Preserving darkness in light

How lighting design in the Delftse Hout can improve the wellbeing of humans and the environment.

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LDE Minor Responsible Innovation
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Introduction

Nearby the brightly lit and bustling university town of Delft is a sleepy patch of nature called '*Delftse Hout*'. This recreational area facilitates diverse activities for people from all flocks of life. Lighting plays an important role in facilitating these recreational activities at night, as well as illuminating the bike paths that pass through the area. However, Delftse Hout is dealing with a multiplicity of problems pertaining to their current lighting management. On the one hand, the nights are so dark that they are perceived as unsafe. On the other hand, this darkness is one of the area's key strengths, making it one of the healthiest greeneries in the entire country. How can recreational activity be facilitated safely while also shielding flora and fauna from harmful rays of artificial light?

Before this *Student Project Group* (SPG) got involved, a team had already been brought together to think about a responsible lighting solution in Delftse Hout that caters to the needs of both nature and the area's people. This collaboration consists of the *Ondernemersvereniging Delftse Hout* (ODH), an organization representing entrepreneurs in the area; as well as *Atelier LEK*, which is a company specialized in creating innovative and responsible lighting designs. Additionally, SPG was invited to join this collaboration to come up with a design, while the entire project also enrolled into the *Lighting Challenge*. This is a competition about designing innovative, responsible lighting design and it provides the team with resources to further the development of lighting in Delftse Hout. Thusly a multilevel, multidisciplinary approach was born wherein tasks are delegated to whichever actor is most knowledgeable.

Responsible innovation frameworks will be included in the design and research process to ensure a responsible solution. Stilgoe et al. states "Responsible innovation means taking care of the future through collective stewardship of science and innovation in the present" (2013). Value sensitive design is one of the frameworks for Responsible Innovation that will be implemented in the research. The framework of Value Sensitive Design (VSD) is a theoretic approach within technology design that considers human values in a principled and inclusive way throughout the process (Friedman et al., 2013). In this context a value is seen in a broader meaning, namely what a person or group of people find important in life (Friedman et al., 2013). VSD works with a tripartite methodology, consisting of conceptual, empirical, and technical investigations (Friedman et al., 2013). Conceptual investigation focuses on the affected stakeholders and implicated values. Empirical investigation goes a step further by focusing on the human context the artefact is used in. This is also often needed to evaluate the success of the design. Lastly, technical investigation regards the effect of technical properties or an artefact on human values. In some forms it also involves a proactive design of systems to support the values from the conceptual investigation (Friedman et al., 2013).

Chapter 1 - Problem Identification

Through an interview with the problem owner, Appendix A, the main issue that concerns the stakeholders, like the Ondernemingsvereniging Delftse Hout (ODH) and the visitors, was identified. This chapter will elaborate upon that. The main issue is comprised of three facets, namely *safety, light pollution, and the environment*. From this issue some challenges emerge, like the effect of lighting on the environment and budgetary restraints.

On the one hand, part of the problem is safety, with both perceived and actual safety as two distinct subproblems. This directly induced this project in Delftse Hout. There are multiple hotspots in this area which, according to the chair of the ODH, are perceived as unsafe by the public at night. These hotspots include underpasses leading to Delftse Hout, which are dimly lit. Another detriment to the perceived level of safety are adolescents hanging out in poorly lit parts of the area, as well as a crowd that seeks out this privacy to use drugs. They announce their presence by playing loud music and carousing rowdily, often under the influence. Nonetheless, it should be noted that these people largely keep to themselves and accounts of conflict with other visitors are rare. However, such a dark and secluded area next to Delft is also an attractive location for criminals to congregate. In 2007 somebody was killed with a firearm, illustrating that this fairytale landscape also has its share of bad wolves. The parking lots' lighting solution is inadequate in terms of safety. Moreover, poor visibility in roads can lead to accidents. Illuminating these areas would lead to an increased sense of safety and would -to some extent- promote actual safety too.

On the other hand, a facet to the problems in the Delftse Hout area is light pollution. This contradicts the previous point of people not feeling safe because of a lack of light. Regarding light pollution the area itself is relatively unproblematic in an environmental sense, since it is one of the few 'black spots'. Unfortunately, light coming from the area's periphery counteracts much of the good done by the darkness central to the area. Greenhouses, industrial complexes, and dense urban development envelop the area on all sides after all. These surrounding sources of light are still too close for Delftse Hout to become a certified Dark Sky.

