Dark Acupuncture: A Design Strategy for Sustainable Lighting

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Abstract

This paper outlines a research methodology and design strategy aimed at realizing sustainable lighting within (sub)urban parks. It does so by detailing the research process, as well as resultant vision and design concepts, for the Delftse Hout (a park in Delft, The Netherlands). This process included formulating value-level design requirements, undertaking a detailed site-study to understand stakeholder needs, and combining these to provide conceptual and practical grounding for the future development of a lighting masterplan. A key – and we argue generalizable – outcome of the process is the development and application of dark acupuncture, a scalable design strategy aimed at strategically-placed interventions of darkness and illumination. The paper thus provides three contributions to sustainable lighting theory and practice: a detailed case study of innovative lighting design research; the refinement of dark acupuncture as a design strategy for nature-inclusive park lighting (which itself can be more broadly applicable to urban lighting policy and design); and, as a practical example of transdisciplinary research into artificial light at night.

Keywords: urban park lighting, dark acupuncture, nature-inclusive lighting, light pollution, design for values

1 Introduction

Urban, suburban, and peri-urban parks maintain green spaces within urbanized regions, providing essential services for both nearby residents and wildlife. They can likewise contribute to the realization of "dark infrastructures" [1], and form key nodes of "dark ecological networks" [2] within regions of abundant artificial illumination. This can serve to create "dark habitats" aiming to mitigate the impacts of ecological light pollution [3], while also creating unique nighttime experiences and atmospheres. Starting with the position that parks are an important consideration for sustainable lighting – and more idealistically that they offer an opportunity to re-imagine urban nightscapes – this paper details a research approach and design strategy developed for this goal (but, we later argue, with more generalizable applicability). Here, we conceptualize "sustainable lighting" on three interrelated and progressive levels. First, as an instrumental target, in the sense of optimizing efficiency towards energy and costs savings. Second, as adhering to dark-sky friendly lighting standards, to minimize both astronomical and ecological light pollution [3]. Third, as a means to re-connect our lived spaces to natural rhythms, challenging the built-natural geographical dualism often reinforced by artificial lighting [4-6]. In this way, sustainable lighting can go beyond instrumental gains, stimulating a process of urban ecological restoration via the reintroduction of darkness into our lived experiences [4]. Urban parks can serve as a focal point for combating light pollution, adopting dark-sky friendly policies, and developing innovative and experimental lighting strategies. In doing so, park lighting can complement both dark sky reserves and urban lighting masterplans, serving as intermediary and/or transitional spaces. Parks therefore offer a unique opportunity to explore the relationship

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between artificial light and darkness at the periphery of our cities (and daily lives), and to create impactful aesthetic moments that can serve to re-imagine how and why we illuminate our nightscapes.

With these broader goals in mind, here we describe and detail an interdisciplinary research methodology and resultant design vision for the Delftse Hout[2], a multi-use park and recreation space located in Delft, The Netherlands. Currently there is minimal artificial lighting in the Delftse Hout, and through stakeholder consultation the Ondernemersvereniging Delftse Hout (ODH)[3] identified improved lighting as a priority for future development plans. Based on this need, the ODH initiated the present research project with the goal of envisioning and realizing a safe and sustainable future for the Delftse Hout at night. Important to note is that the initial phase was to establish a guiding vision for the park at night, to serve as a first step in this process and foundation for the future development of a masterplan and/or pilot projects. As a result, the scope of the present study is focused primarily on establishing high-level design concepts. Technical specifications, budgets, and other potentially contentious downstream issues (e.g., how our plans align with EN13201 standards) are outside the scope of the presented analysis.

The project began with apparently conflicting goals of improving the park's public lighting without disturbing the park's nocturnal ecosystem; the Delftse Hout serves as a dark habitat within a heavily light-polluted region. However, we actively worked to re-frame the initial problems, and see these as complimentary – rather than competing – goals. We developed an interdisciplinary research process that utilized a design for values [7,8] orientation from the ethics of technology to formulate value-level design requirements, which were then translated into site-specific needs. Together, this offered conceptual and practical groundwork for an overarching vision, which in turn led to a set of design and policy proposals aimed at improving accessibility while preserving darkness. Through this process, we refined a design strategy we call dark acupuncture [9]. At its core, dark acupuncture strives to create moments for positive experiences of darkness, acting as a catalyst for the (ecological) restoration and revitalization of urban nightscapes. As applied to the Delftse Hout, dark acupuncture can be understood as a design strategy for enacting what we term nature-inclusive lighting [10]. Such an approach can, we believe, contribute to the identified need to re-define the meaning of "efficiency" for nighttime lighting [11], to the growing call to protect and preserve darkness and the night sky [12], and more generally to the realization of social and environmental values through design [7]. Further, the in-depth site analysis also presents a vision tailored specifically to the needs of the Delftse Hout.

The contribution of this paper to sustainable lighting theory and practice is therefore threefold. First, it outlines a vision and design concepts specific to the site of investigation, serving as a case study of innovative lighting research and design. Second, in refining the notion of dark acupuncture, it details a generalizable design strategy for sustainable park lighting (which itself can be more broadly applicable to urban lighting policy and design). Third and relatedly, it can serve as a case study to further advance calls for transdisciplinary research into artificial light at night [13], as the research was carried out via a close collaboration between an academic researcher and lighting designers.

2 Project Overview & Goals

The Delftse Hout is a park and recreation space in Delft, The Netherlands, located immediately east of the city center (Figures 1, 2). Delft has a current population of just over 100,000, but is located within the densely populated and industrialized Randstad metropolitan region. The Park was created in the 1970s, in an area that was previously largely agricultural and outside Delft's urban development. It covers approximately 300 ha, in roughly the shape of a rectangle 2.5x1.2 km (see Figure 1 for the exact footprint). It includes a large green space with a lake in its center, several walking and cycling paths, sports and recreational facilities, restaurants, a campground, a petting zoo, and a cemetery [14-15]. Given its size and uses, it is an important recreational area and green space for Delft and nearby cities. However, it is seeing increasing pressure due to rapid urbanization of the surrounding areas. Since the original planning of the Delftse Hout in the 1970s, its surroundings have undergone significant changes and growth. This includes: tens of thousands of new homes within the vicinity of the park, and entire new neighbourhoods abutting the northern edge; widening of the A13 highway, which runs between the park and city center; new commercial complexes developed along the highway, including large box stores; and, large greenhouse complexes built in nearby regions. Additionally, protected green space has been extended east via the

[2] In English, the Delft woods

[3] In English, the Delftse Hout business entrepreneurs' association

creation of additional lakes, forests, and recreational spaces, creating a continuous green belt for several kilometers. Delft and the surrounding region have ambitious plans for additional growth in the coming years, expected to increase usage of the sports facilities, green spaces, and pathways. Alongside this growth, there is therefore also an acknowledged need to preserve the green (and dark) spaces of Delftse Hout, and the essential social and ecological services they provide [14-16].

