was therefore discussed separately.

4.3.2. Hoofdgroenstructuur

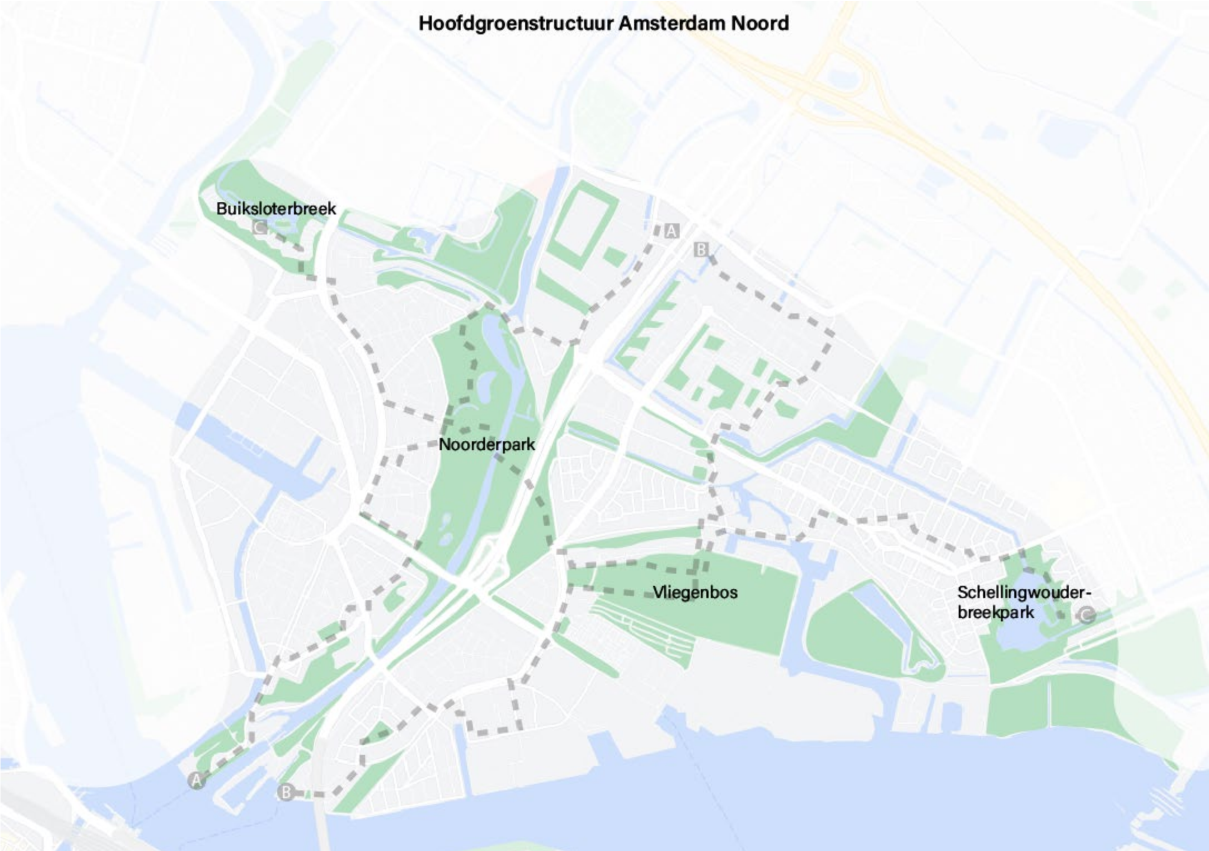


Figure 20: Hoofdgroenstructuur, highlighting the four parks that were crossed during the transect routes. Own visualisation.

The three transect walks crossed a couple of green areas from the Hoofdgroenstructuur in Noord, the Schellingwouderbreekpark, Vliegenbos, Noorderpark and Buiksloterbreek (see Figure 20). In the Beleidskader Verlichting (Policy framework public lighting), the Gemeente Amsterdam states that it illuminates its green structure as little as possible, and that lighting is only needed on the connecting routes through the green structure and their directly adjacent area. The light distribution should be as uniformly as possible to ensure enough visibility (Gemeente Amsterdam, 2017).

During the transect routes, LED lamps in Rondstralers (Kegelarmaturen) on 4-meter-high conical lamp posts illuminated most of the routes through and along the edges of the green structure (see figure 21 and 22). Except for the main routes, the rest of the green structures didn't have lighting. The distance between the posts differed, it ranged between 20-25 meters in most areas, but on the Floraparkweg, the distance between the posts was 10 meter. The posts were placed on one side of the road, in the so called Single Side Pole arrangement (Appendix G). The lighting level, measured when walking through the green structure, lay between 3 – 5 lux. The Rondstralers were still visible from far away, as their light wasn't targeted towards the road, but spilled horizontally, which gave the directly adjacent area next to the road good visibility, but also caused light trespass. The contrasts between illuminated and non-illuminated routes were high, and we felt discouraged to take the darker routes: it felt safer to stay on the illuminated path, also because the area felt abandoned.

Figure 21: Lighting in Vliegenbos

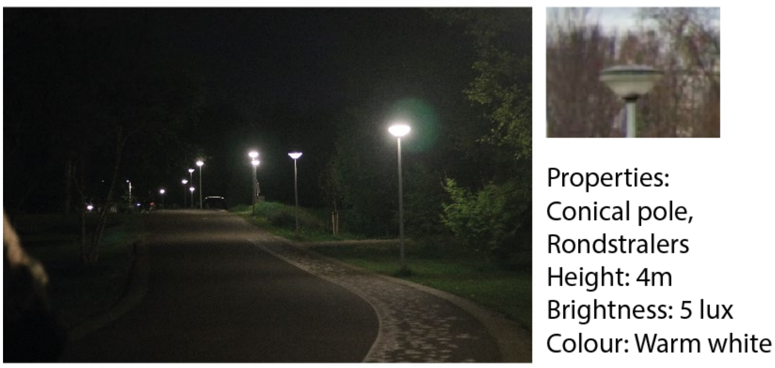


Figure 22: Lighting in Noorderpark

Two "highlights" in this context were the Rondstralers with LED lamps on the foot-cycle path east of Noorderparkbad (Figure 23), which had a measured brightness of 16,5 lux. We judged that the lights caused glare, and weren't pleasant to look into. The second highlight were three spotlights, probably

LED, which were attached to the wall of the Vox college (Figure 24). The lighting was aimed almost horizontally, and penetrated the green structure next to it; the Vliegenbos. This white light had a brightness that was higher than 10 lux. The light was clearly visible when walking on the dark route through the Vliegenbos, as it illuminated the path that was intentionally kept dark.

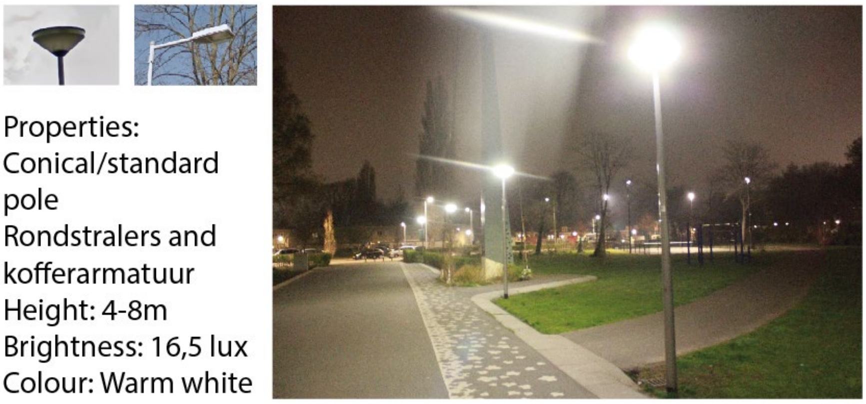


Figure 23: Lighting next to Noorderparkbad

Figure 24: Lighting from Vox college towards Vliegenbos

4.3.3. Neighbourhoods

4.3.3.1. Historical neighbourhoods (Dijk and Tuindorpen)

Figure 25: Dijk- and Tuindorpen in Amsterdam Noord that were passed during the transect walks

The three transect routes passed multiple neighbourhoods in Noord. A big part of these neighbourhoods belonged to the pre-war historical structure: the Tuindorpen, and a part of the old dike structure, the Dijkdorpen, along the Nieuwendammerdijk and Buiksloterdijk (Rijksdienst voor Cultureel Erfgoed, 2012) (see Figure 25). Due to their unique structure, the lighting attributes in these neighbourhoods are discussed separately from the modern neighbourhoods.

Along the Nieuwendammerdijk (See Figure 26 and 27) and Buiksloterdijk, the streetlighting strengthened the historical character of the Dijkdorpen, and consisted of Ritterarmaturen on old, 4-meter high classical lampposts (1883). These were arranged in a Single Side Pole layout, with an average distance of 15 meters between each lamp posts. Some lamps were retrofitted, which meant that the fixture itself was kept intact, but the interior was redesigned to fit the LED lighting system (Hoes, 2021). The dataset from the municipality of Amsterdam showed that some fixtures still had the older QL lamps in this zone (Gemeente Amsterdam, 2022). We observed that the brightness of the lights depended on the kind of lamp: LED often had higher lux levels (8-10 lux), while the QL lamps had lower ones (2-6 lux). It was judged that the overall distribution of the light was uniform, and the feeling of safety was high, probably due the historical, secure character of the streets and houses. Next to the brightness of the lights, it was clearly visible that the colour of the lights depended on the kind of lamp. The older QL lamps emitted warmer yellow light (Gemeente Amsterdam, 2012), while the LEDs emitted blue-white, or even green light. This green colour turned out to be a malfunction of LEDs; due to damage they can get this colour (Interviewee 15). Compared to the older lamps, we observed that LEDs were brighter and caused glare, and with their white blue light, they created a less comfortable atmosphere.

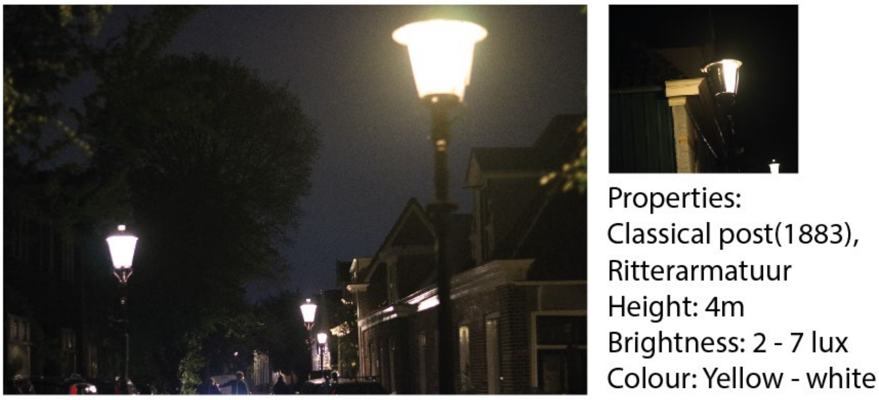


Figure 26 and 27: Lighting along the Nieuwendammerdijk

Next to the Dijkdorpen, the kind of lighting and the brightness in the Tuindorpen also varied (See figure 28 and 29). There were some Rondstralers, Holbein fixtures and some Ritterarmaturen on the route, on 4 meter high conical or classical (1883) lampposts. Most of the lamps were retrofitted with LED (confirmed by the municipal datasheet (Gemeente Amsterdam, 2022)), but not all fixtures seemed suitable for this, and reflected the light in a glary way. The lampposts were always located at one side of the road, but it was judged that the placement of the lighting was inconsistent: some streets had a lot of streetlights, others only had one (working) light. This irregular distribution of the light created dark contrasts in the landscape, which decreased our feeling of safety. The brightness of the lights lay between 5 – 8 lux , and the colour was warm white if the light came from LED lights, or yellow, if it came from QL lamps. In both the Tuindorpen as the Dijkdorpen, the route led past a couple of fixtures that were painted black, which was probably done by residents to prevent the light from shining in their windows. As the streets were so narrow in these historical neighbourhoods, the lighting was placed very close to houses and windows.

Properties:
Classical post (1883)
Ritterarmatuur
Height: 4m
Brightness: 7 lux
Colour: Yellow

Figure 28: Lighting in Silenestraat, Tuindorp Nieuwendam

Properties:
Post 1924
Holbeinfixture,
Height: 4m
Brightness: 5,25lux
Colour: Warm white

Figure 29: Lighting in the beginning of Mosveld, Bloemenbuurt

Two highlights were collected in this context; firstly the streetlighting on Mosveld, next to the Mosveldbrug on the south side of the Bloemenbuurt (Figure 30). Here, the lighting from the main road Johan van Hasseltweg was not only placed on the road itself, but also in the neighbourhood next to it, around an empty square in front of houses. These were conical posts with modern fixtures and LED bulbs, with a height of around 5 meters. 67 lux was measured, the brightest of all measurements that was carried out during the transect routes. The lighting felt uncomfortable here and glary: it was clear that this place was grim both during the day as the night, and that lighting didn’t make the place any safer or softer, even if the lighting was distributed uniformly over the landscape. The second highlight was the only architectural lighting that was noticed during the transect routes, which was located on the Buiksloterdijk (Figure 31). Here, an old dike house from Heritage Europe was illuminated with subtle up- and downlighting, that accentuated the old structure of the building. This created a beautiful atmosphere, that didn’t provoke feelings of unsafety, although the lighting wasn’t bright.

Properties:
Standard high pole,
Standard fixture
Height: 8m
Brightness: 67 lux
Colour: Warm white

Figure 30: Lighting on the end of Mosveld- Johan v Hasseltweg

Properties:
Architectural lighting,
Up-and downlighting
Brightness: 4 lux
Colour: Warm white

Figure 31: Lighting at the Buiksloterdijk

4.3.3.2. MODERN NEIGHBOURHOODS

Figure 32: Modern neighbourhoods that were passed during the transect walks

Three modern neighbourhoods were passed during the transect routes, namely IJplein, Buiksloterbreek and Buikslotermeer (see figure 32). At the beginning of the route on IJplein, the lighting consisted out of flat, targeted fixtures with LED lights on modern, 8 meter high modern lampposts (Figure 33). The posts were placed in a Both Side Opposite Pole arrangement, on a distance of 25 meter from one another. The street had white apartment blocks, which white walls reflected the light, and made the place look brighter. This contributed to a good visibility and light distribution. The lux level that was measured here was low (3 lux), but due to the reflectance on the vertical surfaces and the clear boundaries in the landscape, the environment felt safe and comfortable. Multiple interviewees confirmed that illuminating the vertical surface and creating clear boundaries in the landscape can increase the perception of safety (Interview 2, 3, 5, 8, 10, 12, 13), and this was also confirmed by literature (Schielke, 2013; ERCO, 2022). In Buikslotermeer, in the Plan van Gool area, all the apartment blocks in the streets Het Breed and Het Laagt had an open hall on the ground floor (see figure 34). These illuminated halls reflected light into the street, which created good visibility and clear boundaries in the landscape, which improved the feeling of safety. It could not be confirmed if this lighting came from LEDs. The brightness, measured in one of the halls, was 40 lux. The same effect with reflectance of surfaces was applied in the street in Buikslotermeer. Here, the lighting in the hall on the first floor illuminated the street. Except for one light pole, there wasn't any other streetlighting in this street, as all the light came from this hall. The distribution of the light was comfortable and the visibility was high. 8 lux was measured when standing far away from the lighting, so the brightness of the lighting in the hall itself was a lot higher. After correspondence with the lighting engineer of Amsterdam Noord, this person shared two of his Dialux simulations of the lighting in the Station area of Buikslotermeer, to show how the lighting plan for a modern area was built up. These can be found in Appendix I.

Properties:
Standard high pole,
Standard fixture
Height: 8m
Brightness: 3,2 lux
Colour: Warm white

Figure 33: Lighting in IJplein

Properties:
Hall lighting
Brightness: 8,1 lux
Colour: Warm white

Figure 34: Lighting in Buikslotermeerplein

Two highlights in this context were found in the South of Buikslotermeer, on a construction terrain in Het Breed, and in Het Hoogt, with an example of light nuisance. On the construction terrain in Het Breed (Figure 35) green light was emitted high spotlight of around 4 meters in height, probably LED, that illuminated the whole terrain. This light felt uncomfortable, almost alienlike, it didn't fit in the surroundings, and felt brighter than it actually was when measuring it (5 lux). Green lighting is used on construction terrains to provide temporary security, preventing crime (Bouwatch, 2021). The other highlight was the light nuisance that was created by a 4 meter high Rondstraler in het Hoogt (Figure 36), that emitted light with a brightness of 6 lux. The street light was practically placed against the window of the apartment block.