As one of the few dark spots in the region, the Delftse Hout is especially valuable for the fauna and flora. In surrounding areas, waste light disrupts wildlife by disorienting them and disturbing their biological clocks. Since some species are affected more than others, it follows that this threatens the food supply and by extent biodiversity. Being relatively distant from the strong permanent lighting of these adjacent cities, the area hosts rich ecosystems. Therefore, stakeholders seek to preserve this ecosystem as much as possible, with external groups also pushing for this cause. It is not only an environmental matter since many entrepreneurs' businesses hinge on natural life, so it is to be promoted.

While trying to come up with solutions for these problems some challenges arise. The first challenge regards the effect of lighting on the environment and the biodiversity in Delftse Hout. Many species that inhabit the Delftse Hout currently may be disrupted if the lighting designs do not take them into account, this applies especially to the insects. This could lead to a decrease in the biodiversity in this area. A decrease of only one of the species could also cause a disruption within the food chain. The problem owners would like to avoid this at any cost. The lighting design should therefore cause a minimal disruption to the environment and habitants.

Through meeting with the target stakeholders, it was also discovered that the gemeente Delft is not involved in the improvement of this area, nor is it expected to be mainly due to a lack of budget. The target stakeholders themselves also do not have any budget allocated for research into this lighting project. Because of this lack of funding, the target stakeholders need to find other ways to research and develop ideas for innovation within the Delftse Hout. Delegating this project to a university student group can be considered as a way to resolve this problem, because it is more cost-efficient.

Chapter 2 - Problem Analysis

The problems stated in chapter 1 affect different stakeholders in different ways. This chapter will elaborate upon several stakeholders. These stakeholders were identified through interviews with the problem owner, Appendix A, and research from the Actieprogramma Delftse Hout. To have a clear overview of these stakeholders a table that shows stakeholders, their corresponding type, the extent of their power, their involvement and their values and interests is provided below. We will identify two stakeholder types: *passive* stakeholders' stakes only depend on their interests or rights not being harmed by the project's activities, whereas *active* stakeholders are positively and voluntarily involved in the project. These stakeholders are committed to the project (Mahoney, 1994), which subsequently influences their power over the innovation. Their involvement in implementing and creating the innovation is also added to the table. These will be marked as either *small*, *average*, or *large*. Finally, their values and interests are included in the table.

A value is what a person or collection of persons find important in life (Friedman et al., 2013). Underneath the table we will further expand the reasoning behind the statements in the table. Stakeholders with similarities in values and interests are combined. This is also paired with literature that has helped to broaden our understanding of the problems this innovation deals with.

Stakeholders	Type	Extent of Power	Extent of Involvement	Values and Interests
ODH	Active	Large	Large	Overall prosperity of the Delftse Hout region ← Creating the possibility for all stakeholders included to come to an overall agreement in which all values and interests are considered.
Entrepreneurs: **Sport facilities**	Active	Large	Large	Make money ← more members ← more safety + promote physical health
Entrepreneurs: **Catering industry**	Active	Large	Large	Make money ← more Customers ← more safety + better experience (more emphasis on nature preservation)
Entrepreneurs: **Commercial companies**	Active	Large	Large	Make money ← more customers ← safe travel for customers (less about nature)
Entrepreneurs: **Nature and activity**	Active	Large	Large	Wellbeing of environment ← Experience customers ← value in lighting which doesn't harm the environment.

Environment	Passive	Small	Small	Wellbeing of environment Preserving nature/natural habitat for animals Non-intrusive manner of implementation
Wildlife/nature watch / sanctuary / environmental NGOs	Active	Average	Average	Preserving nature/natural habitat for animals, experience for recreational visitors ← enough light for visitors to experience nature in a non-intrusive manner
Recreational visitors	Passive	Average	Average	Good environment/experience ← safety ← good lighting, nature preservation ← not too much light, aesthetically pleasing design
Commuters	Passive	Small	Small	Safe travel, visibility ← good, consistent lighting (less about nature)
Organized sports	Passive	Average	Small	Safety and visibility at night ← good lighting (less about nature)
Municipality	Passive	Large	Small	Area improvement without spending money, more customers ← more money Landscape and nature
Atelier LEK (Lighting designer)	Active	Large	Large	Effective long-term solution <- interest in well-being Unique lighting solution <- consolidation in market
Lighting manufacturers	Passive	To be determined	To be determined	Market share