Currently there is minimal artificial lighting in the Delftse Hout, and through stakeholder consultation the ODH has identified improved lighting as a priority for future development plans. It has also been recognized that any future lighting installations should preserve, as much as possible, the ecological integrity of the park. The ODH therefore asked for a vision and design concepts that took into account two (potentially conflicting) goals:

- Improving lighting: public lighting should contribute to improved safety and accessibility, specifically at entry points, parking lots, pathways, and key destinations
- Preserving darkness: lighting should be sensitive to the nocturnal ecological conditions, creating minimal adverse effects on local flora and fauna

The identified goals for the Delftse Hout present a challenge, and possible conflicts between competing values. However, it can also be seen as an opportunity to envision solutions that utilize careful analysis, innovative lighting technologies, and creative design choices to simultaneously satisfy these competing goals. Such an approach requires a bold vision for the park, which is sensitive to local needs and broader concerns regarding artificial light at night. Our starting point was therefore to assess how the goals framed the "problem" at hand, and more generally a critical assessment of how and why we light our urban parks at night. Instead of basing our project goals solely on constraints or precautions, we adopted an optimistic perspective that sees conflicting values – as well as the growing public awareness of light pollution – as an opportunity to propose innovative solutions. We therefore sought a vision to inform a sustainable and responsible lighting strategy attuned to the needs of all stakeholders (humans and wildlife), and that incorporates best practices regarding lighting design and scientific research into the effects of artificial light. With this framing in mind, our project goal was formulated as: can the creative use of new lighting innovations, as well as a careful consideration of when and where illumination is truly needed in the park, allow us to create a space that is accessible for users but also nature-inclusive, serving to preserve (or even enhance) the darkness of Delftse Hout?

Figure 1: Delftse Hout within surrounding region (images from openfietskaart.nl).

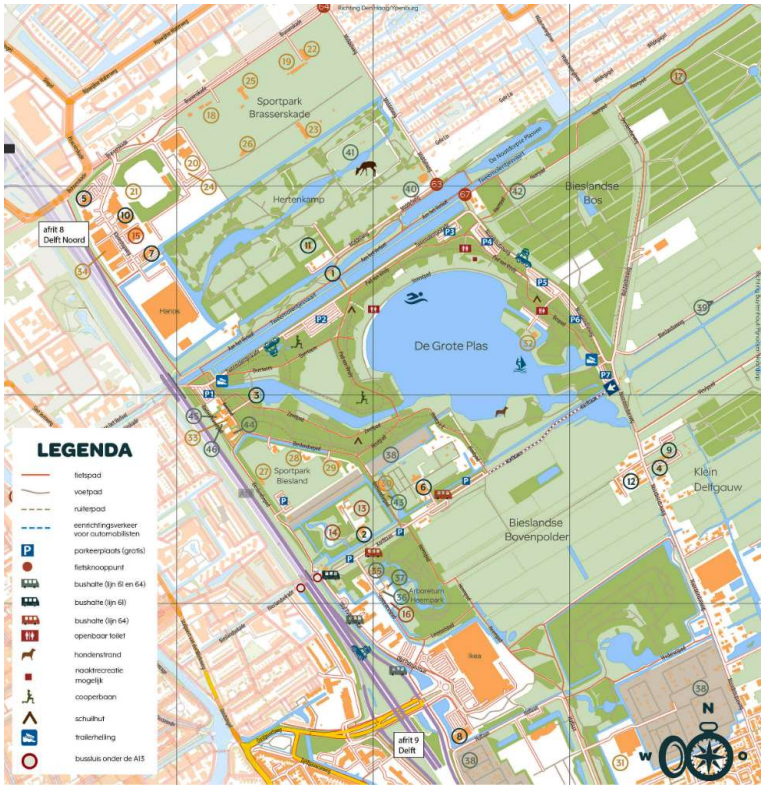

Figure 2: Site map of Delftse Hout (from www.beleefdelftsehout.nl).

3 Identifying Values as Design Requirements

The above-mentioned goals can be easily appreciated in abstract terms (i.e., "we should improve lighting," and "we should preserve darkness"). But what do we actually mean when discussing these terms? How do they manifest in lighting strategies generally, and the Delftse Hout nightscape specifically? Towards clarifying these questions, we began with a conceptual analysis of the values of lighting and darkness, which serves as a foundation for the in-depth site analysis of Section 4. While this analysis focuses specifically on artificial lighting, it is based on the methodological approach from ethics of technology known as design for values [7]. Design for values begins with the postulation that technological artefacts and systems are value-laden, meaning they can embody and manifest social and environmental values. Further, it asserts that a proactive consideration of values at stake – as well as how they may be fostered or hindered by design and policy choices – can better align our technologies with moral values.

To frame the goals of the project, we began with a value-level analysis, towards defining the values of lighting and darkness as "supra-functional" design requirements [17]. To do so, this Section examines the valuableness of both (artificial) lighting and (natural) darkness as applicable to the Delftse Hout, and ends with a set of general design requirements. These will be contextualized via the site analysis in Section 4, and operationalized via the design proposals in Section 5.

3.1 The Value of Lighting

Arguably, the primary value – and function – of artificial lighting within parks (and along pathways) is safety, broadly construed. Nighttime illumination has held a deeply embedded association with safety throughout the modern history of cities at night, which continues today. We often uncritically accept that the brighter our streets, paths, parking lots, or public spaces, the safer they are. However, in seeking a responsible lighting strategy that strives for a balance of different values, we should scrutinize this association. Further, we should be careful to delineate exactly what is meant by "safety" in this context: simply putting forth the goal of "making Delftse Hout safer" is too broad to operationalize within a lighting strategy alone, and would risk the adoption of short-sited solutions that may have minimal positive effects while increasing energy usage, light pollution, and ecological impacts.