Properties:
Construction lamp
Height: 4m
Brightness: 5 lux
Colour: Green

Figure 35: Lighting in Het Breed

Properties:
Conical post
Rondstraler
Height: 4m
Brightness: 6 lux
Colour: Warm White

Figure 36: Lighting in het Hoogt

4.3.4. Functional area

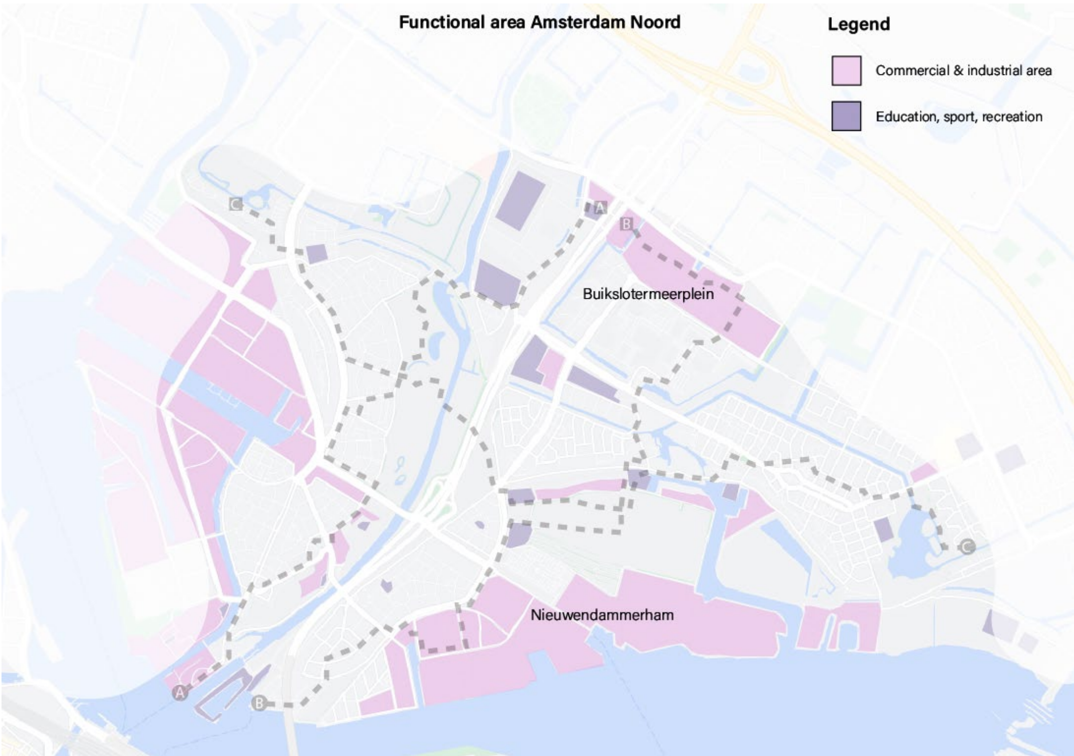


Figure 37: Functional area in Amsterdam Noord

The functional area (Figure 37) that was crossed during the transect routes included the industrial/commercial areas in Nieuwendammerham and Buikslotermeerplein. The lighting that came from a school, the Vox college next to the Vliegenbos, was already discussed in paragraph 4.3.2.

The commercial/industrial area in Nieuwendammerham and the shopping district Boven 't IJ in Buikslotermeerplein were both illuminated after closing time. In Nieuwendammerham (Figure 38), the large, empty parking terrain in front of the Jumbo Foodmarkt was lit up by a high modern spotlight of around 9 meters high with yellow light, which was probably LED, but this wasn't confirmed. The measured brightness was 20 lux. The place felt abandoned and uncomfortable to be in. Also, the Jumbo letters produced a white glary light. The lights in the building were still on, which was also the case in other company buildings in this area.

The roofed shopping street Boven 'IJ had spotlights integrated in the roofs which lit up the empty street with a brightness of 20 lux (Figure 39). It could not be confirmed if these were LED lights. The light reflected on the white walls and there was good visibility. It didn't feel unsafe, but empty and abandoned, which wasn't comfortable.

Properties:
Modern post,
LED spotlights
Brightness: 20lux
Height: 9 m
Colour: Yellow

Figure 38: Jumbo foodmarkt Nieuwendammerham

Properties:
Spotlights
Height: 4m
Brightness: 20,5 lux
Colour: Warm white

Figure 39: Boven 't IJ shopping district

The transect routes also passed a couple of sports fields, which were all closed, so their lighting was off. During the interviews came forward that the impact of sports field lighting on light pollution could be significant: "sport illumination is a very specific area of urban lighting, sport architecture is enormously significant. So if you don't manage that well, then the neighbourhood will be too bright, the sky will glow!" (Interviewee 1). As sports field lighting lay outside the scope of this research, this wasn't further investigated, but it would be a valuable topic for future research.

4.3.5. ROAD STRUCTURE

Figure 40: The different roads that were crossed during the transect walks

The characteristics of the lighting on the connecting roads to the ferry (figure 40), the local roads, in tunnels and on the bridge that were passed during the transect routes, are described here.

4.3.5.1. ROAD TO THE FERRY TERMINAL

The Buiksloterweg and the south side of the Meeuwenlaan both provided a connection to the ferry terminals, and weren't very busy during the night when we passed. The lampposts on these roads had small ornaments, and were called Apollomasts. They were 8 meters high, with Bolarmaturen. The data sheet from the municipality couldn't confirm if these had LED bulbs. Some posts had two fixtures, one halfway on the pole and one on top, which illuminated the road and the cycle path. Others had just one fixture that illuminated the road. The light poles were placed in a staggered pole arrangement (Appendix G), and the distance between the poles was around 20 meters. The brightness and the number of fixtures per light pole varied; the roads closer to the ferry terminal (Figure 41) were illuminated with a brightness of 25 lux and the streetlighting had two luminaires per pole. This was the case on the south part of both the Buiksloterweg as the Meeuwenlaan. On the northern part of the Buiksloterweg, further away from the ferry terminal (Figure 42), the brightness decreased to 2,5 lux and the lighting only had one luminaire per pole. During the transect route, the transition from the brighter to the darker part of the Buiksloterweg was notable, our eyes needed to adapt. The lighting in the darker part only illuminated the main road, and the foot and cycle path stayed in the dark. When our eyes were adapted to the lower light level, there was enough visibility, but it felt less comfortable to walk on the darker side of the road.

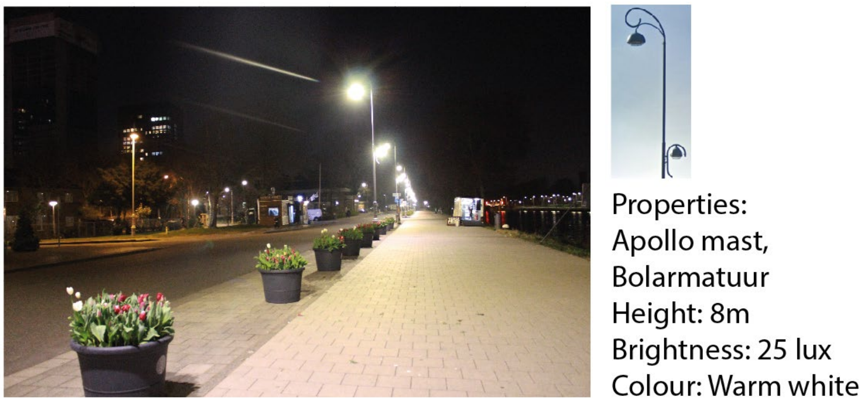


Figure 41: Start Buiksloterweg (south side)

Figure 42: Continuing Buiksloterweg (northwards)

4.3.5.2. Local roads

On the Kamperfoelieweg, Elzenhagensingel and the northern part of the Meeuwenlaan (Figure 43), four rows of lighting could be distinguished. Two rows of 4 meter high Rondstraler with LEDs were placed on the two outer lanes designated for slower traffic, on a distance of 15 meters from one another, on one or both sides of the street. The middle two lanes either had 8 meter Apollomasts with Bolarmaturen and LED fixtures or HPS lamps, placed in a Both side staggered pole arrangement (on the north side of the Meeuwenlaan), or 8 meter high standard poles with standard fixtures with targeted LEDs, in a Both side opposite pole arrangement(on the Kamperfoelieweg and Elzenhagensingel) (Figure 44). The distance between these taller light poles was 25 meters. The brightness at the Rondstralers was around 5 lux, the brightness at the taller standard lights was between 15-25 lux. The distribution of the light was uniform, but the different rows of lighting made the street look chaotic and decreased the clarity of the road.

Properties:
Conic pole and
Standard high pole,
Rondstralers and
Bolarmaturen
Height: 4-8m
Brightness: 5,5 lux
Colour: Warm white

Figure 43: Meeuwenlaan lighting

Properties:
Conic pole and
Standard high pole,
Rondstralers and
modern fixtures
Height: 4 - 8m
Brightness: 10 lux
Colour: Warm white

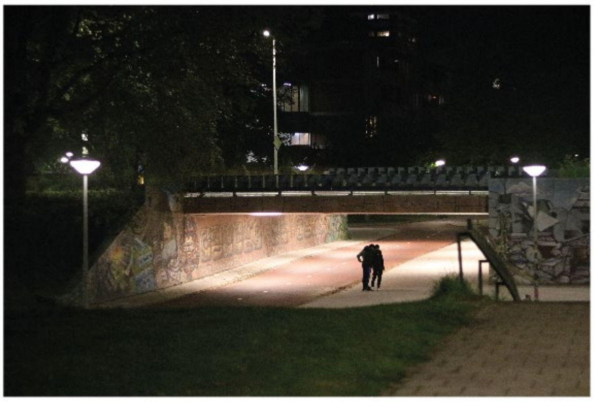
Figure 44: Kamperfoelieweg lighting

4.3.5.3. Tunnels

The two tunnels that were passed during the transect routes were found underneath the Johan van Hasseltweg, on the Adelaarsweg (Figure 45), and underneath the Nieuwe Purmerweg, between the Rode Kruisstraat and het Hoogt (Figure 46). The lighting was incorporated in the wall, with vandal-proof fixtures. The datasheet from the municipality indicated that these fixtures weren't replaced by LED, but still had TL tubes (Gemeente Amsterdam, 2022). The area felt abandoned, but the artwork in and around the tunnel was beautiful and was judged to make the environment more comfortable to be in. The brightness of the light was around 30 lux, but it felt brighter due to the reflectance of the white surfaces. When moving out of the tunnel, the contrasts were high, and our eyes needed to adapt.

Properties:
Tunnel lighting,
fixtures in the wall
Brightness: 26,5 lux
Colour: Warm white

Figure 45: Lighting in tunnel under the Johan van Hasseltweg (on Adelaarsweg)

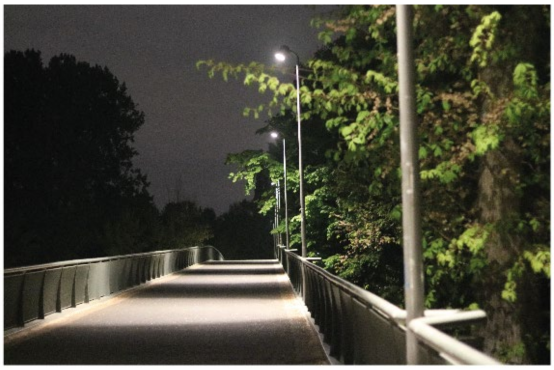


Properties:
Tunnel lighting,
fixtures in wall
Brightness: 33 lux
Colour: Warm white

Figure 46: Lighting in tunnel under the Nieuwe Purmerweg (on Rode Kruisstraat)

4.3.5.4. Bridge

The only bridge that was crossed during the transects was the Noorderparkbrug over the Noordhollandsch kanaal (Figure 47). Around 6 meter high poles, from an unknown type, were situated on one side of the bridge deck on a distance of 20 meters from one another. These illuminated the bridge deck with modern targeted LED spotlights. Hard contrasts in the landscape were visible, caused by the lighting that was strongly targeted towards small strokes of the bridge, leaving the other parts, the “stripes”, completely dark. One could read a book in this light. In the dark stripes, the lux value was lower than 0,5 lux, while in the brighter parts it was more than 40 lux; the light distribution was bad. The place felt distant, uncomfortable, and it was judged that the lighting wasn’t meant for this road, which could only be crossed by small traffic.



Properties:
Unknown pole type,
Targeted LED spotlight
Height: 6m
Brightness: 40,5 lux
Colour: Warm white

Figure 47: Lighting on the Noorderparkbrug

One highlight in this context was the lighting at the start of the Meeuwenlaan, close to the ferry terminal (Figure 48). Here, the lighting was incorporated in the backrest of the benches, and illuminated the street. Due to the low brightness of the lights, 2,4 lux, we only observed soft contrasts in the landscape. This gave the location, with a beautiful view over the IJ, an atmosphere that was cosy and well cared for. The high spotlight that stood next to the bench only had one working light, which didn't disturb this artistic lighting.

The other highlight in this context was the colour of the streetlighting on the Kamperfoelieweg (Figure 49). Three different colours of light could be distinguished on this part of the road, namely yellow-orange, blue-white, and warm-white which was the common colour of LED on this road. The yellow-orange light came from an old high pressure sodium lamp, that wasn't replaced by LED yet, and the blue-white came from LED lights (Interview 15). There were two other locations during the transect routes that also had one orange-yellow light, while the rest was warm-white. This was probably another high pressure sodium lamp that wasn't replaced by LED yet.


Properties:
Light from benches
and from spotlight
Brightness: 2,4 lux
Colour: Warm white

Figure 48: Bench lighting at the start of Meeuwenlaan

Properties:
Standard high pole
Kofferarmatuur
Height: 8m
Brightness: NA
Colour: Varying

Figure 49: Different colours of the lighting on the Kamperfoelieweg

4.3.6. Wrap up of the observations

To summarize, the kind of luminaires, lampposts and their arrangement differed per zone. Some fixtures had LED bulbs and some didn't, and this was visible when the brightness and colour of LEDs differed from older light bulbs. We felt less safe and comfortable in areas where the distribution of the light was not uniform, or where hard contrasts between the dark and the illuminated space were visible. We felt more comfortable in spaces with clear boundaries in the landscape, and where the lighting was applied in the vertical plane, with reflection on walls. Furthermore, on some locations, light nuisance, in the form of light trespass and glare could be recognized, which are components of light pollution that should be prevented. These components will be used to formulate a Design for Darkness strategy for Noord, which is discussed in chapter 5.

The results, collected during the transect routes, were summarized and processed into table 3.

		Neighbourhoods				Road structure			
	Hoofd-groenstructuur	Historical		Modern	Functional area	Road to ferry	Local roads	Tunnels	Bridge
		Dijkdorpen	Dijkdorpen						
Lighting layout									
Kind of luminaires	Rondstralers	Ritter	Rondstralers, Holbein, Ritter	Standard fixtures/hall lighting	Spotlights	Bolarmaturen	Rondstralers + Bolarmaturen/ standard fixtures	Vandal proof fixtures	Spotlights
Kind of lampposts	4 meter high conical	4 meter high classical (1867)	4 meter high conical/classical (1883)	8 meter high standard	hanging lamp/ 9 meter high pole	8 meter high Apollomast	4 m high conical, 8 m high Apollo-mast/standard	Incorporated in tunnel wall	6 meter high unkown type
Kind of lamps	LED	LED retrofit or QL	LED retrofit or QL	LED?	LED?	LED?	LED or HPS	LED	LED
Arrangement (distance betw. poles)	20 m-25 m	15 m	Inconsistent	25 m	NA	20 m	15 m, 25 m	NA	20 m
Arrangement (pole layout)	Single side	Single side	Single side	Both Side opposite	NA	Both side staggered	Both side staggered/ Both side opposite	NA	Single side
Lighting quality									
Lighting level	3- 5 lux	2 - 10 lux	5 - 8 lux	3 - 8 lux (40 lux in hall)	20 lux	2,5 - 25 lux	5 lux, 15 - 25 lux	26 - 33 lux	0,5 - 40 lux
Spatial distribution of the light	Good	Good	Bad	Good	Good	Bad on quieter part of the road	Good	Good	Bad
Colour of the light	Warm white	Warm white/ green/orange	Warm white/ yellow	Warm white	Warm white/ yellow	Warm white	Warm white	Warm white	Warm white
Personal observation									
Feeling/ atmosphere	Safe on lighted paths	Safe and comfortable	Sometimes unsafe	Safe and comfortable	Uncomfortable in abandoned area	Unsafe in quieter part	Confusing	Safe and comfortable	Distant, uncomfortable
Issues per zone	Light trespass to green areas	Glare and light trespass in narrow streets	Inconsistent lighting arrange-ment, glare, light trespass	Lighting in halls is too bright, light trespass	Lighting is too bright and still on when place is abandoned	Uncomfortable transition between light and dark	Too many rows of streetlights, decreased clarity of the road	Lights in tunnel are too bright, transition light - dark too high	Lights are too bright, light distribution is bad: contrasts

Table 3: Summarized results of the elements of the current public lighting in the different zones in Amsterdam Noord

4.4. Focus of the current lighting plans deducted from interviews

From the interviews with lighting designers, lighting engineers and with the municipality of Amsterdam, different themes could be deducted regarding the focus of the current lighting plans. First, in the context of public lighting in Amsterdam, the LED transition is discussed, and the up and downsides that the LED technology can have. Secondly, the focus of the current public lighting plans, deducted from the interviews with lighting engineers, is discussed. Lastly, the focus of the plans for city illumination, deducted from the interviews with lighting designers, is illustrated.