If we put aside the symbolic connotations of nighttime lighting, we can instead explore contemporary research into the links between artificial light at night and improved safety. Studies have reached differing conclusions, showing contentious results regarding the extent to which lighting decreases crime or accidents. Conventional wisdom dictates that increasing brightness levels or colouring with improved visibility will increase safety. However, studies have shown this association is often not based on concrete evidence, or that existing evidence is limited [18]. It is therefore useful to further delineate exactly what benefits improved illumination can bring to the Delftse Hout. Broadly, we can divide this into two (interrelated) benefits: reassurance and wayfinding.

Reassurance, defined as "that which provides the comfort that makes someone feel less worried, less afraid or doubtful and restores confidence," is thus a central consideration [19]. It is meant to be an encompassing term that accounts for perceived safety as well as fear (of crime). Reassurance is influenced by three key factors [19-21]:

- Prospect – how well a person can see their surrounding environment (including other people)
- Escape – the possibility to exit a path or street (negatively referred to as entrapment)
- Concealment – places for a potential attacker to hide

While improving these factors should be a goal of lighting for the Delftse Hout, it is important to note some likely limitations. Reassurance generally decreases after dark for many reasons: there are fewer people, there is reduced visibility creating more opportunities for concealment, etc. [19]. These factors are further exacerbated due to the location and function of the Delftse Hout. It is a space outside the city, physically separated via an above-ground highway (see Section 4.2). Further, depending on time and activities there is often minimal or sporadic nighttime traffic. Along the many pathways through forested areas, the prospect, escape, and concealment levels will all be lowered. And, studies have suggested that improved lighting alone may not significantly affect perceived social safety (similar to reassurance), but rather depend on factors such as gender and levels of entrapment [20]. This would suggest that simply increasing brightness levels in the park would not improve perceived social safety or feelings of reassurance to a significant degree. Thus, while improved reassurance is taken as a central goal and design requirement, "success" should be understood relatively, and within the limitations of the park's existing spatial and physical limitations.

While reassurance is an important factor, it is not the only benefit that improved lighting can bring. Even if users or commuters feel safe in the park, there is still a practical usefulness to lighting. It can assist with routing, directionality, and accessibility of the park – a factor often referred to as wayfinding [22]. The accessibility of key locales, as well as directionality and orientation along the pathways, is thus another important function that lighting brings to the park. It is also important to note that these two goals are not mutually exclusive. Improved wayfinding can create a sense of safety and security while reducing stress, thus likely positively contributing to reassurance within the park.

3.2 The Value of Darkness

A responsible lighting strategy – and one striving to outline a vision for best practices in urban park lighting – must also take into account broader concerns regarding the impacts of artificial illumination. In recent years the adverse effects of artificial light at night, known as light pollution, has emerged as a topic of concern [23]. The causes and effects of poorly designed or excessive illumination can have far-reaching consequences. Instrumentally, it consumes large amounts of energy, which results in high (and often unnecessary) costs to municipalities. In addition to economic costs and energy usage, artificial lighting at night can have negative effects on human health, as well as wildlife and ecosystems. While the relationship between safety and lighting is complex and debated, it has been shown that poorly-designed lighting, which can create glare and strong contrasts between illuminated and dark spaces, can actually decrease visibility. And, ever-present skyglow, perhaps the most pervasive effect of light pollution around urbanized regions, is increasingly cutting off access to a starry night sky – experiences that arguably carry significant cultural value. Skyglow is a problem particularly relevant for this project: the atlas of artificial night sky brightness found that 100% of The Netherland's population, and over 99% of its surface area, are now under "light-polluted" skies [24].

The growing awareness of light pollution creates new challenges for how we light our cities (and parks) at night. However, it can also be seen as an opportunity to re-frame our design goals, and re-imagine the relationship between illumination and darkness – away from focusing on what is bad about artificial illumination, and instead about what is good, or valuable, about darkness. By focusing on the value of darkness, we can identify specific (environmental) goals to incorporate into our lighting strategies [4,8-9]. Darkness – as a value and design requirement – should be understood as an umbrella term encompassing various environmental concerns that are seen as negatively impacted (degraded, hindered, threatened, or otherwise) by light pollution, and nighttime lighting more generally. When arguing for a reduction in illumination levels for energy savings, or alternatively

when striving to protect access to the starry night sky, it is implied that darker nights – and hence darkness – embody or foster important values. To articulate these values, the commonly agreed upon effects of light pollution are re-framed as nine ways by which, or through which, value is derived from darkness (Table 1, adapted from 8]).

The value of darkness is particularly relevant for the Delftse Hout. This project aims to bring artificial light into a park, and must to do so in a way that is sensitive to, and in harmony with, the ecology of the park. However, seeing darkness as a positive and desirable feature of the Delftse Hout nightscape does not mean de-valuing artificial illumination and the benefits it can undoubtedly bring. Rather, it asks us to think holistically about the values, needs, and consequences of lighting choices. And further, it strives for a balance between lighting and darkness – for quality over quantity. If done creatively and conscientiously, this can achieve the benefits of artificial lighting while minimizing light pollution, all while creating a unique and pleasant atmosphere in the park after dark.

To design for darkness in the Delftse Hout, an important step is to ask which values are most applicable in this context. Because of the surrounding light pollution (see Section 4), access to an unpolluted night sky is currently not possible. Further, as it is not a lived-in space, long-term exposure to artificial light is also not a primary consideration. We can therefore refine the list, to focus on four values of darkness most applicable for the Delftse Hout (Table 1).

Table 1: Darkness-related design requirements to consider in nighttime lighting [18]. The four highlighted values represent the priorities for the Delftse Hout.

Value of darkness	**Definition**
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
Ecological conservation	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

3.3 Summary: value-level design requirements

Summarizing the above analysis, we can identify five key value-level goals for the park, as well as outline associated design requirements (Table 2). This is a complex list of design requirements, including some which would initially lead towards differing lighting solutions. However, this should not just be seen as a challenge, but an opportunity to envision solutions that can satisfy all (or many) of these goals.

Table 2: Overview and specification of value-level design requirements.

Value	Design requirement
1. Reassurance	- Prioritize new or improved lighting at spots with high usage and low reassurance - Establish appropriate site-specific illumination levels for visibility - Develop dynamic lighting that responds to individual preferences based on best practices, specifically in (urban) park settings [25] - Consider alternative design interventions (in addition to lighting) that can increase social safety and reassurance, such as routing through park and connections to surrounding neighbourhoods
2. Wayfinding	- Improve routing, connections between spaces; better identification of important routes - Ensure access and directional needs for key users and destinations (e.g., commuters, recreational paths, sports facilities)
3. Efficiency + Sustainability	- Adopt best practices and technologies for low (operating) costs and energy usage
4. Ecological conservation	- Ensure all (new) lighting adheres to dark-sky friendly lighting standards [26] - Use illumination levels and colours that best fits local biodiversity needs [27]
5. Connection to nature	- Create opportunities for (positive) nighttime experiences in the park [4,28] - Explore strategies for aligning dynamic lighting with natural rhythms (e.g., weather, ecology) [27, 29]

4 Site Analysis

With value-level design requirements established, Section 4 presents an overview of the site analysis conducted. This helped to clarify the various functions and programs of the different spaces, a hierarchy of the transit routes, exiting site conditions (e.g., lighting, ecology), specific stakeholder concerns regarding the Delftse Hout at night, and priority areas for new interventions.

4.1 Programming and Pathways

There are various (public) spaces within the park, including walking trails, green space, and a beach. Further, there are various programs and semi-private spaces, such as a campground and sports facilities (Figure 3). There are also a few key east-west axes that run through the park (for both vehicle and bicycle traffic). These paths allow access to the Delftse Hout programs and spaces, as well as increasingly serve as commuter routes for the surrounding neighborhoods (Figure 4).

Figure 3: Programmatic uses and spaces within the Delftse Hout.

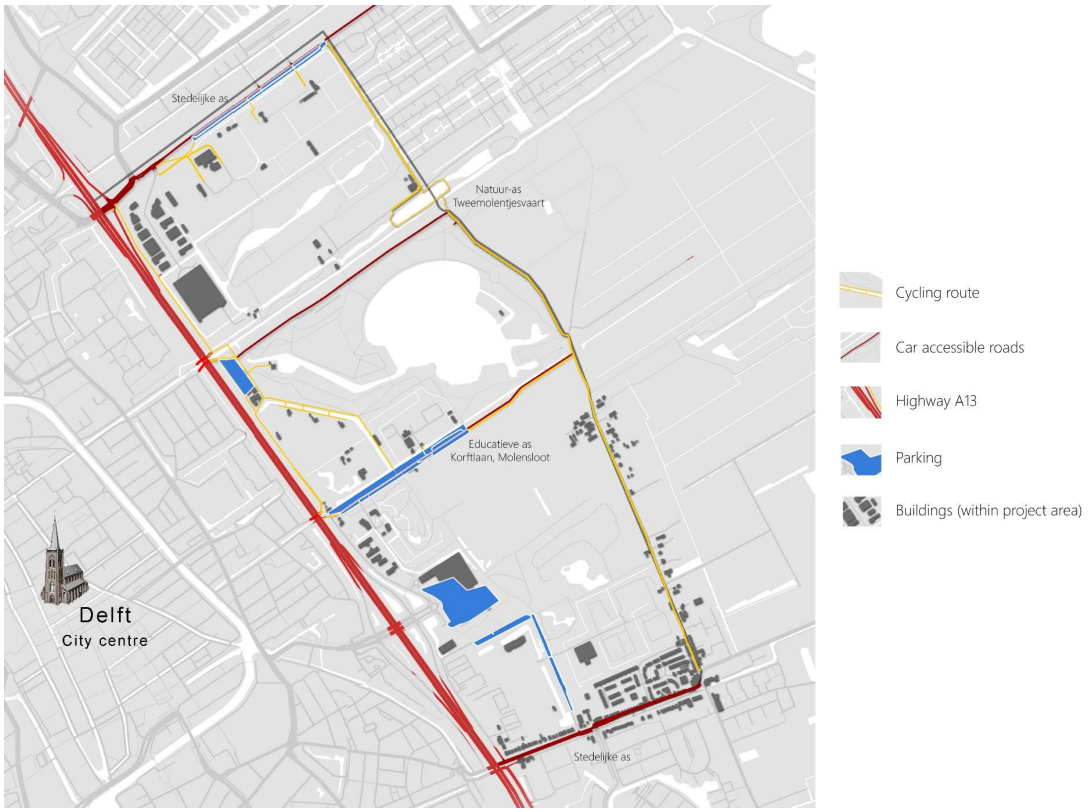

Figure 4: Main routing through Delftse Hout (red for vehicle, blue for parking, yellow for cycling).

4.2 Transition Zones (Highway Underpasses)

The historical structural lines from Delft to the countryside are oriented more or less east-west. However, the A13 highway was laid across these structures as an autonomous (and above-ground) infrastructure layer. As a result, the A13 effectively serves as a divider between Delft's city centre and the Delftse Hout (Figures 4, 5). In order for the main east-west axes to actually function as a link between Delft and the Delftse Hout – to overcome the perceptual and physical barrier between city and park – it is essential that these axes are interrupted as little as possible by the A13. Only then can the axes be fully utilized themselves as structural lines that extend from far into the countryside to the heart of Delft, and conversely that extend from the core of Delft to surrounding green spaces. If successful, the entrances to the Delftse Hout would no longer be somewhere behind or beyond the A13, but rather within (or continuous with) the city itself. The axes can then develop into “green” and “blue” runners that take city inhabitants (as well as local wildlife) from the city into nearby green areas [15].

Figure 5: One of four A13 highway underpasses connecting the Delftse Hout to Delft’s city centre.