4.4.1. Public lighting; the LED transition

In 2015, the municipality of Amsterdam started transitioning all its public lighting to LED, the so-called "verledding". In 2035 at the latest, it has planned to complete the transition (Gemeente Amsterdam, 2017). The Amsterdam Lighting Policy Framework (2017) indicates that LED light currently is the most energy-friendly lighting solution and saves a lot of money compared to the old incandescent light bulbs. In phases, all the lighting in the city will be replaced by LED, with the aim to reduce the CO_2 emission by 45% percent in 2025 (Gemeente Amsterdam, 2017).

Not all interviewees agreed with the current way of “verledding”. As interviewee 8 puts it: “… anyone with any level of education should know that you should never put a technology in the lead to say: we are going to become more sustainable. The most economical lamp is a lamp that is off or that is not there.” Moreover, it is becoming more and more clear that poorly designed LED lighting with blue-rich colour temperatures contribute to more light pollution and to rebound effects (Schulte-Römer et al., 2018). Quoting Ruskin Hartley, Executive Director of the International Dark-Sky Association: "Over the past 25 years, the transition to solid-state LED lighting has been accompanied by rapid increases in light pollution globally”(University of Exeter, 2021). Multiple interviewees (8, 10, 13) confirm that the LED transition has its downside and can do more harm than good: “LED is not Valhalla, it is way too high in the Kelvins. Blue light is bad for stargazing, and bad for animal species. If they apply the right lighting colour it's fantastic, and if they dim. If they don't, LEDs will give you more trouble than pleasure, in spite of their energy efficiency” (Interviewee 10).

Despite the drawbacks of the LED technology, LED systems also offer possibilities to design lighting in a more sustainable way (Schulte-Römer et al., 2019). Interviewee 13 and 17 note that the controllability of LEDs is a benefit, compared to older lighting solutions. Smart LED systems can offer lighting on demand, which give people full control over the brightness and colour of the lights. Smart LEDs with dynamic dimming regimes are able to adjust their colour and brightness, based on the amount of human activity in an area. The lighting can be dimmed or switched off when there is no human activity detected (Interviewee 16), and the lighting can have a warmer colour temperature, below 3000K. Multiple interviews also recommend adding a dimming regime to a lighting plan (interview 1, 3, 4, 10, 13, 16 and 17), as with this solutions, the effects of light pollution can be minimized(Montjoy, 2022).

Although the municipality of Amsterdam indicates that they are aware of the benefits of smart lighting, this technology is not yet applied on a large scale, due to budgetary reasons: the total costs of ownership are higher for dimmable or dynamic LED applications than for the standard LEDs (Gemeente Amsterdam, 2017). Consequently, the municipality of Amsterdam currently only invests in standard LED lighting which has one fixed brightness and colour, which lies between 2700-3000K (Gemeente Amsterdam, 2017). The asset manager public lighting of the Gemeente Amsterdam explains the decision for the standard LED systems as follows: “dynamic lighting is more expensive, because you can't remove the extra modules from your energy bill, so it's not a profitable investment. And two, it's less durable, because you need more material, which often breaks and where people need to go to to repair it. The only advantage is that you create extra darkness, which is good for people and animals and plants” (Interviewee 15).

To conclude, the municipality of Amsterdam is currently replacing all its fixtures with LEDs, as it is the most energy friendly and money-saving solution. The use of LEDs can increase or decrease light pollution, depending on how the technology is applied in the public space: literature and interviews suggest that LEDs that can be dimmed and that have a warm colour temperature below 3000K have the potential to reduce light pollution, while blue-rich LEDs with a bad design can increase light pollution. Although smart LEDs, with adjustable brightness and colour temperature, have the potential to reduce light pollution, this technology is not applied in Amsterdam, as the municipality’s budget isn’t large enough to invest in smart LED systems. The public lighting in Amsterdam still mainly consists of standard LEDs that cannot be dimmed and that have a standard colour temperature that cannot be changed.

4.4.2. PUBLIC LIGHTING; GUIDELINES, SAFETY AND LIGHT NUISANCE

The guidelines and approach that the municipality of Amsterdam uses for its public lighting, are clarified in the Policy framework Public lighting of Amsterdam (Gemeente Amsterdam, 2017). Public lighting in the city is shaped by guidelines that focus on providing safety: road safety or social safety Public lighting plans are solely based on quantitative lighting design, as outlined in chapter 2.1.4. The road authority should design the roads to be safe, but it is not legally established that the road or public space should be illuminated, and there are no laws specifying the requirements for public lighting (Gemeente Amsterdam, 2017). However, there is a national Guideline Public Lighting, the R-OVL 2011, or the newer version, the NPR 13201-2017, which is created to guarantee road safety. This guideline advises the lighting engineers, who design the street lighting for municipalities, on the illuminance and uniformity of the street lighting that should be applied on the road. The guideline is based on the visual needs and the speed of road users, and the focus is mainly on light in the horizontal surface (Gemeente Amsterdam, 2017). The R-OVL/NPR only recommends minimum values for the brightness of street lights, and no maximum value. There are no limits to the brightness, and the minimum levels can be exceeded. “the easiest thing the municipality can do when there is a demand for more safety is simply by applying more light”(Interview 4).

Next to the R-OVL, the municipality of Amsterdam uses the Politiekeurmerk Veilig Wonen (Police Security certification) (Politiekeurmerk, 2022) to safeguard social safety, and the Puccini method to standardise the design and arrangement of the public space, where public lighting is a part of (Gemeente Amsterdam, 2021) (See Appendix F). The Police security certification is given to locks, smoke detectors and fixtures to guarantee safety and prevent crime. The certification is applied for existing houses, and during the spatial design of new neighbourhoods. (Politiekeurmerk, 2022). People who install the certified lighting around their house don’t always know what the impact of these floodlights is on their environment, quoting Interviewee 12: “They (the certified floodlights) are blinding to scare people off, but people are not aware of this. Residents who put up those floodlights blind everyone who walks by. You're trying to teach people how that works so that they have it pointed downwards.”

Although the Police Security Certification advises the use of light to prevent crime, not all lighting designers agree with this. As Interviewee 5 states: “It is often said that when its dark, then crime happens. I am not sure that is the case, because criminals also need light to commit their crimes.” Interviewee 16 adds: “It's no use having an illuminated route through no man's land. If something happens and someone calls for help, no one is there to hear it. So in that sense I say: only illuminate routes that are also safe in terms of social safety, and sometimes deliberately leave routes dark, so that people choose a safer route, if there is one.”

Next to guidelines that advise engineers about safety, there also is a Directive for light nuisance, which advises lighting engineers and designers on the responsible usage of outdoor lighting, and aims to limit the negative effects of artificial lighting on the environment as much as possible (NSVV, 2020). Mizon (2012) describes the effects of light nuisance as follows: “Unnecessary horizontal and vertical street lighting permeates living spaces, particularly bedrooms. This light intrusion, even if dim, is likely to have measurable effects on sleep disruption and melatonin suppression. Even if these effects are relatively small from night to night, continuous chronic circadian, sleep and hormonal disruption may have longer-term health risks” (p.80). To prevent these harmful effects, the guideline for light nuisance does give maximum values for the brightness of the lighting, and also recommends to dim the lighting between 23.00 – 07.00h. The focus in this directive is not only on public lighting, which is the case for the R-OVL/NPR, but the directive also pays attention to private lighting coming from sports fields, companies and billboards, and how to manage that in such a way, that it doesn't disturb residents or nature (Interview 6). According to interviewee 6, this guideline isn't widely known under lighting designers, and still needs to gain popularity. This was also noticed during the interviews with lighting engineers and designers; the light nuisance guideline was hardly ever mentioned. Most of the interviewees did however indicate that they applied shielding to reduce light trespass and light spill, or that they used targeted fixtures to prevent the light from shining into the sky. The Policy Framework public lighting of Amsterdam also names the issue of light nuisance, and indicates that it aims to minimise this in their approach (Gemeente Amsterdam, 2017).

4.4.3. City illumination; a different focus

Practice experience in Amsterdam and other cities has taught that city illumination can also increase people's feeling of safety in the public space: "road safety and social safety are not only improved by standard light poles and hanging fixtures. Also a careful combination of street lighting, decorative lighting and city illumination can contribute to this" (Gemeente Amsterdam, 2017, p. 13). This was confirmed by an interviewed lighting designer: "We designed lighting for a street with a lot of crime, but this was not due to the lighting, but to people's distance to that street. High light levels actually backfired. In the end we highlighted two beautiful buildings, and the quality of the space improved: people became proud of their street" (Interviewee 12).

The municipality of Amsterdam has set up a couple of quality criteria for city illumination. The lighting designers who design this kind of illumination, are advised to complement the aesthetical value of the public space with the lighting, while using as little light as possible to prevent light pollution (Gemeente Amsterdam, 2017). The interviewed lighting designers indicate that aesthetical and emotional values play a major role in their design, in which light is the design tool, but not the goal (Interview 13). Their goal is to create an evening experience with lighting (Interview 4, 13), that gives the space its identity, and that supports people's wayfinding through an area(Interview 3, 5, 8). As interviewee 8 puts it: "It is not scientific stuff that you can measure, but it's about the psychological experience of the lighting." We can recognize a perception-based, qualitative lighting design approach in the aforementioned statements by lighting designers. This approach is described in chapter 2.1.5.

While the guidelines for public lighting mainly focus on lighting in the horizontal plane, the interviewees with a qualitative lighting design approach emphasize that light in the vertical plane is essential for our visual perception and feeling of safety(Interview 1, 3, 5, 8, 10, 12, 13). Also literature suggests that 80% of our visual perception is formed by vertical surfaces (ERCO, 2022), which is supported by a quote from Interviewee 12: "You can measure the horizontal illuminance in an area, and get the right values, but if all your vertical surfaces or objects are darker, you have the feeling that you are in a dark environment, even if you are in the light. Whereas, if you light up trees or buildings around you, and leave everything dark in the middle, your perception or sense of lightness is much higher, because vertical planes are much more dominant in your perception". Schielke (2013) also states that illuminating a vertical surface, for example with the concept of wallwashing, contributes to impressions of brightness. "Nevertheless, the illumination of vertical areas frequently plays a minor role in lighting design, in spite of the number of publications available on the topic"

(Schielke, 2013, p. 223). In the recent guideline for public lighting, the NPR, attention is paid to lighting in the vertical surface, but only its effect on facial recognition is mentioned(NSVV, 2017).

Although these results suggest that a qualitative lighting design approach can help illuminating the public space with techniques that strengthen the identity of a space, and improve people's feeling of safety and sense of lightness, this approach is not yet used in public lighting plans, and only quantitative lighting designs are considered. Lighting designers who design city illumination with a qualitative approach, and lighting engineers who design public lighting with a quantitative approach now fulfil two separate disciplines with different starting points and values, but as interviewee 13 puts it: "I actually think that they should go together, that you should make it in one design".

To conclude, the interviewed lighting engineers mainly focus on functional and technical values, and follow the guidelines to provide social and traffic safety. The public lighting plans revolve around the same guidelines, and focus on the transition towards to more energy efficient LEDs. The interviewed lighting designers focus on creating an evening experience that supports wayfinding and placemaking, while also taking into account the vertical planes. Lighting engineers and lighting designers now fulfil two different tasks.

4.5. CHAPTER WRAP UP

This chapter first outlined the stakeholders in Amsterdam Noord, and how they interacted with public lighting: The department public lighting in the municipality is responsible for the lighting in Noord, and manages lighting engineers and lighting architects, who design street lighting and city illumination. The Materiaalbureau Amsterdam purchases the lighting equipment for the city. Both the inhabitants and the police are in favour of more lighting and complain when it is too dark. But in Noord, civil society and residents indicate that they are in favour of more darkness.

Then, the current state of light pollution was analysed, by zooming in on Amsterdam Noord. Due to gentrification, this district has seen an increase in illumination in the last couple of decades, and will probably become brighter, as 50.000 new dwellings will be constructed here in the coming years, at the expense of nature and natural darkness.

Thirdly, the observations that were done during three transect routes through Amsterdam Noord were illustrated, and the different elements of the lighting were listed in a table. Results indicate that a lower perception of safety was experienced in areas where the distribution of the light was not uniform, or where hard contrasts between the dark and the illuminated space were visible. Areas that were perceived safe and comfortable had clear boundaries in the landscape, and had vertical illumination, with reflection on walls. On some locations, light nuisance, in the form of light trespass and glare could be recognized.

Lastly, the different focus points of the current lighting plans, which were deducted from the interviews with lighting designers and engineers, were highlighted. The current lighting plans mainly focused on continuing with the LED transition, and on following the guidelines for road and social safety, but less attention was paid to preventing light nuisance. Furthermore, while results indicate that a qualitative lighting design approach has the potential to be applied in the public space, this is currently not the case, and only plans based on a quantitative approach are applied.

5. Discussion

The major findings that are extracted from the results section are described in the following paragraph. Then, these findings are interpreted and discussed with the help of the conceptual framework, and additional concepts are added to make the framework more complete. The findings from this research are translated into a Design for Darkness strategy, and per zone, a short term strategy to reduce light pollution is developed. Also, a list of policy measures, based on the Design for Darkness strategy, is drawn up for the municipality of Amsterdam.

5.1 Explanation of the results

This thesis deals with the increasing problem of light pollution in cities, which is caused by the inappropriate and excessive use of outdoor lighting, and has multiple negative side effects on the earth and all its living beings, including humans (IDA, 2013). The aim of this thesis is to develop a Design for Darkness strategy to reduce light pollution caused by public lighting in the context of Amsterdam Noord, and to answer the research question:

What public lighting plans are currently used to illuminate Amsterdam-Noord, and which elements can be applied to a Design for Darkness strategy to reduce light pollution in the short term?

In the result section, the following sub-research questions were discussed:

- What is the historical context of public lighting?
- Why is public lighting necessary and what do we use it for?
- What are the causes and effects of light pollution?
- Who are the stakeholders in Amsterdam Noord and how do they interact with public lighting?
- What is the current state of light pollution in Amsterdam Noord?
- What is the current situation of public lighting in Amsterdam Noord?
- What is the focus of the current public lighting plans in Amsterdam Noord?
- Why do the public lighting plans currently have this focus?

The key findings from the result section are highlighted in the following two paragraphs:

Currently, many cities, including Amsterdam, are transitioning their public lighting to LED, as it is the most cost and energy efficient solution. Public lighting is applied to guarantee the safety and visibility for road users, and it is also used to provide social safety on the street. Multiple residents and the police in Amsterdam are in favour of more lighting, and complain to the municipality when a street is too dark, as they think the environment will become safer when more lighting is applied. However, it has never been demonstrated that more light equals more safety (Bogard, 2013), and interviews suggest that it is not the brightness, but the quality of a space that increases safety. Although the municipality is be aware of this, it applies more lighting to the streets when residents complain. In contrast, a recent study in Amsterdam Noord suggests that residents in Noord would be open to a reduction in the brightness of the lighting. Also, people in the civil society in Amsterdam Noord who signed the Manifest of nature park Noord, are in favour of more darkness, and strive for less light pollution and nature preservation in Noord. It was an unexpected finding that both multiple residents as the civil society in Noord indicated that they would be open to experiment with a darker living environment. This is a significant outcome for this thesis, as it offers a promising opportunity for Noord to decrease the amount of light in the area and possibly reduce light pollution.

Amsterdam Noord has seen an increase in illumination in the past decades due to gentrification, and the district will probably become even brighter, as according to interviews, 50.000 new dwellings will be constructed. Walking the transect routes in Noord, the public lighting that is observed sometimes causes glare or light trespass, which are two elements of direct light nuisance, a component of light pollution. Also, too bright lighting and hard contrasts between dark and light are observed. Although in the Policy framework public lighting (2017), the municipality formulates the goal to prevent light nuisance in the coming years, the observations show that this goal has not yet been achieved. In places where the distribution of the lighting isn't uniform, and hard contrasts between dark and illuminated spaces are visible, a lower perception of safety is experienced. Places with vertical illumination, where light reflects on walls and clear boundaries in the landscape are visible, are perceived as more comfortable and safe. Literature (ERCO, 2022; Schielke, 2013) and interviews (Interview 1, 3, 5, 8, 10, 12, 13) confirm that vertical illumination, and other elements of a qualitative, perception-oriented lighting approach are beneficial for people's visual perception and feeling of safety in an area. While a qualitative lighting approach for public lighting can be a way to introduce more darkness into the public space, the current public lighting plans, shaped by the guidelines for public lighting, only focus on horizontal illumination, increasing brightness, and other aspects of a quantitative lighting approach (NSVV, 2017). Moreover, due to budgetary reasons, the municipality of Amsterdam currently only invests in standard LED solutions with one fixed brightness and colour (Interview 15), although literature and interviews (interview 1, 3, 4, 10, 13, 16 and 17) suggest that dimmable LEDs with adjustable colour are favourable for the reduction of light pollution (Schulte-Römer et al., 2019; Montjoy, 2022). To prevent light pollution, the interviewed lighting designers and engineers indicate that they use targeted or shielded fixtures to prevent light spill and trespass. However, a couple of interviewees mention that there are no regulations for private lighting (Interview 2, 12, 16), and as a consequence, the private sector causes light pollution with commercial lighting and lighting inside buildings, which was also observed during the transect routes.