4.3 Ecology

One known and studied nocturnal species within the Delftse Hout and surrounding area are bats. Different bats have different behaviours, as well as different sensitivity to artificial lighting. Based on existing knowledge of sleeping and foraging behaviour, combined with studies undertaken by the city of Delft, there is potential to adapt the lighting in a way that creates minimal disturbances to the habitats of the bats [30] (Figure 6). Other wildlife, as well as trees and other flora, are also influenced by artificial lighting. The most vulnerable and crucial to the ecosystem are insects; their ecosystem is easily disturbed by a small amount of artificial light. Scientific research identifying the extent to which various animals are affected, and by what part of the light spectrum exactly, is still emerging [3]. However, it is important that we take a precautionary approach, and strive to minimally disrupt the diurnal cycles essential for natural processes.

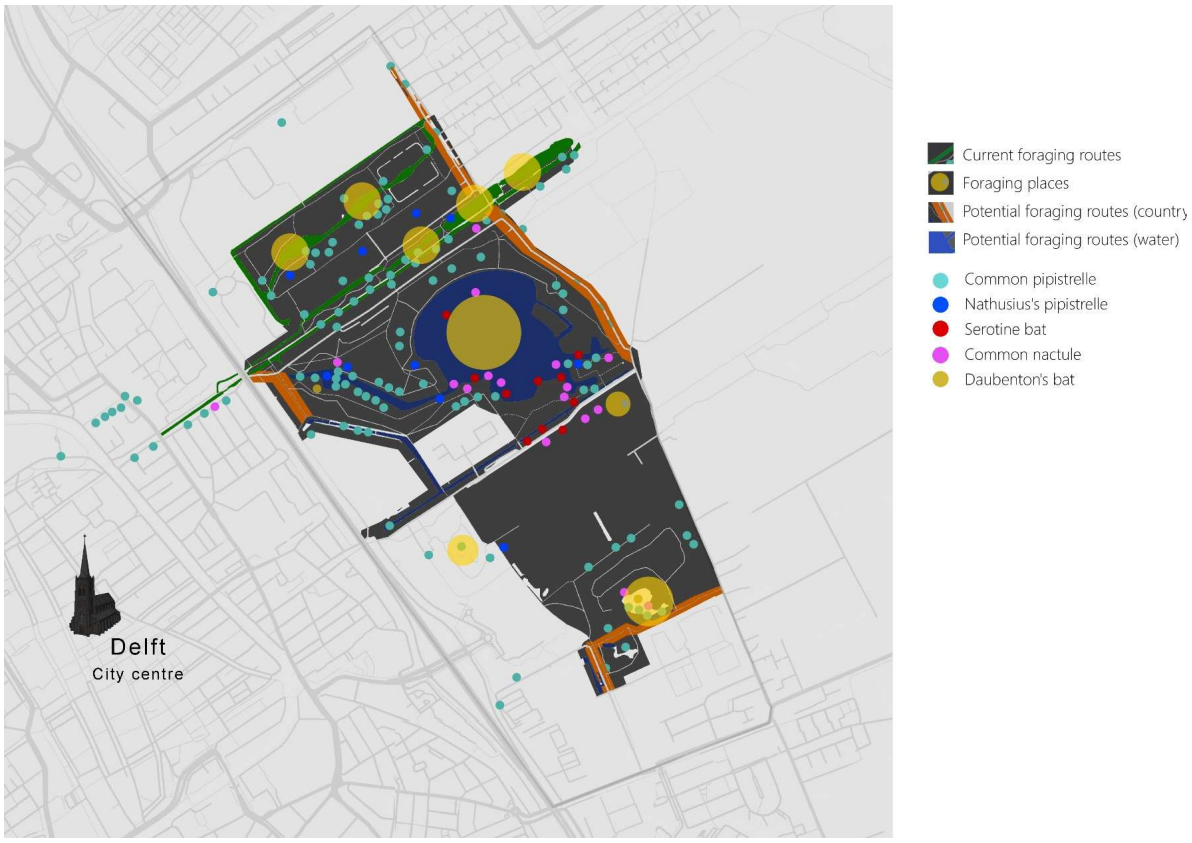

Figure 6: Plot of bat foraging overlaid on areas of Delftse Hout currently with no/minimal artificial light.

4.4 Existing Park Lighting

There is currently lighting in selected areas of the Delftse Hout, namely along a few paths running next to specific programming spaces (e.g., sports facilities), as well as the main parking lots (Figure 7). These are predominantly sodium vapor, however a few other types are also present. Much of the pathway and parking lot lighting is quite bright (measured at 48 lx in one parking lot), creating strong contrast with the surrounding dark spaces (Figure 8). Because of conventional techniques (i.e., roadway-style lampposts) the lighting is not as flexible as it could be, and the colour and luminance of the fixtures does not fit the green surroundings. Light levels on the pathways and on the parking lot meet local guidelines (although not International Dark-Sky Association standards [26]), but compared to the surrounding light level (which is relatively dark) the contrast is so high that the eye adapts to make the surrounding forest appear even darker. Intensity, colour, and positioning of the lighting can be improved to make the nightscape friendlier, healthier, and safer for all users.