First, these key findings will be interpreted with the conceptual framework in the following paragraph, and translated into a Design for Darkness strategy. Then, the three last sub-research questions can be answered:

- What elements in the lighting plans can be used in or changed into a Design for Darkness strategy to reduce light pollution in the short term?
- How can the Design for Darkness strategy be applied in the context of Amsterdam Noord?
- What Design for Darkness policy measures can be developed for Amsterdam Noord?

5.2. Interpretation of the findings with the conceptual framework

The following paragraphs include an interpretation of these findings in the context of the conceptual framework, with concepts including the Direct Rebound Effect, Dynamics of Demand, the Shifting Baseline Syndrome, and the Values of Darkness.

5.2.1. The Direct Rebound effect

In the context of the lighting in Amsterdam Noord, the Direct Rebound effect can be recognized. The district has seen an increase in illumination in the last decades (Interview 18). This can be linked to the gentrification in the area, and the introduction of LED lighting, which was cheaper and saved more energy compared to previous light sources. LEDs were therefore excessively used, which caused light pollution to increase (University of Exeter, 2021). Although LEDs would be the most energy saving option, it is, however, not clear how much energy the municipality of Amsterdam is currently saving with the implementation of LED, as data about this topic haven't been published (yet). Older numbers from 2018 show that Amsterdam saved 0% energy compared to the year 2013 (Regionale Klimaatmonitor, 2018). The goal of the municipality is to reduce its CO2 emission between 2012 and 2025 with 45% by means of the LED transition (Gemeente Amsterdam, 2017). How far they are with this goal, and if they will reach it, remains unclear.

5.2.2. Dynamics of demand

The asset manager public lighting of the municipality of Amsterdam points out that he only receives complaints from people who want more light in their environment, because they feel unsafe in the dark. When the municipality planned on dimming the Vondelpark, the police protested, as their task to safeguard the streets would be hindered. With their Politiekeurmerk the police also recommends people to use lighting to prevent crime. This shows that people in Amsterdam need lighting to feel safe, and it demonstrates that people have become dependent on lighting at night. The growing demand for lighting can be explained by the Dynamics of demand, which also explains why "any attempts to reduce light pollution run up against positive connotations of lighting, which are deeply ingrained in modern societies." (Hölker et al (2010), p. 5). However, the Manifest, signed by civil society in Noord, and the interviews with residents in Noord, conducted by the UvA students (Cramer, Lücker, Osinga, Stojanovic, 2022), suggest that people in Noord are less dependent on lighting, and would be open to experiment with less lighting. This suggests that that the Dynamics of demand concept would be less applicable to all the people in Noord. As the UvA students only interviewed a selection of residents in Noord, other residents might have a different opinion about lighting, and the Dynamic of Demand concept would be applicable in their case.

5.2.3. Shifting baseline syndrome

The Shifting baseline syndrome can lead to perceptions of darkness as being unsafe. The syndrome can be recognized in the way residents in Amsterdam and the police think about light. It may seem common knowledge that lighting improves safety and reduces crime, and that the more light people add, the safer their environment becomes. This is, however, not based on any scientific evidence, and there is no direct correlation between increased street lighting and reduced crime. Bogard (2013) even states that more light may increase the number of crimes.

What could play a role here, is that people's perception of safety sometimes differs from their actual safety. Our evolutionary response to darkness as being unsafe (Tarantola, 2013) could be an example of this. Even when a dark environment is safe, we can be afraid of the dark. The opposite is also true: bright lights can also create a false sense of safety (Bogard, 2020).

During the transect routes, it was mentioned that the brightness of lighting did not always improve our feeling of safety, but that the quality and identity of a space, the uniformity of the lighting, the vertical illumination and boundaries in the landscape did contribute to this. This was also confirmed by literature and interviews. These insights should be taken into account when developing a Design for Darkness strategy. But also people's actual safety should play a role in this strategy. As interviewee 16 indicates in chapter 4.4.2., we should only illuminate routes through inhabited areas where social safety can be guaranteed. This is a valuable insight that can be used in the development of the Design for Darkness strategy, later in this chapter.

Returning to the shifting baseline syndrome, the theory suggests that its effects may be reversed if people are aware of the effects of light pollution on their environment, and want to re-introduce darker nights. The results indicate that this is the case in Noord, and that the people and civil society in Noord are generally more open to a darker environment. What can also play a role, is that Amsterdam Noord has long been a dark area, and illumination has only started to increase in the last couple of decades (Interview 18). This would also indicate that generational amnesia, part of the theory of SBS, is not fully applicable to the residents in Noord, as residents can remember what a darker Noord looked like in the past.

5.2.4. Values of darkness

When the nine environmental values of darkness, and their prima facie obligations (see Table 1 in chapter 2.2.4.), are compared to the current public lighting plans in Amsterdam Noord, it is clear that most of the obligations are not met, except for efficiency and maybe sustainability. We can recognize a moral overload, which means that only a few values of darkness are satisfied, which can have a negative effect on the other seven values. The current LED applications in Amsterdam Noord only have one default setting, and cannot change in brightness or colour. With a value-sensitive approach, which focuses on the controllability and efficiency of LEDs, Amsterdam could provide a more holistic solution to the problem of light pollution (Stone, 2019).

5.3. Proposed additions to the conceptual framework

During this research, new insights from literature and interviews came to the fore that needed support from new concepts. Therefore, the conceptual framework, as described in the previous paragraphs, turns out to be incomplete. Two new theories will be presented, the LED paradox and the theory of Invisible infrastructures, and an explanation is given why these are relevant in the context of this thesis.

5.3.1 The LED paradox

The LED paradox is added to this conceptual framework. The paradox critically looks at the current lighting practices and principles, and reframes what we should understand as the sustainable revolution of LED lighting: "Paradoxes draw attention to incomprehensive or limited assumptions about actual contexts and empirical evidence that questions established lighting practices and principles." (Schulte-Römer et al., 2019, p.11). The fact that LEDs can both increase as reduce light pollution is the paradox here. That the lighting plans in this thesis didn't focus on reducing light pollution, but on guidelines and safety, can be explained by this paradox. It can also be used to interpret the results from the observations during the transect routes. The LED paradox challenges two issues which are both relevant for this research, namely Unquestioned industry standards and Ignorance. These are explained as follows:

5.3.1.1. Unquestioned industry standards

"Unquestioned industry standards that are designed to make products and lighting systems compatible with global production and usage, might not lead to the most sustainable project- and situation-specific LED applications. Instead, light specifiers, planners and users require professional skills and knowledge of both LED technology and application contexts, before they are capable of interpreting technical standards in a way that meets and mediates their specific needs" (Schulte-Römer et al., 2019, p. 11).

This part of the theory substantiates why the current guidelines for public lighting should not be the only thing considered when making a lighting design. Interviewee 8 states that "guidelines take a very long time to come into existence, and must be substantiated before they are established, also internationally. The current guidelines are based on old techniques, old thick lamps". Guidelines may be outdated and don't provide sufficient information on the new lighting standards for modern lighting like LEDs. Furthermore, not all engineers that apply these guidelines are educated to design lighting. According to interviewee 13, these people are electrical engineers who make lighting plans as a side job: "Electrical engineers know very well how to lay cables through the ground, and they also make lighting plans. Lighting was never part of their training, they just follow the guidelines. Even if they have had training, the focus is on: how do I ensure that a row of masts meets a certain standard, and that the light that the fixtures emit also meets the standard?" (Interview 13). Interviewee 17 adds to this: "often what people do is simply choosing a certain lighting type X, plop-plop-plop and they are done, kind of like that. Those are types of lamps that people have been placing for years, perhaps it is better if you make time for it once so that you really make a good plan."

The theory of unquestioned industry standards can be recognized in this context, and should be prevented by educating lighting engineers on LED applications and technology before they are able to interpret standards and design lighting. According to this theory, this will lead to more sustainable LED design practices. In the Netherlands, there are special courses and trainings for lighting engineers available, to improve their knowledge about lighting quality and design. People not only learn about the technical part of lighting, and what the ROVL says, but also about the societal, environmental and political impact that lighting can have (Lighting Design Academy, 2022). Examples of institutions in the Netherlands that specialise in this kind of education are the Lighting Design Academy, the NSVV and the Philips Lighting Academy.

5.3.1.2. Ignorance

Ignorance, or non-knowledge, as described by Schulte-Römer et al., is another factor that influences the quality of a LED application: "… the negative side effects of LED lighting can be quite easily avoided through well-informed product and design choices. Such sustainable design choices become more likely when builders and investors are willing to commission and pay lighting professionals in the first place. They should know how to avoid bad product choices, bad designs, glare and overlighting and be able to interpret standards. As our interview partners pointed out, binding regulations can offer hard incentives to solicit such professional expertise in lighting projects." (Schulte-Römer et al., 2019, p.11)

Ignorance or non-knowledge can explain why there were still fixtures observed during the transect routes that caused glare and overlighting, while "well-considered and appropriate LED fixtures and lighting designs can reduce light pollution" (Schulte-Römer et al., 2019, p.9). It can also explain why only standard LED applications, which lacked a dimming schedule, were used, while literature and interviews suggest that light pollution can be reduced when dimmable LED systems are applied. This can be prevented when municipalities invest in more knowledge and expertise in public lighting projects, and set up binding regulations to incentivize this. Also, more budget should be made available to be able to invest in more sustainable LED solutions.

What is not outlined in this concept, but what also plays a role in the reduction of light pollution in the context of Amsterdam Noord, is that there are currently no regulations for private lighting, and that the private sector seems to ignore the effects of light pollution when using lighting. This was also confirmed by interviewee 16: "you can't enforce anything. You have no basis as a municipality to say that people should not cause light pollution. You can only convince by: shield lights, or respond to the fact that people waste a lot of energy with lighting." The same interviewee also explained that he had heavily invested in shielding to minimise light pollution caused by public lighting, but due to the business park close by, which had lighting similar to that on sports fields, the amount of light pollution that was measured in his city was higher than he had hoped for. This indicates that also the private sector needs to be educated about the causes and effects of light pollution, and on how to preserve darkness as much as possible.

5.2.3. Invisible infrastructures

In sociotechnology, invisible infrastructures are infrastructures that have sunk into the background, and from which we don't mention that they exist anymore (Schulte-Römer, 2022). Schulte-Römer(2022) places invisible infrastructures in the context of public lighting: "Lighting infrastructures are invisible in the sense that they have become so taken for granted, that we don't see their light anymore. This is also their paradox" (5:50). The researcher adds that when small changes in the lighting occur, people won't notice the difference. Only when there are major changes in the lighting, like when streetlights are broken, or more extreme, when there is a power outage and an area is completely dark, people will notice this. The notion that small, gradual changes in lighting won't be noticed by the public is a valuable insight for this thesis, and can be used in the Design for Darkness approach for Amsterdam Noord.

During the interviews with lighting engineers and designers, the concept of invisible infrastructures also came to the fore. Interviewee 16 and 19 state that lighting infrastructures are currently invisible and that even project managers take public lighting for granted during urban planning. Where Schulte-Römer(2022) only focuses on existing lighting infrastructures and how people experience this, the interviews with lighting engineers suggest that the effect of invisible infrastructures is also applicable on new urban planning. The interviewees indicate that public lighting is currently seen as a neglected child, and interviewee 16 remarks: "you also see that lighting is the last thing to be filled in in urban planning designs. They think: it is just a dot on the drawing, but that dot can have very major influences." The interviewees argue that more attention should be paid to a lighting plan that is carefully integrated with urban planning.

5.4. Translation of the findings into a Design for Darkness strategy

In this paragraph, elements in the current lighting plans of the interviewed lighting designers and engineers, of which the major findings are discussed in the previous paragraphs, are compared to the three concepts in the Design for Darkness framework, created by Stone(2019), which was already outlined in chapter 2.2.5., but that will be further worked out in this chapter. This comparison is made, to see what similarities can be found between the current lighting plans and the DfD concepts, to eventually apply these elements to a future Design for Darkness strategy for Amsterdam Noord to reduce light pollution in Amsterdam Noord. With this, the sub-research question can be answered: What elements in the lighting plans can be used in or changed into a Design for Darkness strategy to reduce light pollution in the short term? It will also help answering the question how a Design for Darkness strategy be applied in the context of Amsterdam Noord.

In his Design for Darkness framework, Stone (2019) describes three concepts; Dark acupuncture, Incremental darkening and Environmentally responsive lighting (see chapter 2.2.5.). The concept of Incremental darkening and Environmentally responsive lighting are two longer-term strategies, that are applied on a larger, city wide scale. Dark acupuncture is a more short-term approach that uses little pricks in the landscape that are explicitly left dark, and these interventions can happen on a smaller scale. When Dark acupuncture would be applied in Amsterdam Noord, a selection should be made of places where the lights can be turned off. The municipality of Amsterdam has already started applying less lighting in the Hoofdgroenstructuur (Gemeente Amsterdam, 2017), but most of the routes that were observed through the green structure still had their lighting on during the night. Interviewee 16 argues that routes through uninhabited areas, like parks, should be left dark, as social safety cannot be guaranteed with lighting in empty areas (see chapter 5.2.3.). This statement is used to support the application of Dark Acupuncture in the Hoofdgroenstructuur in Amsterdam Noord. This approach is further elaborated in the next paragraph.

In contrast to the short term, radical approach of Dark acupuncture, Incremental Darkening is a more gradual approach that dims all the city lighting over a longer period of time. Multiple interviewees and literature also indicated that dimmable streetlighting had the potential to reduce the amount of light pollution. Stone mentions that "current lighting practices typically give rise to street-level illumination of between 10 and 60 lux, which is several magnitudes greater than natural conditions" (Stone, 2019, p. 107). The transect route observations confirm this, and even a peak of 67 lux was measured. Moreover, the researcher states that current lighting often has inconsistent brightness and distribution (Stone, 2019), which was also noticed during the transect routes. Recent studies suggest that lighting levels between 1-3 lux are sufficient to create enough visibility and facial recognition for pedestrian activities, both for younger as senior citizens (Dick, 2014). These lux levels do not apply for the lighting on main roads with faster traffic (Stone, 2019). To implement Incremental Darkening, Stone explains that first a citywide system of smart LEDs is needed, which will be programmed in such a way that the gradual darkening of a city is initiated. "This concept positions the act of darkening cities as a long-term process implemented uniformly across an entire city or region, to reverse our shifting baselines and gradually re-introduce darkness into our lived spaces" (Stone, 2019, p.108). What does not become clear from Stone's incremental darkening approach, though, is in what timeframe the darkening should be achieved, and how big the gradual changes in the lighting level can be so that people won't notice these changes. Also, it is not specified what lighting levels should be applicable for main roads with faster traffic, which, according to Stone (2019), need a higher lighting level. It also isn't specified what kind of qualitative lighting design could be applied, but the focus is only on light levels. As the plenoptic function suggests, all the dimensions in the light plane should be taken into account when making a lighting plan (see Chapter 2.1.5) and this is not the case in Stone's approach.

The last Design for Darkness concept is Environmentally responsive lighting, a system that attunes public lighting to seasonal, nocturnal and diurnal cycles and to the natural brightness levels. Sensors need to be developed which control the brightness and colours of the smart LEDs, and that can react to changing lighting conditions during different seasons and weather conditions (Stone, 2019). An example that Stone gives of lighting that is symbiotic with natural brightness levels is lighting that responds to an increase in ambient brightness after fresh snowfall or during sunrise, by reducing its brightness (Stone, 2019). This approach can be a part of qualitative lighting design, as it can be a way to optimize artificial lighting in such a way that it enhances the perceptual and aesthetical aspects of an area. This is however not further highlighted by Stone.

Currently, this system is only tested on a small scale, but it can have the potential to change the public lighting system in the future and reconnect citizens to the natural day and night cycle of the planet(Stone, 2019). As this technology is still in its development phase, and wasn't mentioned in the lighting plans of interviewees to be a potential aspect of a Design for Darkness strategy for an urban area like Amsterdam Noord, this concept will not be further discussed.

From this analysis, Dark acupuncture and Incremental darkening are the two concepts that can become part of the Design for Darkness strategy for Amsterdam Noord. A problem with Incremental Darkening is that it needs a city with a lighting system that is fully switched to smart LED before this entire concept can be rolled out. It is not clear if and when the municipality of Amsterdam will allocate enough money to make a full switch to a smart LED network (Gemeente Amsterdam, 2017). This imposes a challenge for the reduction of light pollution in the Amsterdam Noord, as dimming the lighting cannot be applied to the lighting plans in this area, while it is a big part of the Design for Darkness strategy, and was frequently named during the interviews as a way to reduce light pollution. What can be used from this approach is the insight that a brightness level between 1-3 lux creates enough visibility on smaller roads with slow traffic (Stone, 2019). For the Design for Darkness strategy for Amsterdam Noord, this aspect will be combined with the concept of Dark Acupuncture, which will be applied to the lighting in the Hoofdgroenstructuur.

5.4.1. A short term Design for Darkness strategy for Amsterdam Noord

For the rest of the Design for Darkness strategy, elements from the interviews with lighting designers and engineers will be applied to the issues that were found while observing the current public lighting in the different zones in Amsterdam Noord (see table 3). Also, Dark acupuncture and Incremental darkening will be used to shape this strategy. The zonal approach that was used in chapter 4.3 to structure the observations, will again be used to structure the elements for a short term Design for Darkness strategy in Amsterdam Noord. Based on the issues per zone, an advice is given on how to change the lighting to decrease the effects of light pollution.

5.4.1.1. Hoofdgroenstructuur

In the Hoofdgroenstructuur, the public lighting, and the lighting from private parties caused light trespass to the areas in the green structure that were intentionally left dark. If the concept of Dark acupuncture would be used in the green structure, this would mean that the lighting in the entire green structure isn't turned on during the night anymore. An advantage of this approach is that the municipality can save costs and energy, and that the flora and fauna living in the green structure won't be negatively affected by the lighting anymore. Another advantage, formulated by Interviewee 11, is that loitering youth will also stay away if lighting in parks is turned off. A negative result of this approach will however be that the Invisible Infrastructure that public lighting normally is, will become visible, as people will mention that the lighting is off (Schulte-Römer, 2022). This will possibly cause concern and "trigger" the shifting baseline syndrome, which will decrease the feeling of safety (Stone, 2019). For the implementation of the Dark acupuncture, it is therefore recommended to set up pilots to experiment with a decrease in lighting in the green structure in Noord, to see how people react to the darkening of the green space. Also, advice from lighting designers/engineers is needed so that the lighting outside the park is designed in such a way that it doesn't cause light trespass to the green area. Moreover, it is recommended to regulate the lighting from private parties that are located around the Hoofdgroenstructuur, as it was observed that light from schools penetrated through the green areas (See chapter 4.3.2).

5.4.1.2. Historical neighbourhoods

Tuindorpen

In this zone, the observations indicated that the LED retrofitted fixtures emitted a brighter and cooler light than the older HPS lamps. Interviewee 16 and 17 both state that the colour of the lighting in residential areas should be 3000K, and their advice is adopted for the colour temperature of all the lighting in this zone, also for the modern neighbourhoods. Other observations suggest that the LED retrofitted fixtures caused more glare than the older HPS lamps. It is therefore recommended to re-evaluate the design of these fixtures together with a lighting expert, to see if glare can be prevented.

Dijkdorpen

The issues that were observed in the Dijkdorpen differed from the Tuindorpen. The number and placement of the light poles in the streets in the Dijkdorpen was judged to be inconsistent, and caused contrasts in the landscape, which triggered feelings of unsafety. It is recommended to review the lighting plan together with a lighting expert who also takes into account the qualitative lighting aspects and perceptual based lighting, so a more structured lighting plan can be developed, as explained in chapter 2.1.5. under Discernability/Comprehension.

Both in the Tuin as Dijkdorpen, several fixtures were observed that were painted black, and streetlighting was placed close to windows, which caused light trespass that spilled in people's windows. Literature shows that this can a negative impact on people's health (Mizon, 2012). It is therefore recommended to investigate whether these light poles can be removed or placed elsewhere, so that light nuisance can be prevented.

5.4.1.3. Modern neighbourhoods

In the modern neighbourhoods, light nuisance was also observed. To prevent light nuisance in modern neighbourhoods, Interviewee 17 uses the following approach: "In a residential street with houses next to it, you don't want the light to shine in the bedroom window. That is a form of light nuisance. You can take this into account in your plan, then you choose a certain type of fixture that mainly radiates the light to the front but less to the rear. If light does shine backwards, you can take measures again, with a shielded cap or something, that is certainly possible.” This approach can be used to prevent light nuisance in the modern neighbourhoods. Instead of Rondstralers, another shielded fixture may be applied. Also, the removal or displacement of light poles can be considered.

Both the historical as the modern neighbourhoods are part of the residential area in Amsterdam Noord. The Incremental darkening concept by Stone (2018) indicates that the minimum lux levels of the lighting in residential areas, to still create enough visibility, can lie between 1-3 lux. Interviews with residents (Cramer, Lücker, Osinga, Stojanovic, 2022) pointed out that residents would be open to experiment with lower lighting levels in their neighbourhood. Therefore, it is recommended to test what the effect of a decrease in brightness is on the inhabitants of Noord. If these tests turn out to be positive, an integral lighting design for the residential area in Noord could be developed with lower lighting levels. But this can only be the case when smart LEDs are installed, so investments in this newer system will then be needed.

Furthermore, literature, interviews and observations suggest that vertical illumination, and the reflection of light on vertical surfaces is beneficial for peoples feeling of safety (Schielke, 2013; ERCO, 2022). This lighting approach is part of qualitative lighting design. The advice for all the zones is therefore to apply this kind of illumination on a larger scale, and remove streetlighting if the lighting on walls offers enough visibility and brightness.

5.4.1.4. Functional area

The functional area mainly consisted of private lighting. In chapter 5.3.1. under Ignorance, it was already mentioned that there are currently no regulations that prevent the private sector from causing light pollution. Although the municipality of Amsterdam indicates that they focus on reducing light pollution and preventing light nuisance in the coming 5 years by “actively stimulating residents, sport clubs and businesses to limit the amount of light pollution and light nuisance” (Gemeente Amsterdam, 2017, p.51), this doesn’t seem to have been accomplished in Amsterdam Noord, as light nuisance, in the form of light trespass and glare, was still observed when crossing schools and businesses. Therefore, it is recommended to use stricter regulations so that the private sector causes as little light pollution as possible. In France, businesses are since 2013 obliged to switch off all the lighting in non-residential buildings, like illuminated signs, advertising, and window displays (Légifrance, 2013). This intervention is estimated to save 1000 GWh per year, which is enough to power more than 370,000 households (Connexion, 2018). It is not clear how much energy the municipality of Amsterdam can save when lighting in non-residential buidlings would be switched off, but this would be an interesting topic to investigate.

5.4.1.5. Road structure

Road towards ferry terminal

The lighting on the road towards the ferry were considered to have an inconsistent brightness and design, and suddenly shifted from 25 lux to 2,5 lux. This transition felt uncomfortable, and we had to wait before our eyes could adapt. When smart LEDs are installed, the advice, adapted from the

Incremental Darkening approach by Stone(2018) is to give all the lighting on roads an equal brightness, preferably between 1-3 lux, but this could be higher if there is fast traffic. Another solution, recommended by Interviewee 11, would be to install cat's eyes or road stud reflectors on the road surface, as cat's eyes use the concept of natural reflection to improve people's orientation of the road (Dreyer, 2022). This solution would be mainly applicable for busier roads with faster traffic with headlights which is reflected by the cat's eyes. Overall, a more qualitative lighting approach could be considered that doesn't switch between higher and lower brightness, but that uses lower lighting levels, vertical illumination and other aspects that improve visibility and orientation, as explained in chapter 2.1.5.

Local roads

The lighting on the local roads in Noord was judged to have a confusing pattern, there seemed to be too many streetlights that could be distracting for road users. An advice for this road would be to re-evaluate this lighting plan together with a lighting designer or engineer, and to investigate the possibility to remove rows of streetlights, for example the Rondstralers on the outer lanes for slower traffic. What could also be considered, is to use the cat's eye reflectors, as described above, or to apply a smarter designed light pole. This kind of light pole, shown in figure 50, was spotted on the Klaprozenweg, a road in Amsterdam Noord that wasn't analysed during the transect routes, but that offered a good example of a lighting design with less poles to create a better overview of the road. This kind of light pole design could also be applied on more local roads in Noord.

Figure 50: Integrated lighting plan with a smartly designed light pole on the Klaprozenweg in Noord. Google Maps 2022

Stone (2018) doesn't elaborate on the lux levels on main roads with higher traffic intensity, like the local roads observed during the transect routes. Hence, the value for the brightness of the lighting is based on the interview with interviewee 17 about his lighting plans. This person uses the minimum lux values prescribed by the ROVL, which are 5 lux for main roads, and 8 lux for crossings, when the traffic intensity is higher.

More research should be done in the field of traffic safety and road lighting on main roads and highways, as there is no demonstrable evidence that more light improves traffic safety. The differences between the percentage of traffic deaths on a dark or an illuminated highway are for example negligible (Natuur en Milieufederatie Drenthe, 2019). An example of a city that turned off all their highway lighting is Montpellier in France. Since October 2021, all lights are off on arterial roads to protect nature, and this shows promising results: the number of accidents haven't increased since this shift, and people have started driving slower (Bouma, 2022).

Tunnels:

The overall issue, observed for the tunnels was the brightness of the lights, and the transition between light and dark when coming out of the tunnel. The municipality of Amsterdam is currently redesigning the lighting in tunnels, and is doing tests with decorative lighting and light art (Gemeente Amsterdam, 2017). As was earlier stated in paragraph 4.4.3, practice experience in Amsterdam and other cities has taught that this way of illuminating increases people's feeling of safety in the public space, and also lighting designers indicate that increasing the brightness of lighting isn't always the solution, but that highlighting buildings can strengthen the identity of the area, and improve the safety in a street (Interview 12). More research needs to be done in the way tunnels can be illuminated, but city illumination and light decoration should be considered.

Bridge:

The main issue that came forward when crossing the bridge over the Noordhollandsch Kanaal, was that the lighting was too bright and that there were harsh contrasts between dark and light areas, which caused "zebra stripes" on the bridge deck. An artistic solution for this bridge would be to install lighting in the railing, aimed in an angle down towards the bridge's surface. This design solution was recommended by interviewee 9, and would be a way to provide enough orientation and visibility on the bridge, without overlighting it. The asset manager of the municipality of Amsterdam, however, pointed out that this solution would be unfavourable for facial recognition, and he therefore didn't recommend it. This thesis didn't dive deeper into the effects of lighting on facial recognition, but this would be a valuable topic to investigate in future research.

5.5. Design for Darkness policy measures

Hölker et al. (2010) states that "there is a need for light pollution policies that go beyond energy efficiency to include human well-being, the structure and functioning of ecosystems, and interrelated socioeconomic consequences. Such a policy shift will require a sound transdisciplinary understanding of the significance of the night, and its loss, for humans and the natural systems upon which we depend." The policy recommendations in this paragraph are deducted from the Design for Darkness strategy, and based on recommendations from table 2 in Chapter 2.2.5. These new policy measures are written for the municipality of Amsterdam, to re-evaluate their current policies about lighting, and to shift the focus from energy efficiency to a more transdisciplinary approach that focuses on the values of darkness. The measures are divided into three categories, Lighting plans and investments, Pilots and experiments, and Education and regulations. Recommendations are given per category on how to reduce light pollution.

5.5.1. Qualitative lighting design and re-evaluation of lighting plans

> Re-evaluate the lighting plans in Noord and invest in more qualitative, user-centred lighting design

- Give qualitative, perception-oriented lighting designs a more prominent role in urban planning: don't only focus on quantitative lighting design when making a lighting plan, but take a more user-centred, perception-based approach: collaborate with lighting designers who develop qualitative lighting designs. These people can improve the quality and identity of a space with vertical illuminance, accentuation, and glare control. This approach can be more effective for the visibility and perception of safety than increasing brightness levels.
- Re-evaluate the lighting plan in the Dijk and Tuindorpen in Amsterdam Noord together with a lighting designer or engineer, to investigate if light nuisance and glare can prevented with redesigned fixtures or with the removal or replacement of light poles.
- In the Dijkdorpen, review the lighting plan together with a lighting engineer, to develop a more consistent, structured lighting plan.
- Install cat's eyes or road stud reflectors on the road surface of local and main roads, as this can improve people's orientation on the road.
- Make more budget available to be able to invest in smart, dimmable LED solutions

5.5.2. Pilots and experiments

> Conduct pilots and experiments with less lighting or lower lighting levels in areas in Noord.

- Set up pilots in the Hoofdgroenstructuur in Amsterdam Noord to experiment with the darkening of the green space.
- Set up pilots in residential areas in Amsterdam Noord to experiment with lower lighting levels (between 1 – 3 lux) and monitor the effects on residents.
- Experiment with less lighting on main roads, as examples from France show that the number of accidents did not increase after turning off the lighting on arterial roads.
- Experiment with perception-based lighting design in the public space
-

5.5.3. Education and regulations

> Invest in more knowledge and expertise in public lighting projects and set up binding regulations that preserve natural darkness as much as possible

- Educate lighting engineers on LED applications and technology, but also on the effects of lighting on human perception and health and wellbeing, and effects on flora and fauna, before they are able to interpret standards and design lighting.
- Educate the public and the private sector on the causes and effects of light pollution, and how they can use lighting in such a way that darkness is preserved as much as possible.
- Set up regulations for public and private parties that force them to preserve darkness and cause as little light pollution as possible

5.6. Limitations and future research

This paragraph outlines the limitations to this research, and possible future directions for new research that can follow up on the findings in this thesis.

This thesis only focused on elements in the current lighting plans from a selection of lighting designers and interviewees, to develop a Design for Darkness strategy for Noord. However, multiple other elements for a qualitative lighting design, which are also described in chapter 2.1.5., weren't further outlined in these plans, but should also be considered when making a perception-based lighting plan for an urban area like Amsterdam Noord. Light varies per place, space, and time, and according to the plenoptic function, is seven dimensional(Chan, 2014). During the observations in Amsterdam Noord, only the illuminance of surfaces (lux levels) was measured with a lux meter in the horizontal plane, but this couldn't give a complete image of all light. Also, the lighting was only measured during the months of March, April and May. As lighting varies per time, other moments in the year, during Winter for example, when the nights are longer, should also be observed, to develop a more complete overview of the impact of lighting over the different seasons. Moreover, a more elaborated measurement of the entire light plane should be conducted, before a complete description of the light can be given, and before a lighting plan, based on these insights, can be developed.

As this thesis focused on interviewing lighting designers and engineers, and some residents and officials from the municipality of Amsterdam, I wasn't able to speak to suppliers of lighting products, like fixtures, who could have given me a better image of the available lighting material. I also did not interview an ecologist, affiliated with the nature in Noord, as the scope of this research was not to make an ecological lighting plan. But this could have given me a better overview of the ecological status in Noord, and how lighting impacted the nature living there. More research is needed on the impact of lighting on ecology in Noord, to develop lighting strategies that take ecology into account. More research is also needed on the impact of light on human health. The health risks for people, caused by lighting, are currently investigated by the Dutch BioClock Consortium (BioClock, 2022). The results from this research can potentially shake up the lighting industry, and can possibly trigger the development of stricter regulations on the brightness and colour of lighting, and the development of other lighting strategies that focus on darkness, to safeguard human health.

The people I interviewed possibly gave me a distorted image of the lighting industry. They were quite involved with darkness, and were aware of the effect of light pollution. I didn't speak to lighting engineers who made lighting plans with older standards, or who only designed public lighting as a side job. This would have given me a better image of the entire lighting industry, as I now wasn't able to determine how big the lighting industry was, and if the approach of the interviewed lighting designers an engineers was currently the standard, or that these were exceptions.

More interviews in Noord are needed to confirm the findings by the UvA students about the residents in Noord and their openness towards more darkness. Statements in this thesis that people in Noord would be open to experiment with darkness, were solely based on the results from the UvA research, and this is currently the only source that shows these results. Therefore, more interviews are needed to show that the results weren't biased.

The zonal structure that was used to divide the research area in different zones was only a way to structure the observations during the transect routes, but another zonal structure could be considered when implementing a Design for Darkness strategy in Amsterdam Noord. For example the one highlighted in the Light nuisance directive, which divides an area in E0 to E4 zones, in which E0 stands for intrinsically dark areas, like international Dark sky parks, and E4 represents urban areas with a lot of activity, where the light levels are higher (NSVV, 2020). Each zone uses a limit value for the amount of light and light nuisance that is allowed in the zone. This zonal approach can be an interesting way for Noord to regulate the preservation of darkness per zone.

In this thesis, I could only focus on public lighting, but as interviews, observations and literature suggest, private lighting and highway lighting can also have a significant effect on light pollution. With public lighting, only part of the problem of light pollution can be tackled. A future design for Darkness strategy should therefore take into consideration all kinds of lighting, and involve all the different parties that are responsible for light pollution, for example Rijkswaterstaat and businesses. Only three transect routes were walked for this thesis, but these didn't cover the whole area of Noord. The whole district of Amsterdam Noord should be mapped out before a Design for Darkness strategy for the entire area can be rolled out.

The development of smart cities, and the corresponding smart public lighting that would fit in this context, aren't explained further in this thesis, but should be taken into account when making a future Design for Darkness strategy for cities.

The greenhouses in the Netherlands are a good example of a source of light pollution that wasn't investigated for this thesis, but that is an important factor to consider when developing a Design for Darkness strategy for cities in the Netherlands that are situated around the Westland, like Delft or The Hague, where greenhouses impact people's view of the stars (Sotto le Stelle, 2020). A strategy as applied in Amsterdam Noord will probably not work for these cities, other solutions to light pollution, caused by greenhouses, need to be developed.