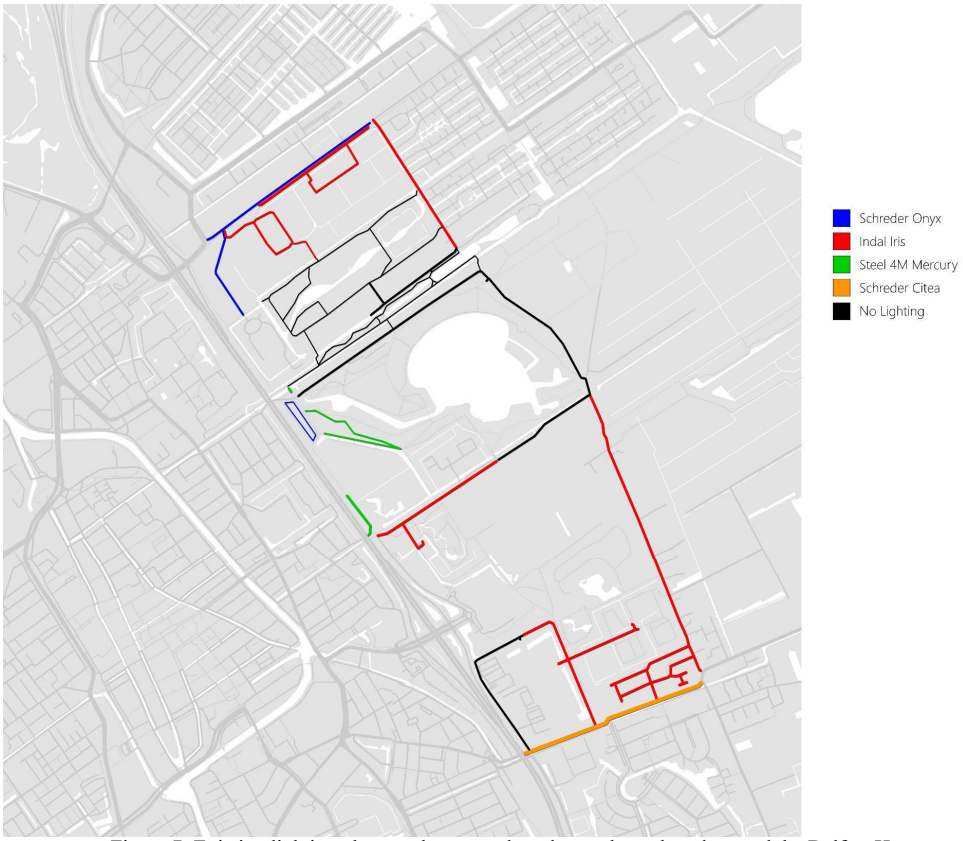

Figure 7: Existing lighting along pathways and roadways through and around the Delftse Hout.

Figure 8: Example of existing lighting (Steel 4M Mercury) along a pathway within the Delftse Hout.

4.5 Surrounding context

While the interior green zones of the park are relatively dark, the periphery zones – which includes box stores and sports fields – are much brighter (Figure 9). Further, the park lies within a densely populated region, with The Hague, Rotterdam, and greenhouses nearby (Figures 1, 10). This creates a large amount of skyglow within even the darkest spaces of the park. Appreciating the park's broader context acknowledges a challenge to the preservation of dark spaces, yet also highlights an opportunity to widen the scope of the project: to consider if and how to include the peripheral spaces in future project phases, and to appreciate that any preservation of darkness within the Delftse Hout may require a consideration of the region's lighting policies.

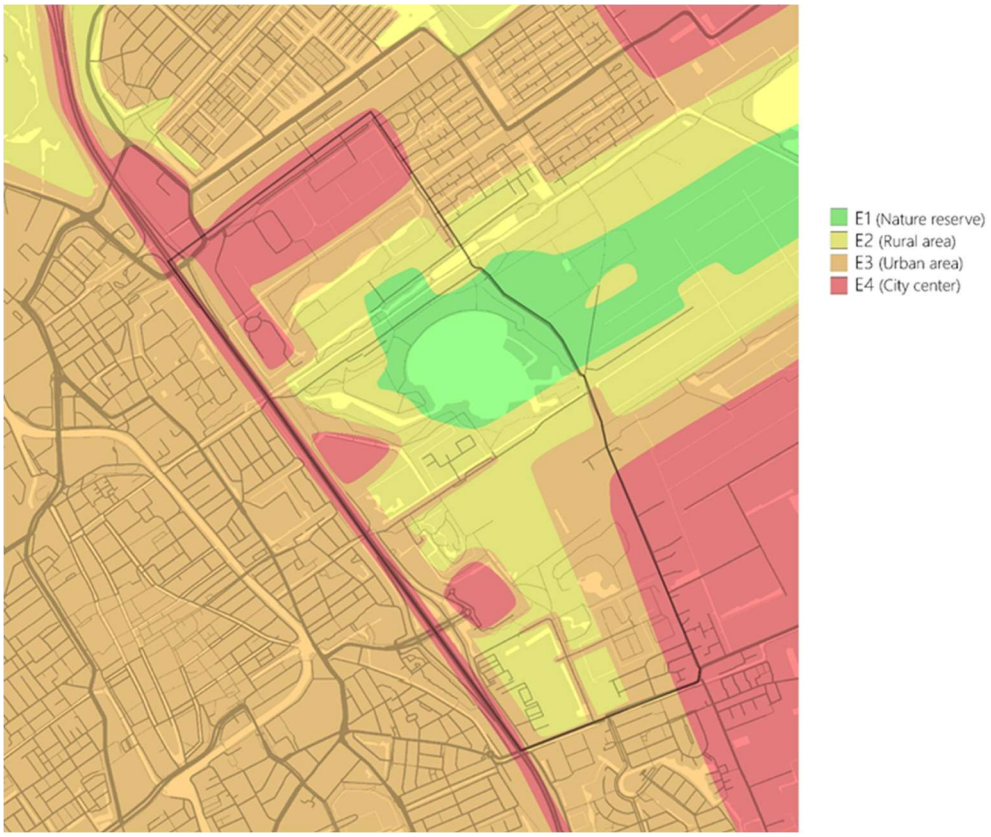

Figure 9: An estimate of the current "lighting zones" in the Delftse Hout, based on different lux measurements (zones are adapted from the Dutch Foundation for Illumination (www.nsvv.nl), which utilizes standards established by the International Commission on Illumination (cie.co.at)).

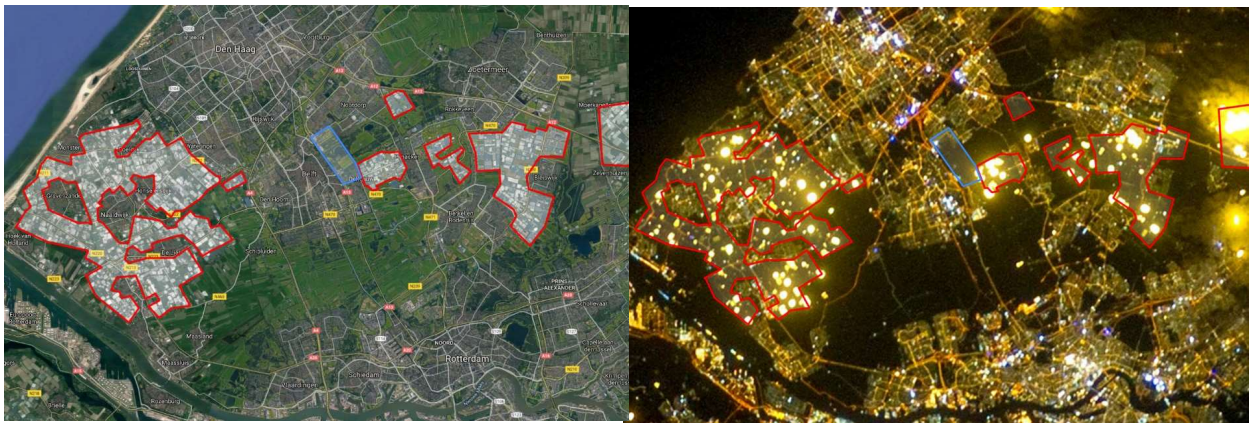

Figure 10: The Delftse Hout (outlined in blue) in its regional context, including The Hague (top), Rotterdam (bottom), and greenhouses (outlined in red).