The interviews with the asset manager and lighting engineer from the municipality indicate that facial recognition is becoming a more important aspect in the public lighting plans of the municipality. This thesis didn't dive deeper into the necessity of facial recognition, and more research, which is also performed by one of my supervisors, will show what the importance of facial recognition and appearance in lighting plans really is. The same thesis supervisor also investigates the different spectra of light. While the colour of light in this thesis only played a minor role, more research is needed on the colour and colour temperature of lighting in the public space.

5.7. Chapter wrap up

This chapter discussed the major findings that were extracted from the literature research, interviews and observations that were described in the result section. With the help of the conceptual framework and three Design for Darkness concepts, a Design for Darkness strategy for Amsterdam Noord could be developed that could help decreasing the amount of light pollution. Also, Design for Darkness policy measures were drawn up, that can empower the municipality of Amsterdam to initiate the reduction of light pollution in Amsterdam Noord. Lastly, limitations of this thesis and further research opportunities are outlined, as this study only dealt with the issue of public lighting in Amsterdam Noord, and a collection of interviews and observations about this topic. To apply these insights on a larger context, more research is needed on the impact of lighting on ecology and human health, on other kinds of lighting, like that coming from greenhouses, and on other ways to preserve natural darkness.

6. Conclusion

To conclude, the lighting plans that are currently used to illuminate Amsterdam Noord are shaped by the LED transition, and by guidelines that prescribe social safety and road safety. The observations in Amsterdam Noord indicate that some fixtures cause glare and light trespass, which are elements of light pollution that should be prevented. Observations and interviews indicate that not only public lighting, but also private lighting, although not the focus of this research, can be a source of light pollution. To reduce light pollution in Amsterdam Noord, a selection of the elements from the lighting plans, formulated by the interviewed lighting designers and engineers, is made to structure a Design for Darkness strategy. This selection includes the idea that all the lighting in the green space should be turned off, since the light level cannot guarantee social safety in these areas, and that a more qualitative design approach is required to create a feeling of social safety in the public space, and to improve people's orientation and the visibility of the road. Furthermore, the insight is used that an increase in brightness of the lighting doesn't always improve the safety in a street, but strengthening the identity and quality of an area with a qualitative lighting design approach does. And lastly, dimmable LEDs that decrease their brightness after midnight, when the streets are empty, should be applied to the strategy for Amsterdam Noord.

However, applying dimmable lighting, which is also an important part of the Design for Darkness strategy as formulated by Stone (2019), creates a problem, as this is currently not possible in Amsterdam Noord, as smart LEDs are required to apply dimming regimes, and the municipality of Amsterdam currently only invests in standard LEDs with one fixed brightness and colour. Dimming the lighting in Amsterdam Noord therefore belongs to a longer term strategy, while this thesis focuses on short term goals. The Design for Darkness strategy that is developed for Amsterdam Noord includes the conduction of experiments with lower light levels in residential areas and on main roads. Dark acupuncture is also part of the strategy, and is applied to the green structure of Noord, to darken the entire green structure. Furthermore, the strategy includes the prevention of light nuisance, and the re-evaluation of the lighting together with a perception-oriented lighting designer, to start applying vertical illuminance, accentuation, and glare control. Based on the insights from the Design for Darkness strategy, a list of policy recommendations for Amsterdam Noord is drawn up, and these policy measures express the need to invest in more knowledge and expertise for people that design lighting, the application of a more user-oriented lighting design approach, and elaborates on regulations for the private and public sector that should be applied to incentivise the preservation of darkness.

This research offers an insight in the development of a Design for Darkness strategy that focuses on public lighting in an urban area in the Netherlands. However, light pollution is a worldwide problem that has much more causes than public lighting alone. This research can therefore only be seen as part of a bigger picture of ways to initiate the reduction of light pollution in cities. The results of this thesis contribute to the field of study by indicating how a Design for Darkness strategy, developed with insights from interviews and observations in the field, can be formulated for an urban area, and what possible problems can be encountered when developing such a strategy. Together with this strategy, and the proposed policy measures, the first steps are taken towards the darkening of Amsterdam Noord. With this strategy, Amsterdam may be one of the first cities in the Netherlands to apply a Designing for darkness strategy. Implementing this strategy can offer promising results which can be expanded to other urban areas in the Netherlands, and may help other cities in the rest of the world to start preserving darkness.

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APPENDICES

APPENDIX A: THE BORTLE SCALE

The Bortle scale as visualised by Bortle, J. E. (2001) in 'Introducing the Bortle Dark Sky Scale'. The Limiting Magnitude is "the magnitude of the faintest star that an observer with good eyesight can see once their eyes have fully adapted to the dark. The higher the magnitude the fainter the star" (Explaining Science, 2020).

	Limiting Magnitude	Sky Description	Milky Way	Astronomical Objects	Zodiacal Light / Constellations
1	7.6 – 8.0	Excellent, truly dark-skies.	MW shows great detail and light from its centre casts shadows on the ground.	M33 (the Triangulum Galaxy) is an obvious object.	Zodiacal light has an obvious colour and can stretch across the entire sky.
2	7.1 – 7.5	Typical, truly dark skies.	MW shows great detail and has veined appearance.	M33 is visible with direct vision, as are many globular clusters.	Zodiacal light bright enough to cast weak shadows after dusk and has an apparent colour.
3	6.6 – 7.0	Rural sky.	MW still appears complex, dark voids and bright patches and meandering outline are all visible.	Brightest Globular Clusters are distinct, but M33 is only visible with averted vision. M31 (the Andromeda Galaxy) is obviously visible.	Zodiacal light is striking in Spring and Autumn, extending 60 degrees above the horizon.
4	6.1 – 6.5	Rural / suburban transition.	Only well above the horizon does the MW reveal any structure. Fine details are lost.	M33 is a difficult object, even with averted vision. M31 is still readily visible.	Zodiacal light is clearly evident, but extends less than 45 degrees after dusk.
5	5.6 – 6.0	Suburban sky.	MW appears washed out overhead and is lost completely near the horizon.	The oval of M31 is detectable, as is the glow in the Orion Nebula.	Only hints of zodiacal light in Spring and Autumn.
6	5.1 – 5.5	Bright, suburban sky.	MW only apparent overhead and appears broken as fainter parts are lost to sky glow.	M31 is detectable only as a faint smudge; Orion Nebula is seldom glimpsed.	Zodiacal light is not visible. Constellations are seen and not lost against a starry sky.
7	4.6 – 5.0	Suburban / urban transition.	MW is totally invisible or nearly so.	M31 and the Beehive Cluster are rarely glimpsed.	The brighter constellations are easily recognizable.
8	4.1 – 4.5	City sky.	Not visible at all.	The Pleiades Cluster is visible, but very few other objects can be detected.	Dimmer constellations lack key stars.
9	4.0 at best	Inner city sky.	Not visible at all.	Only the Pleiades Cluster is visible to all but the most experienced observers.	Only the brightest constellations are discernible and they are missing stars.

Figure 51: The Bortle Scale, Reprinted from: Explaining Science. (2020). Measuring and mapping light pollution. Retrieved from: https://explainingscience.org/2020/03/18/measuring-and-mapping-light-pollution/

Appendix B: Overview interviews

Overview of interviews. The interviewees were anonymised, and were instead given a number, based on the order in which the interviews were conducted. Specified are the function of interviewee, and date the interview was conducted.

Interview 1: Lighting designer, 21-03-2022

Interview 2: Lighting designer, 23-03-2022

Interview 3: Lighting designer, 24-03-2022

Interview 4: Lighting designer, 25-03-2022

Interview 5: Lighting designer, 28-03-2022

Interview 6: Light Hindrance committee member, 29-03-2022

Interview 7: Futurologist, designer of a future scenario of darkness in cities, 05-04-2022

Interview 8: Lighting designer, 07-04-2022

Interview 9: Member OVLNL (public lighting NL), 13-04-2022

Interview 10: Lighting designer, 15-04-2022

Interview 11: Architect, 19-04-2022

Interview 12: Lighting designer, 21-04-2022

Interview 13: Lighting designer, 26-04-2022

Interview 14: Lighting designer, 28-04-2022

Interview 15: Asset manager public lighting, municipality of Amsterdam, 10-05-2022

Interview 16: Asset manager public space, 12-05-2022

Interview 17: Design manager & OVL specialist, 16-05-2022

Interview 18: Collected conversations residents Noord, 18-05-2022 & 19-05-2022

Interview 19: Public lighting planner Amsterdam Noord, 20-07-2022

APPENDIX C: EMAIL INTERVIEWEES

Dear…

My thesis supervisor, recommended me to contact you to learn more about the process of lighting design and planning in cities. Currently, I am finishing my Master's track in Metropolitan Analysis Design Engineering (MADE). With a thesis, I want to analyse the current public lighting plans in Amsterdam-Noord, who is responsible for these plans and what are the considerations when making those. Eventually, I am planning to use a Design for Darkness approach to come up with a future strategy to bring back more darkness to the city, with the goal to reduce light pollution.

I would like to plan an interview with you to hear what your insights are about public lighting, what your function as a lighting designer entails, and to learn more about the lighting designs you have made. Would the end of March suit you for his interview, or would one of your colleagues have time for this, if you are too busy?

Thanks in advance for your reply!

Yours sincerely,

Elsemieke Koole

APPENDIX D: INTERVIEW QUESTIONS

	Topics		Questions
	Intro before interview		I sent you a consent form. I explain why I chose to interview them, Explain subject, that I search for answers in the direction of designing for darkness in the context of their job as a lighting designer/engineer. I focus on street lighting, public lighting in Amsterdam-Noord (case study)
1	**Job description**		Could you describe your job and what this entails? (lighting planner/designer/engineer)
2			What is the function of public lighting in your job?
3			Describe in one phrase what your mission is, What you aim for in your projects?
4	**Commissioner/client**		Who are your commissioners/clients (in Amsterdam-Noord or other cities)?
5			What are the expectation of your clients about public lighting?
6			Are these expectations realistic, why(not)?
6	**Current lighting plans**		What are the lighting projects you did for an urbanized area like Amsterdam-Noord
7			What were the consideration behind these plans
8			Can you give me visual examples of the projects you did?
9	**Concept light and darkness**		
10			Why is there a focus on light/darkness?
11			Has this focus changed over the past, or will it in the future?
12	**Concept of light pollution**		What is your definition/interpretation of light pollution?
13			Do you consider the effect of light pollution when making lighting plans?
14			Why/why not? And how?
15	**Decreasing light pollution**		Do your plans decrease the effect of light pollution? Why/why not?
16			If yes: What elements do you use to reduce light pollution in your design?
17			If not: What new elements could you use to reduce light pollution?
18	**Direct rebound/SBS/**		Do people regularily want more or less light?
19	**Dynamics of demand**		Why do you think people want more/less light?
20			Do you agree with this need/expectation. Why (not)?
	Introduce the Design for darkness strategy		
21	**Value of darkness**		What is/are the value(s) of darkness in your opinion?
22			Can you find these values in your own lighting plans?
23	**Design for darkness strategy**		With these values in mind, how would you define a future Design for Darkness strategy in your own context?
24	**Future of public lighting/darkness**		What is in your opinion the future of public lighting (for an urban area like Ams-Noord)?
25			How can we reach this future?
26			Who needs to be convinced to change towards this future?
27	Closing off:		Additional comments?
28			Who would you recommend me to contact about this subject?

APPENDIX E: INFORMATION AND CONSENT FORM INTERVIEWEES

Information Interview Date: *XX-0X-2022*

You are invited to take part in an interview about the future of public lighting in the city. This interview is part of a thesis that will be written by Elsemieke Koole to finalize the master's degree in Metropolitan Analysis Design Engineering, a joint degree by the Wageningen University and the TU Delft, at the AMS Institute.

The purpose of this interview is to gain more insight into who is responsible for the current public lighting in the city, what the current approach is to illuminate the urban fabric, and what a future approach could be, if the focus would lie on the reduction of light pollution. The length of the interview will be approximately one hour. The questions you can expect will be about your own role in the public lighting industry, what projects you have done in this field, but also about the Design for Darkness concept, the reduction of light pollution, and the value of darkness, and if these topics already play a role, or will be playing a role in the future of public lighting in your view.

During this interview, pseudo-anonymised data will be collected in the form of notes and an audio recording that will transcribed. The transcription will be used for quotes, visualisations and summarized results in the thesis, which will be published in the week of the 22nd of August 2022 on the platform of the TU Delft, Wageningen University, the AMS Institute and on the website of openresearch.com.

Your participation in this interview is entirely voluntary and you can withdraw at any time. You are free to omit any questions. The data gathered from this interview will be pseudo-anonymised and securely stored as transcription in the TU Delft, Wageningen University and Openresearch repository for a couple of years.

Contact details from the researcher for more information:

Elsemieke Koole

Elsemieke.koole@wur.nl

06XXXXXXXXX

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: General agreement – Research goals, participant tasks and voluntary participation		
1. I have read and understood the study information dated *21-03-2022*, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: I will be interviewed about the subject of public lighting. My answers will be collected as data in the form of notes and an audio recording, which will be transcribed and processed in a thesis publication.	☐	☐
4. I understand that the results, in the form of a thesis, will be published in the week of the 22nd of August 2022.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study also involves collecting specific personally identifiable information and associated personally identifiable research data with the potential risk of my identity being revealed.	☐	☐
6. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: data will be pseudo-anonymised, transcribed and safely secured in a data base.	☐	☐
7. I understand that the pseudo-anonymised data that I provide in this interview will be stored as a transcription in the secure database from the TUDelft and Wageningen University for a couple of years.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
8. I understand that after the research study the pseudo-anonymised information I provide will be used for a thesis publication in the form of visualisations, quotes and summarized results.	☐	☐
9. I agree that my real name can be used for quotes in research outputs.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
10. I give permission for the transcribed, pseudo-anonymised interview that I provide to be archived in the TUDelft, Wageningen University and Openresearch repository so it can be used for future research and learning.	☐	☐

Signatures

____________________________ _____________________ _________

Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Elsemieke Koole *22-03-2022*

__________________________ _____________________ _________

Researcher name Signature Date

Study contact details for further information:

Elsemieke Koole
Elsemieke.koole@wur.nl
06XXXXXXXXX

APPENDIX F: LIGHTING IN THE PUCCINI METHOD, AND ZONING IN AMSTERDAM

aThe Puccini method is uniquely developed for Amsterdam's image quality, and is part of the citywide policy framework, prescribing a standardisation for the design and arrangement of the public space in Amsterdam (Gemeente Amsterdam, 2017). The street lighting in Amsterdam, including fixtures, light poles and spotlights, fall under the Puccini method. Their design and material should be sustainable, efficient and effectively maintained (Gemeente Amsterdam, 2017). In the figure underneath, the zoning of the public lighting in Amsterdam is shown (Gemeente Amsterdam, 2021, p. 265-266). This system is used in the Puccini Method, and helps applying certain types of lighting per zone. Each zone has its own recognizable character, from pre-war to modern, and lighting types are made for each zone.

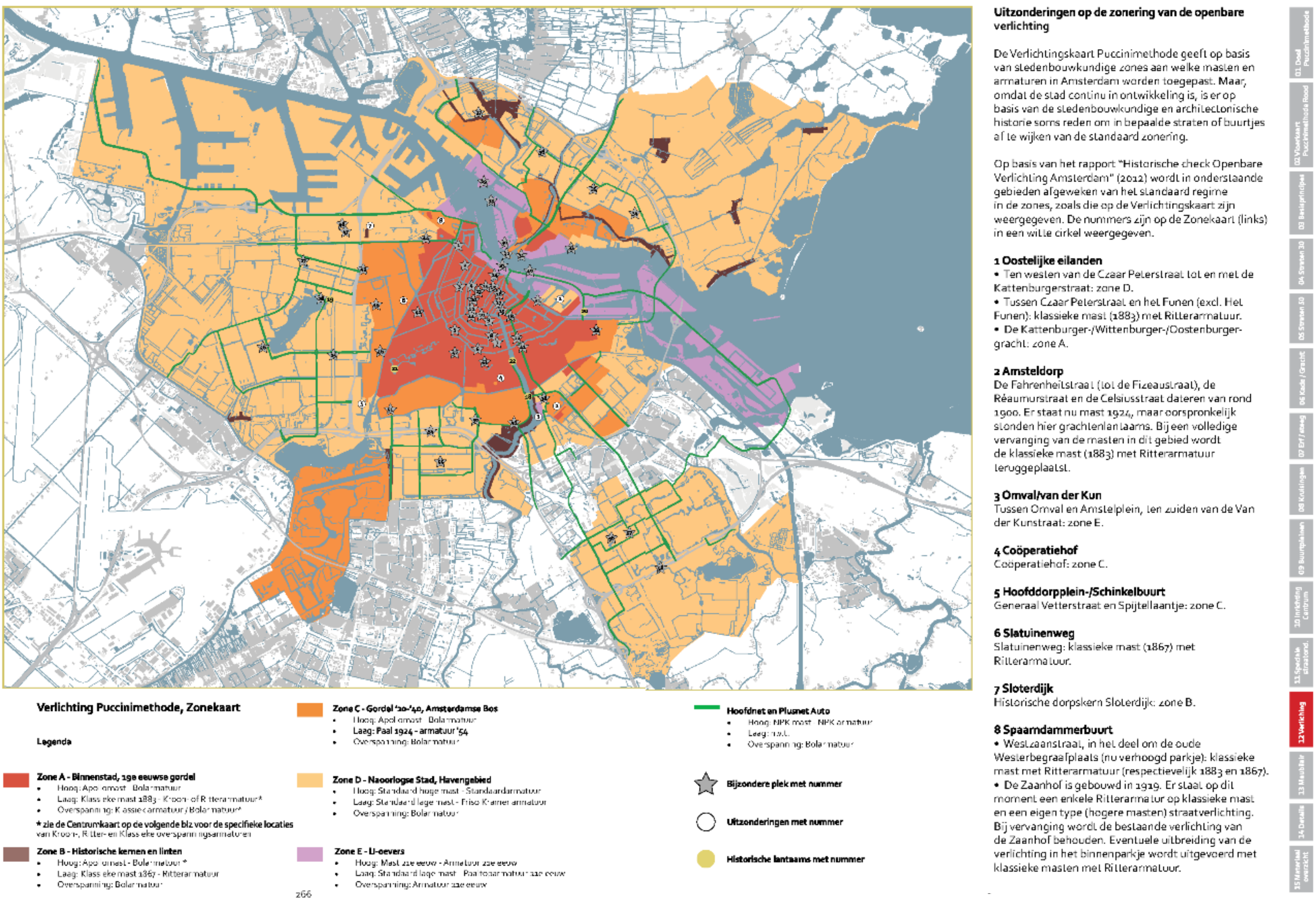
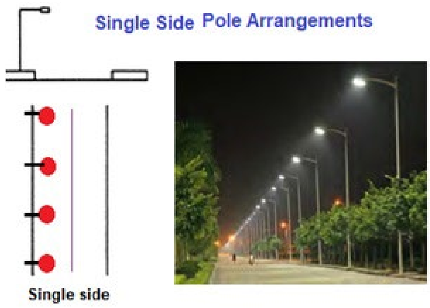


Figure 50. Verlichting Puccini Methode, Zonekaart. Gemeente Amsterdam, 2021, p. 265-266

APPENDIX G: STREET LIGHTING ARRANGEMENT

Street light arrangements, according to Parmar (2019):

"A: Single Side Pole arrangement:



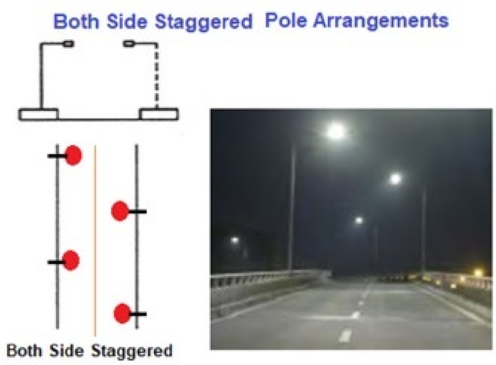
In the Single Side Pole Layout, all luminaries are located on one side of the road.

- Road Width: For narrower roads.
- Pole Height: The installation height of the lamp be equal to or less than the effective width of the road surface.

+ Advantage: There are good indelibility and low manufacturing cost.

- Disadvantage: The brightness (illuminance) of the road on the side where the lamp is not placed is lower than the on which side the light pole is placed.

b: Both Side Staggered Pole arrangement:



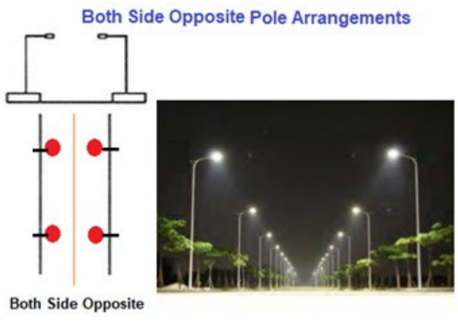
In the staggered arrangement, the luminaires are placed alternately on each side of the road in a "zig-zag" or staggered fashion.

- Road Width: For medium size roads.
- Pole Height: The installation height of the lamp is equal or 1.5 time the effective width of the road.

+ Advantage: This type of arrangement is better than single side arrangement.

- Disadvantage: Their longitudinal luminance uniformity is generally low and creates an alternating pattern of bright and dark patches. However, during wet weather they cover the whole road better than single-side arrangements.

c: Both Side opposite Pole arrangement:



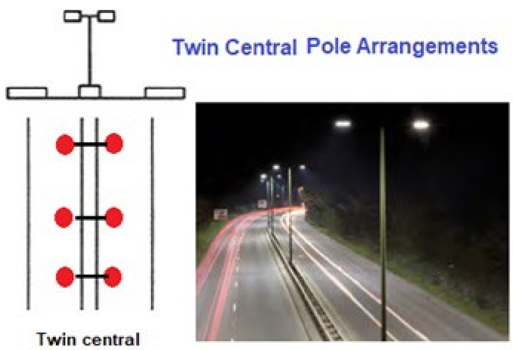
In Both Side Opposite Pole arrangement, the luminaries located on both sides of the road opposite to one another.

- Road Width: For medium size roads.
- Pole Height: The installation height of the lamp will be 2 to 2,5 time the effective width of the road.

+ Advantage: opposite arrangements may provide slightly better lighting under wet conditions.

- Disadvantage:
  If the arrangement is used for a dual carriageway with a central reserve of at least one-third the carriageway with, or if the central reserve includes other significant visual obstructions (such as trees or screens), it effectively becomes two single-sided arrangements and must be treated as such.

d: Twin-central Pole arrangement:



In the Twin central arrangement, the luminares are mounted on a T-shape in the middle of the centre of the road. The central reserve is not too wide, both luminaires can contribute to the luminance of the road surface on either lane.

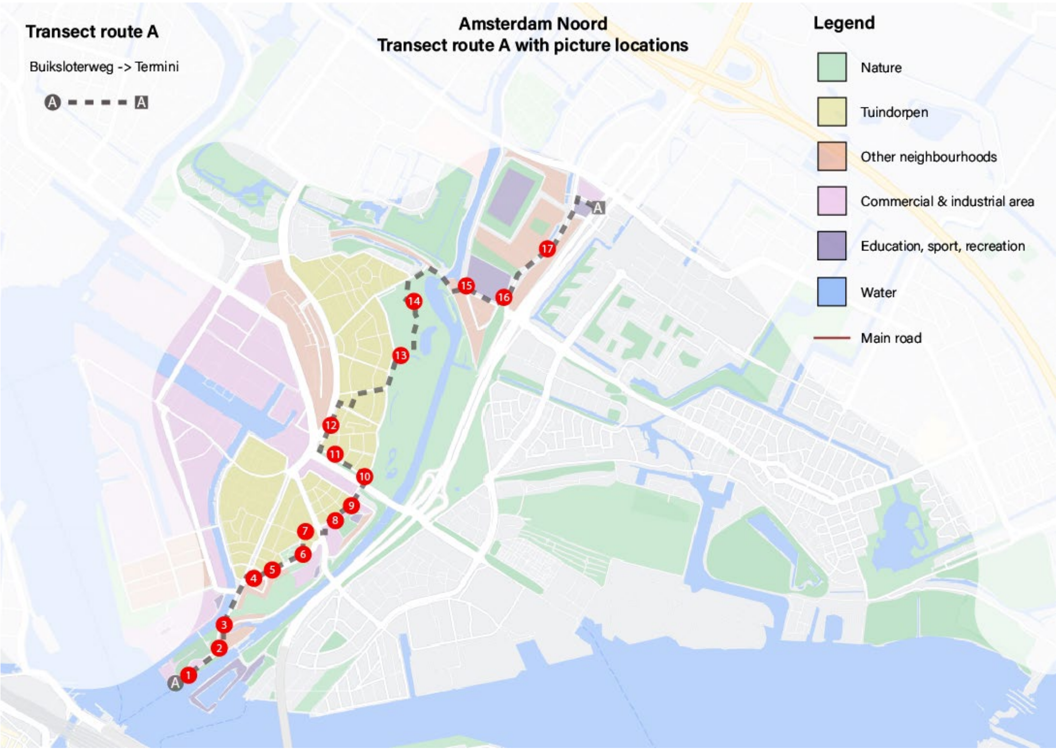
- Road Width: For large size roads.
- Pole Height: The installation height of the lamp is equal to the effective width of the road.

\+ Advantage: This arrangement is generally more efficient than opposite pole arrangements.

\- Disadvantage: However, opposite pole arrangements may provide slightly better lighting under wet conditions.”

APPENDIX H: COMPLETE OVERVIEW OF THE THREE TRANSECT ROUTES

The three transect routes are described here in chronological order. Transect route A was walked on the 28th of March, Transect route B was followed on the 30th of April and transect route C was walked on the 3rd of May. During the transect routes, our impression of and opinion about the lighting was written down, next to the lighting specifications and measurements. Sometimes, we also gave recommendations about the lighting during these routes. A supporting map is added per transect route with numbers on the route that indicate the number of the picture that was taken on that location.



Findings street lighting transect route A: Buiksloterweg - Termini, location 1-5

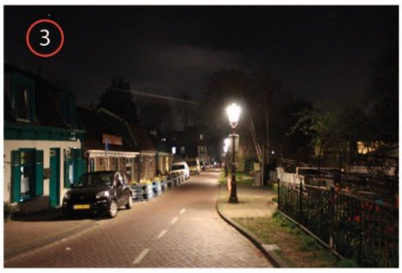
Start Buiksloterweg: We walk on the main road, which is illuminated with bright white light from two fixtures per pole, aimed at the road and foot/bicycle path. Across the street is a orange lighting of "only" 15lux, one fixture per pole. It is weird that there are two different colours and lux in the same street. We feel safe, but light is too bright, they could have done only one fixture per pole. Although this is the crowded, most important route from the pond to the island, we would turn the brightness down.

Properties:
Apollo mast,
Bolarmatuur
Height: 8m
Brightness: 25 lux
Colour: Warm white

Properties:
Apollo mast,
Bolarmatuur
Height: 8m
Brightness: 2,5 lux
Colour: Warm white

Bend in Buiksloterweg: The light suddenly changes, now there is only one luminaire per pole, only focused on the road. Cyclist cycle in the dark, it feels less safe to walk here due to contrasts, compared to the bright road before. Big change in brightness! Placement of poles feels messy. It has a staggered pole arrangement, which makes the street confusing. We prefer poles only at one side of the street, better overview.

Branch Buiksloterweg: We didn't go into this street, but it had old, nostalgic street lights, not even LED, which were only 4m high. We measured 10lux, which we felt was too bright. It also shattered everywhere. It was an old, cute street with old street lighting, in contrast with the main street, where everything was modern.



Properties:
Classical post (1883)
Ritterarmatuur
Height: 4m
Brightness: 10 lux
Colour: Warm white

Properties:
Conical pole
Rondstraler
Height: 4m
Brightness: 5 lux
Colour: Warm white

Crossroad Laanweg-Meidoornweg:
There are three different kinds of street lighting here; 1: the same ones as in bend Buiksloterweg, 2: the old "Rondstralers", which had a lot of shattered light. We only measured this type. We also saw type 3: The most modern ones with flat fixture, 8m high, small LED bulbs with really targeted light. It felt really messy with all those different lights, contrasts in the landscape were high for pedestrians. Rondstralers aren't shielded, so you are easily blinded.

Continuing Meidoornweg, we came across a playground where we measured 0 lux. Even when we stood next to the flat street lighting, it was so targeted that this playground wasn't illuminated at all. Also the trees seemed to cover the place. On our side, the street had Rondstralers, the other side modern flat LED lights. Rondstralers were blinding, even when their brightness was low. We would prefer only the targeted LEDs everywhere.

Properties:
Conical pole
Rondstraler
Height: 4m
Brightness: 0-4lux
Colour: Warm white

Findings street lighting transect route A: Buiksloterweg - Termini, location 6-10

Calisthenics park: Parking place before we walk into a small park: other kind of street lighting again, has less shielding than the modern lighting, feels way brighter than the rest of the area, due to contrast: we stand in the brighter light, everything around us is dark. The place is also more abandoned, people don't live here.

Properties:
Standard high pole,
Standard fixture
Height: 8m
Brightness: 6,3 lux
Colour: Warm white

Properties:
Classical post (1883)
Ritterarmatuur
Height: 4m
Brightness: 7 lux
Colour: Yellow

Silenestraat and Heimansweg: beautiful warm lights, that give a brighter feeling than the small park we just went through. The feeling we get is if we are in the Grachtengordel in Amterdam centre, nostalgic. But again, a lot of contrasts here, and the lighting seems even brighter than the Rondstraler, it produces light spill and causes glare.

Wingerdweg: same flat targeted fixture as in Meidoornweg. So targeted that it didn't light the houses, only the street, you couldn't even read house numbers anymore. We measured 1,5 lux, low! Other side of the street were some Rondstralers again that were brighter, 2,6 lux. We were used to this brightness, opposite side of the street seemed too dark. There were some abandoned buildings here, scary feeling because you miss the window lights that normal houses emit.

Properties:
Standard high pole,
Targeted LED fixture
Height: 8m
Brightness: 1,5 lux
Colour: Warm white

Properties:
Tunnel lighting,
fixtures in the wall
Brightness: 26,5 lux
Colour: Warm white

Tunnel Brug 494: We measure 26,5 lux. Way too bright, also caused by the reflectance of the walls. The light is warm, and we feel comfortable. It is indirect light, which makes the space seem softer. But outside the tunnel, everything feels dark due to contrasts.

Mosveld: again, other fixture, looks like an LED retrofit. Also funny warm lamps above some doors. Across the street is an elevated highway, that illuminates this street from above. It is really bright. Most light we see comes from this highway, it gives us a safe feeling as we can see very far and there are clear borders in the landscape.

Properties:
Post 1924
Holbeinfixture,
Height: 4m
Brightness: 5,25lux
Colour: Warm white

Findings street lighting transect route A: Buiksloterweg - Termini, location 11-15

We come at the end of the Mosveld, where the Mosveldbrug is located. The highway is really bright here. Some highway lighting is even placed in this street, giving an ugly blast of light. We measure 67lux! This is the brightest we find on this route. The Mosveldbrug functions as storage for the AH. It is a creepy place, we mention that this place is grim both during the day as the night, and that lighting doesn't make it any better/safer.

Properties:
Standard high pole,
Standard fixture
Height: 8m
Brightness: 67 lux
Colour: Warm white

Properties:
Standard high pole
Kofferarmatuur
Height: 8m
Brightness: NA
Colour: Varying

Kamperfoelieweg: There are three different colours of light on this picture that we came across, one very yellow, one blue-white, and the rest was (normal) warm white. Strange and messy, why didn't they replace them all with the modern flat fixture and warm white?

Floraparkweg: On our right, the park is super dark. This is the only route through the park that is lit, for pedestrians and cyclists. The Rondstralers are here again. They seem to have a brighter impact due to the dark surroundings of the park. The light is quite warm, but when we take the left turn, the light is suddenly a lot whiter, uglier and brighter.

Properties:
Conical pole,
Rondstralers
Height: 4m
Brightness: 4,6 lux
Colour: Warm white

Properties:
Conical/standard pole
Rondstralers and kofferarmatuur
Height: 4-8m
Brightness: 16,5 lux
Colour: Warm white

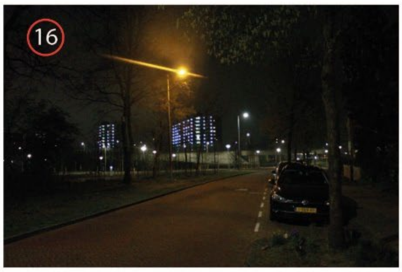
Noorderparkbad: the Rondschijners are so bright and white, they cause a lot of glare. The surroundings aren't able to soften this light, it is just empty here and the light can be seen from very far away, while that isn't necessary. The lighting changes when entering the main road, Sneeuwbalweg, which has more modern targeted fixtures, which feel more comfortable than the ones on the foot/cycle path. We mention that we prefer higher light to look underneath instead of in it.

Cecilia van Alphen-Jagtman Brug:The only beautifully lit building we found on this route was here, a building from Heritage Europe. The Rondschijners were not that bright, so this building was a real eyecatcher. Behind this building were the sportfields. Luckily, those weren't lit, otherwise the effect would probably have been lost.

Properties:
Architectural lighting,
Up-and downlight
Brightness: 4 lux
Colour: Warm white

Findings street lighting transect route A: Buiksloterweg - Termini, location 16-17

Nieuwe Purmerweg: Again, we found one streetlight that had an orange colour, the rest was warm white. This road had a mix of Kofferarmaturen and modern flat targeted fixtures, all 9 meters high above the road. The cycle path that lay parallel to this road had 4 meter high poles with the same fixtures. We see that the slower the traffic is, the shorter the poles are. Is that really necessary? We feel more comfortable with higher posts, the light is less blinding.