4.6 Stakeholder Engagement: Night Right

Alongside the site analysis, a stakeholder engagement activity was organized, to better understand the challenges and opportunities for the Delftse Hout. In December 2019 a night ride was organized through the Delftse Hout with a small group of key stakeholders, including: the research team, members of the Ondernemersvereniging Delftse Hout, an ecologist from the city of Delft, a member of the Delft police, filmmaker Sander van Iersel, and a team of student researchers from TU Delft. The activity was structured as an open discussion while cycling through the park, to learn from those with intimate knowledge and experience of the space. Along the ride, we stopped at five locations representative of the different functions and spaces within the park: commuter paths, parking lots, sports facilities, and unlit green spaces. At each stop we discussed the existing illumination, as well as perceptions and reputations of the different spaces.

4.7 Summary: Site-specific needs

Via the site analysis and night ride, we identified a key needs and "hotspots" that can be then put into dialogue with the design requirements outlined in Section 3 (i.e., understood as priority sites for improving reassurance and wayfinding) (Table 3; Figure 11).

Table 3: Overview of key issues identified via site analysis and stakeholder engagement.

Concern	Description
1. Wayfinding and lighting along key routes	A central east-west axes and main pathway (*Aan het Verlaat*, Figure 11) has no lighting, and runs through the ecologically-sensitive regions of the park. The increasing amount of mixed traffic creates safety and wayfinding issues. The boundary of the path is difficult to detect, and oncoming traffic is difficult to see. As such, lighting is only one facet of a likely solution alongside improving the organization of the traffic (e.g., creating separate lanes for pedestrians and cyclists).
2. High contrasts	The feeling of safety is largely impacted by high contrasts; places that look dark compared to their immediate surroundings lower reassurance. Thus, solutions should not only be conceived by location needs, but also address transitions between zones and functions (e.g., underpasses separating the city centre from the Delftse Hout; changes between the sports fields and green spaces).
3. Neglected spaces	The neglect of a key internal route (*Het Bieslande Pad*, Figure 11) makes it a hotspot for small crimes such as vandalism and drugs, yet is also a route used by youth to reach their sports facilities. The parking lot at the beginning of the lane is a gathering spot for runners, but not a comfortable place to wait.
4. Surrounding light pollution	Within and immediately adjacent to the park is a major highway, as well as large box stores and commercial sites, which leave their outdoor lighting on all night. Further, the nearby cities and industry (greenhouses) creates ever-present skyglow in the park at night (Figure 10).

Figure 11: Site map with problem areas ("hotspots") in red, as identified by stakeholders. This includes areas perceived as unsafe due to way finding or neglect, as well as areas with negative connotations due to past crimes.

5 Dark Acupuncture: A Guiding Vision and Design Concepts for the Delftse Hout at Night

The value-level design requirements, combined with site-specific needs and priorities, allowed for the formulation of a guiding vision and design concepts to drive a lighting strategy for the Delftse Hout. Central to this guiding vision is the desire to create a unique atmosphere in the park, use artificial light sparingly and conscientiously, and accentuate and foster the inner dark spaces of the park. Taken together, these goals allowed for the refinement and application of a design strategy we call dark acupuncture [9]. This strategy draws inspiration from Jaime Lerner's idea of urban acupuncture [31], a bottom-up planning theory positing that a few well-placed "pinpricks" of a certain service, amenity, or structure can begin a process of urban renewal. This concept is most often applied to social improvements, such as safety, or of "restoring the cultural identity of a place or community" [31]. Here, this is adapted specifically for lighting design, asking how a few strategically placed interventions can serve the larger project goals and site needs. Importantly, this applies to moments of darkness and moments of illumination within the park. More broadly, the Delftse Hout itself can be seen as a site of dark acupuncture within the broader region – a pinprick of darkness within a bright and urbanized nightscape, which could stimulate awareness and action to curb light pollution.

Our vision therefore explicitly aims for minimal – yet well-planned and targeted – interventions in the Delftse Hout nightscape. Further, it advocates for a variety of different interventions and innovations within the park, rather than a homogeneous application across all spaces. With this approach, we actively re-focus our attention on qualities of darkness within the park, understanding the inner dark spaces as a core service and aesthetic identity of the park. By starting with darkness as the baseline, we critically and creatively explored where illuminated "lines" or "nodes" can be added, and how new or improved lighting can be complimentary to – rather than in competition with – the dark spaces in the park. Thus, the design vision emphasizes quality over quantity; both the quality of illumination, and the quality of the dark spaces.

To further define what qualities these moments of lighting should have, the vision advocates for the development of nature-inclusive lighting [10]. Street lighting has traditionally been controlled by a clock, with modern systems often controlled by a photoelectric cell to detect daylight and adjust operating times accordingly. Still, such systems are limited because they operate as binary on/off systems. However, with LEDs greater control is now possible. We therefore suggested further research and specification of a dynamic and responsive lighting system that creatively exploits the controllability and dimming capabilities of LEDs to be:

- User-responsive: utilize sensors that respond to activity and/or preferences, turning on lights in the immediate surrounding and ahead on pathways to satisfy wayfinding and reassurance requirements.
- Environment-responsive: prototype sensors that adjust illumination to changing ambient conditions, including twilight hours, cloud conditions, the brightness of the moon, and snowfall [9]. Preliminary studies have shown this to be effective for decreasing energy usage and costs [27,29], while in the process aligning artificial illumination with natural conditions and diurnal rhythms.
- Ecology-responsive: develop lighting scenarios that are responsive to local ecological needs, for example the foraging times of bats. Further research into the technical possibilities and local conditions is required, but could inform decisions regarding dynamic changes to colour and brightness for different times and seasons. It could also offer educational opportunities, creating new meaning for the lighting conditions, and potentially affecting perceptions of acceptable lighting levels for safety [32].