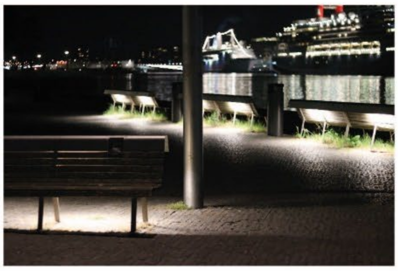
Properties:
Standard high pole
Kofferarmatuur
Height: 4-9m
Brightness: NA
Colour: Varying

Properties:
Modern and conical pole
Modern fixtures and Rondstralers
Height: 4-9m
Brightness: 12lux
Colour: Warm white

Buikslotermeerdijk: the last mile. This is a very new neighbourhood where the light felt all over the place. There were Rondschijners for the cyclists on both sides of the road and modern high targeted lights on both sides of the main road. Why didn't they do just one two sided light pole in the middle? It feels chaotic to drive here, some poles could be removed and the light would probably still be fine.

Findings street lighting transect route B: IJplein - Termini, location 1-5

At the start of IJplein, there are benches that have lighting in their backrest, that shines downwards on the ground. This is a nice way to create a beautiful, artistic atmosphere, also with a great view over the river IJ. There is one streetlight next to the bench that has multiple spotlights, but only one light is on. The focus is on the lighting under the benches, which spreads indirect, comfortable light. We like this way of illuminating the street.



Properties:
Light from benches and from spotlight
Brightness: 2,4 lux
Colour: Warm white

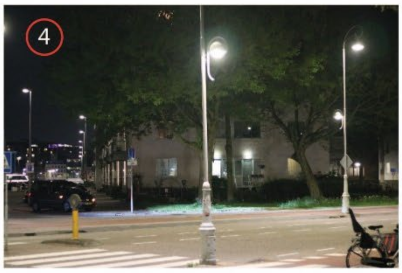
Properties:
Rondstraler, conical post & fitting
Height: 4m
Brightness: 5,7 lux
Colour: Warm white

Following the water, there are multiple Rondstralers that are blinding our eyes. The streetlights are placed around a small park, which comes over as an uncomfortable and sad place, the centre is very dark and there are too many contrasts. If the light would be less bright and better spread, the environment would improve.

Going left onto the extention of IJplein, we walk through a street with multiple white apartment blocks. The brightness of the lights turns out to be very low. Due to the white colour of the buildings, the light on the vertical surface that improves our sense of orientation, and the well-spread lighting, the lighting in this street feels comfortable and is well executed.

Properties:
Standard high pole,
Standard fixture
Height: 8m
Brightness: 3,2 lux
Colour: Warm white

Properties:
Apollo mast,
bolarmatuur
Height: 8m
Brightness: 17 lux
Colour: Warm white



At the crossroad Meeuwenlaan, the lighting becomes five times brighter than where we came from, but it is a busy road with a lot of traffic, so it is understandable.

In Spreeuwenpark, the buildings are made from dark-coloured brick, so the feeling of the area is also darker. The street lighting is targeted at the street, and positioned with a staggered pattern. On the sidewalks we walk in the dark. The park on the left is dark as well, we wouldn't like to walk there. The lighting varied between each pole, based on the shielding.

Properties:
Classic post,
Schreder fixture
Height: 5m
Brightness: 1- 6 lux
Colour: Warm white

Findings street lighting transect route B: IJplein - Termini, location , location 6-10

Following Spreeuwenpark into the Leeuwerikstraat, we come across a more historical area, with older lighting, no LED. This light is targeted to the ground and shielded, but it is better spread over the area. Under the lamppost it is bright, but from a distance it is not blinding. We get a warmer feeling, more comfortable.

Properties:
Classic post (1883),
Ritterarmatuur
Height: 4m
Brightness: 7,9 lux
Colour: Warm white

Properties:
Apollo mast,
Bolarmatuur
Height: 8m
Brightness: 24 lux
Colour: Warm white

Again we cross the Meeuwenlaan, but this time the light feels even brighter and it also is, compared to our previous measurement. We think the light could be less bright, the houses are also quite close to the road and can be affected by this brightness.

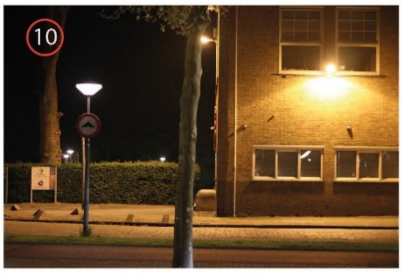
Gedempt Hamerkanaal: The parking place before the Jumbo Foodmarkt is lit with a bright, yellowish spotlight. Also the letters from the Jumbo Foodmarkt are too bright. We would turn these lights off, or dim them considerably.

Properties:
Modern post,
LED spotlights
Brightness: 20lux
Height: 9 m
Colour: Yellow

Properties:
Conical pole and
Standard high pole,
Rondstralers and
Bolarmaturen
Height: 4-8m
Brightness: 5,5 lux
Colour: Warm white

Meeuwenlaan: There are four layers of lighting here, Rondstralers on both sides of the street and the Bolarmaturen for the main road. We would take one line of Rondstralers out, the Bolarmatuur also shines on that side of the road. It only makes the street more chaotic, and there doesn't seem to be a clear lighting plan.

Meeuwenlaan next to Bredero: a bright spotlight on the wall illuminates the street, this isn't necessary, but probably it is to scare off loitering youth from hanging around. Maybe the school should find another way tackle this issue.



Properties:
Spotlight on wall
Brightness: 34,6lux
Colour: Yellow

Findings street lighting transect route B: IJplein - Termini, location 11-15

Around the corner of Bredero and Vox college, brighter spotlights are placed on the walls of this school. Three spotlights shine white light horizontally into the Vliegenbos. This was quite a shocking discovery. These lights should be dimmed considerably and targeted towards the ground instead of towards the Vliegenbos. The school should become aware of the light pollution that they cause.

Properties:
Politie Keurmerk?
spotlights on wall
Brightness: >10 lux (should be higher but hard to measure from a distance)
Colour: White

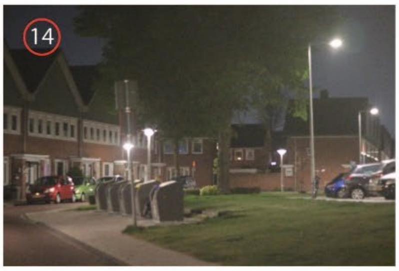
Properties:
Conical post,
Rondstralers
Height: 4m
Brightness: 3-4 lux
Colour: Warm white

Further in Vliegenbos, one path is illuminated with Rondstralers, the rest is dark. We are not used to this darkness as the lamps and the spotlights from the school have blinded our eyes. We would dim these Rondstralers, or even put movement sensors in them. We would turn the lights off after 11 or 12h in the night, as there is no one here. When taking the dark route through Vliegenbos, we could see a lot of stars, as it was a cloud-free night. This was a bit scary, but also a mystical experience.

Nieuwendammerdijk: historical street, but the lighting is very bright (also no LED?). There seems to be a mismatch with the soft surroundings and the blinding lights here. The street is quiet, so the lights could definitely dim. The whole neighbourhood seems to have this brightness, should be adapted.

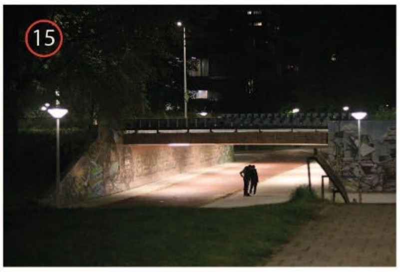
Properties:
Classical post (1883)
Ritterarmatuur
Height: 4m
Brightness: 9,9 lux
Colour: Yellow-white

Properties:
Holbein and Schreder fixtures
Height: 4-8m
Brightness: 5,8 lux
Colour: Warm white



Waddendijk: This newer part of the neighbourhood has other lighting, whiter, less bright. The transition from the old part to the newer part with other lampposts and fixtures is quite abrupt. The lighting is softer here, a part is on the dike, higher above us. More shielding, more comfortable lighting overall.

Tunnel under Nieuwe Purmerweg: The place was a bit abandoned, but the artwork in and around the tunnel was beautiful and made the environment more comfortable to be in. The tunnel itself was bright, but not as bright as other tunnels on other routes. There weren't many contrast, Rondstralers made the environment soft. We think that the artwork contributed to the good atmosphere.



Properties:
Tunnel lighting,
fixtures in wall
Brightness: 33 lux
Colour: Warm white

Findings street lighting transect route B: IJplein - Termini, location 16-20

New building on Het Breed: green light is used to illuminate this building, the lights in the building were still on. Green light is often used on construction sites with temporary security, having a preventive function to scare off unwelcome visitors (Bouwatch, 2021). Despite its natural colour, research has shown that green light has a bad effect on nature (Cup&Boere, 2016). This place felt strange, alienlike, it didn't fit into the surroundings. The light felt brighter than it actually was when we measured it.

Properties:
Construction lamp
Height: 4m
Brightness: 5 lux
Colour: Green

Properties:
Lamps in halls
Brightness: 40 lux
Colour:Warm white

Het Hoogt and Het Laagt: under every building, there is an illuminated hall, that gives the area clear boundaries, and prevents light pollution. Good solution! The halls function as tunnels, and also reflect light. The brightness therefore is quite high, we would turn it down. Next to the buildings, there are multiple Rondstralers, their light sometimes feels unnecessary.

Het Hoogt 336-470: A clear example of light nuisance, a Rondstraler was placed only one meter away from a window. If the residents from this apartment would complain about this, the lamppost would have to be removed.

Properties:
Conical post
Rondstraler
Height: 4m
Brightness: 6 lux
Colour: Warm White

Properties:
Spotlights
Height: 4m
Brightness: 20,5 lux
Colour: Warm white

Buikslotermeerplein, Shopping mall Boven 't IJ: The shopping mall was empty, but bright spotlights illuminated the street. It didn't feel unsafe, but unnecessary that the place was still so bright, we would turn these lights down and only leave some lights on. There are many reflective surfaces that intensify the brightness of the lighting.

Buikslotermeerdijk - Buikslotermeerplein: The lighting in the hall of this building also illuminates the street, caused by the reflective surface of the wall. We think that the rest of the street lighting on this side could be removed, as the light is bright enough without the street lighting. We wonder if this light causes light nuisance, as it shines into the apartment windows. We measure a high brightness standing next to the building.

Properties:
Hall lighting
Brightness: 8,1 lux
Colour: Warm white

Sources:
Bouwatch (2021). Waarom is er groen licht op een bouwplaats? Retrieved from: https://www.bouwatch.nl/blogs/waarom-is-er-groen-licht-op-een-bouwplaats/
Cup, I., Boere, R. (2016). Lantaarnpaal met groen licht slecht voor de natuur. AD. Retrieved from: https://www.ad.nl/binnenland/lantaarn paal-met-groen-licht-slecht-voor-natuur~a745cc75/?cb=4670a0f171553995765f75a5a743f654&auth_rd=1


Transect route C
Zuiderzeepark -> Buiksloterbreek
Amsterdam Noord
Transect route C with picture locations
Legend
Nature
Tuindorpen
Other neighbourhoods
Commercial & industrial area
Education, sport, recreation
Water
Main road

Findings street lighting transect C: **Zuiderzeepark - Buiksloterbeek**, location 1-5

Volendammerweg: the sun isn't fully set when we start our walk. The first lux-measurement may be influenced by this. First, we crossed the Schellingwouderbreekpark. Here we see Rondstralers that illuminate the park, we would like a more targeted fixture, so that the street is lit but not the nature around it. When entering Volendammerweg, the light is more targeted towards the road. We see one orange lamp again, the rest is normal warm white. This lamp turned out to be the only one that wasn't replaced by LED, the rest was.

Properties:
Modern post,
Standard fixture
Height: 8m
Brightness: 13,7 lux
Colour: Orange + warm white

Properties:
Conical pole,
Rondstraler
Height: 4m
Brightness: 6 - 8 lux
Colour: Warm white

Blokkerstraat and Edammerstraat: streets through an old Tuindorp neighbourhood with narrow streets. Sometimes the lightpoles are almost placed against houses. Some streets have a lot of streetlights, others only have one (working) one. The one on the picture is damaged/painted to shield the light from the house. The brightness of each fixture varies, we suspect that some have LED fixtures, others still have the older QL lamps

Havensteeg: the only alley that I came across during the transect routes. One light illuminates the whole alley. Due to the reflection of the surfaces, this seems like a very high brightness, but it wasn't so high as we expected. The alley felt a bit creepy, even with this bright light, as it was quite narrow and there was only one way in and out.

Properties:
Spotlight on wall
Brightness: 9,9 lux
Colour: Warm white

Properties:
Classical post(1883),
Ritterarmatuur
Height: 4m
Brightness: 5 lux
Colour: Green-white

Nieuwendammerdijk: we find one green light in this street, the rest is warmer, almost yellow. Green light is definitely not desirable in these kind of old streets, we would expect yellow/warm white to complement the cosy atmosphere, now it felt weird, distant. After some research, we found out that this fixture was replaced by LED, so something in the colour settings was wrong. The rest of the lighting still has the old halogen lamps. Some lights almost touch the houses in this narrow street.

Continuing the Nieuwendammerdijk, we mention more differences between LEDs and non-LEDs. The LEDs are much more blinding and give a colder, blue-white glow. We prefer the yellow glow from the older lamps, and wonder why the LEDs couldn't also have the same warm, dimmed effect, by just changing some settings? The difference between LED and not LED is more than 5 lux and our eyes can't adapt. We found another painted fixture in this street to shield the light.

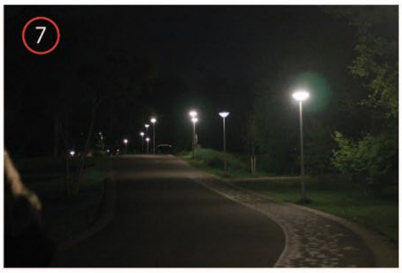
Properties:
Classical post(1883),
Ritterarmatuur
Height: 4m
Brightness: 2 - 7 lux
Colour: Yellow - white

Findings street lighting transect C: **Zuiderzeepark - Buiksloterbeek**, location 6-10

Nieuwendammerkade: suddenly, we come across a few higher lampposts, not what we expected in this silent, pedestrian area. We like the way the light is spread over the area, but the light is too bright and could be turned down.

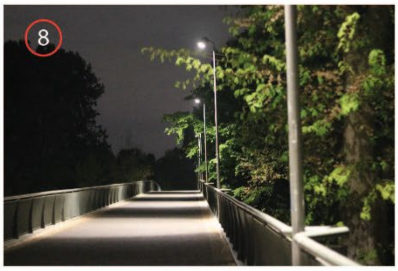
Properties:
Standard high pole,
Standard fixture
Height: 8m
Brightness: 7,4 lux
Colour: Warm white

Properties:
Conical pole,
Rondstralers
Height: 4m
Brightness: 5 lux
Colour: Warm white



From Meeuwenlaan we take the route through the Noorderpark. We mention that this route is abandoned and that dimmable street lighting would fit here, or better; dynamic lighting that reacts on movements from pedestrians and cyclists. The route should be dark when no one is there, to secure a green, dark route from east to west, maybe starting in Vliegenbos. The Rondstralers cause lightspill, and there are contrasts between the lit and unlit spaces.

Noorderparkbrug over Noordhollandsch Kanaal: a very clear example of hard contrasts in the landscape, caused by street lighting that is strongly targeted to a small part of the bridge, leaving the other parts, the "stripes", completely dark. We could read a book in this light, unnecessary, and a bad way to illuminate this bridge. We recommend integrating vertical lighting in the railing of the bridge, aimed at the ground in an angle, to create a soft, clear line in the landscape.



Properties:
Unknown pole type,
Targeted LED spotlight
Height: 6m
Brightness: 40,5 lux
Colour: Warm white

Properties:
Conical pole and
Standard high pole,
Rondstralers and
modern fixtures
Height: 4 - 8m
Brightness: 10 lux
Colour: Warm white

Kamperfoelieweg: there are four layers of street lighting in this street, Rondstralers for cycle path on the left and right side of the main road and modern high streetlights for both sides of the main road. We think that removing one layer of Rondstralers wouldn't be a bad idea. Next to this remark, the lighting plan, the placement and colour of the light, feels consistent.

Vikingpad: a small path with park Buiksloterbreek on the right and houses on the left side. We think these lights should be turned off or dimmed after midnight. This lighting doesn't have a function except for illuminating nature and causing nuisance. The lux we measure is not very high, but dimming it to 1 or 2 lux would still be better, to cause as little light pollution as possible. In the courtyards in between these houses, some lighting should be left on during the night.

Properties:
Conical pole,
Rondstralers
Height: 4m
Brightness: 4,2 lux
Colour: Warm white

APPENDIX I: DIALUX SIMULATION BUIKSLOTERMEER

Two Dialux simulations with corresponding lux measurements of the Station area in Amsterdam Noord, close to the Euroscoop. These screenshots were provided by the lighting engineer from the Ingenieursbureau Amsterdam, who designed public lighting for Amsterdam Noord.