A combination of these three dynamic and responsive strategies has the potential to increase energy and cost savings, while simultaneously reducing unnecessary light pollution. More profoundly, it can also inform a lighting strategy responsive to seasonal cycles and local species, creating an atmosphere closely attuned to natural rhythms. Instead of a generic "smart" lighting approach, it will help to create a lighting strategy and atmosphere that is responsive to – and uniquely situated within – the uses and ecology of the Delftse Hout. Towards realizing this vision, we outlined a series of design and policy proposals, summarized in Table 4. In establishing these proposals, two points are useful to highlight. First, current lighting levels are far from our goal, which would be to have E1-E2 levels throughout (see Figure 9). Towards this overarching goal, we propose striving for the International Dark-Sky Association's Urban Night Sky Place certification [33] – providing both a baseline for policy guidelines and an aspirational target (see concept 5, Table 4). Second, it is interesting to note is that, within this overarching vision and strategy, a few of the proposed interventions that emerged are not about lighting per se; rather, they are more general "nightscape improvement/revitalization" concepts that could help to achieve the identified goals. In this sense, lighting was not advocated as the only (or perhaps even best) solution for the needs of the park. This, in effect, further advanced our critical and creative thinking around the possibilities, and limitations, to "improved" lighting. Further refinement and specification of these proposals, we believe, will allow for the realization of effective dark acupuncture(s) within the park.

Table 4: Design and policy proposals for the Delftse Hout, alongside targeted site concerns (from Table 3) and value-level design requirements (from Table 2).

Concept	Description	Site concern(s)	Value(s)
1. Dynamic lighting	Retrofit existing lampposts on pathways and at parking lots with responsive, dynamic LED lighting - Responsive to users and environmental conditions - Nature-inclusive: brightness and colour spectra that matches local ecological conditions at different times and seasons, adheres to dark-sky friendly standards [25,26,33]	Accessibility High contrasts Neglected spaces	Reassurance Wayfinding Efficiency + sustainability Ecological conservation Connection to nature
2. Wayfinding pathway lighting	Create subtle pedestrian and cyclist-targeted pathway illumination along the central commuter axis of the park - Illuminating edges, turns, changes in topography, etc., to improve wayfinding - Low lux for minimal effects on energy usage, nocturnal species	Accessibility High contrasts	Reassurance Wayfinding Efficiency + sustainability Ecological conservation
3. New cycling route(s)	Extend central commuter axis through park, lengthening cycling path to connect with surrounding neighbourhoods - A central east-west axis should improve wayfinding through park - Reduces need for lighting along other pathways, protecting the inner dark habitats	Accessibility	Wayfinding Efficiency + sustainability Ecological conservation
4. Revitalize A13 highway underpasses	Improve connections to city and identified hotspots via renovation of highway underpasses - Minimize the barrier between the city and park, and the high-contrasts between illuminated residential streets and the darker regions of the park - Revitalizing neglected spaces via stimulating new programming, utilizing urban planning strategies of urban acupuncture [31] and creative placemaking [34]	High contrasts Neglected spaces	Reassurance
5. Regional dark sky ordinance	Use masterplan (and stakeholder coalition) to propose a regional dark sky ordinance - Strive for International Dark-Sky Association's Urban Night Sky Place certification, at least for inner green areas (see Figure 9), but ideally for entire park [33] - Review existing laws, policies, and planning guidelines to propose a new regional strategy; examine if/how restrictions to illumination from surrounding commercial areas could be realized (e.g., curfews on billboards and advertising lights), and the economic and political feasibility of such policies [1,11,35,36]	High contrasts Surrounding light pollution	Ecological conservation Connection to nature

6 Conclusion

This paper outlines an interdisciplinary research methodology and resultant design strategy for the Delftse Hout, a park located in Delft, The Netherlands. The methodology combines a conceptual analysis aimed at identifying value-level design requirements with a detailed site analysis to surface site-specific needs. Combined, the process provided both conceptual and practical grounding for an overarching vision for the Delftse Hout at night, allowing for a refinement and application of the lighting design strategy dark acupuncture [9]. This led to a series of design and policy concepts aimed at increasing reassurance and wayfinding in the park, while preserving and enhancing the qualities of the inner dark spaces – the initial project goal.

The vision and design proposals offer a starting point for the eventual realization of a sustainable lighting strategy in the Delftse Hout. Importantly, however, further work is needed to operationalize the concepts presented here. Technical work on the design of specific luminaires, collaborative research with subject-knowledge experts (e.g., ecologists), continued stakeholder engagement, and the continued involvement and support of municipal authorities are all required to successfully realize the above vision. However, this too can be seen as an opportunity: to use the space as a collaborative and experimental site to refine and pilot best practices in park and (sub)urban pathway lighting. More generally, future research can continue to explore the broader applicability of dark acupuncture as a feasible strategy for (sub)urban park lighting, as well as for urban lighting more generally (for an exploration into the applicability of dark acupuncture for public spaces, see for example [37]).

As an early-stage research project, the goal was to initiate a process aimed at eventually realizing a sustainable lighting plan. Thus, for this project we were less concerned with technicalities (e.g., comparing lighting fixtures), or scientific details (e.g., outlining the specific colouring and luminance best suited to the local bat species). Rather, we wanted to engage our stakeholders to see the Delftse Hout at night from a new perspective; to appreciate that safety and darkness need not be seen as opposing goals, and that preserving darkness can create a unique atmosphere and identity for the park. For good reasons, light pollution mitigation efforts often take a global, national, or regional perspective. Yet, these risks overlooking the lived experiences of darkness within those spaces, and the transformative potential that powerful aesthetic moments can have in allowing us to see our spaces (and values) otherwise. Dark acupuncture explicitly flips this perspective, focusing on the immediate and intimate spatial experiences brought about by conscientious moments of illumination and darkness. In doing so, it can offer a means to realize the broader goals of sustainable lighting and light pollution mitigation in creative and innovative ways.

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