Table 1: Stakeholder analysis

It is important to include and analyze the stakeholders in our research because analyzing both direct and indirect stakeholders is a commitment of VSD. VSD has come to rest on the following definition of human values: *what is important to people in their lives, with a focus on ethics and morality* (Friedman & Hendry, 2019). Additionally, analyzing the stakeholders and their values is a part of the conceptual investigation of VSD (Friedman et al., 2013).

Ondernemersvereniging Delftse Hout (ODH)
The most prominent stakeholder is the ODH. This overarching actor is concerned with promoting the overall prosperity in the Delftse Hout region. To this end, they have decided to

launch this project to provide more lighting in the area in a way that is not harmful for the environment. A large number of stakeholders, all with their own agendas and stakes, need to be considered. Where one stakeholder might be solely interested in increasing the safety in the area, thus increasing the lighting, another stakeholder might be more interested in preserving nature, thus keeping the amount of lighting at a minimum. This is relevant, because the ODH is an overarching stakeholder, representing the local entrepreneurs as one unit. The ODH provides a means of connecting the powerful actors who have stakes in redesigning the lighting in the region. Their final goal is promoting the prosperity in the Delftse Hout by reaching an overall agreement in which all values and interests of the different stakeholders are taken into account. They have a large regulatory power, since they design the way in which the program is set up and executed, and because they are the problem owners. The extent of their involvement is large as well, being the overarching and regulatory actor of the program. In the Light Touch report (Stone et al., 2020) their working method is described extensively. This report describes clearly how the ODH wishes to 'improve lighting' on one hand and 'preserve darkness' on the other hand. Moreover, the report describes how the ODH takes into account the opinions of different stakeholders - where humans and wildlife are valued equally- when it comes to designing new lighting in the Delftse Hout.

Entrepreneurs

In this analysis, entrepreneurs are split into four niches. These are sport facilities, catering industry, retail companies, and nature and activity-oriented entrepreneurs. Catering industry includes restaurants and cafes. Retail companies are stores like IKEA. Nature and activity-oriented entrepreneurs include boat and paddle board rentals (Roots beleidsadvies & Ondernemingsvereniging Delftse Hout, 2020). All of these entrepreneurs have the core interest of running a successful business. Although this is, for the most part, defined by how much revenue or income their company generates, there are still some major differences in the interests of these four types of entrepreneurs. However, the extent of their involvement and power is undeniably large.

The value of sport facilities stems from two key places. Firstly, customers and the value of the assets that they hold. They make more money the more people use their facilities. Their interests therefore lie in creating an environment where people feel welcome, safe, and want to go back time and time again. With this in mind, sports facilities want increased lighting for people traveling to and from the center. However, the value of their property is also an important factor. When the businesses around the sports facilities flourish, the property will become more valuable. So, because the neighboring businesses have an interest in preserving the natural environment, this also becomes an interest of the sport facilities. The property value may be positively affected by the homes that are built close by. This is the case for all nearby businesses.

The catering and retail industries are the most similar. The only relevant difference being that catering industries sell services and retail industries products. Both try to focus on customer experience. While every company has their own unique experience inside, they all share the same external one of customers entering and leaving the premises. Like sport facilities, they want customers to feel and be safe and would therefore be in favor of better lighting. An important difference, however, is that catering industries focus on selling services and experiences that rely more on the surrounding nature. They are more vocal about preserving nature than the commercial industries, who mainly sell products inside their own facilities.

Nature and activity entrepreneurs are the most reliant on the Delftse Hout environment. Seeing how their customers are there purely for the experience of being in nature, activity entrepreneurs have the most at stake. While safety is still important, these stakeholders would most benefit from lighting that isn't intrusive and doesn't take away from the experiences that they sell.

Environment

While atypical, the environment has been included as a stakeholder that is passive and has little impact and involvement. The environment can have an extremely large impact given time, but on such a small scale, any power that it has is given by the people dictating change. Artificial light at night can really disturb biomes, ecosystems, species, and behaviors. Many organisms are extremely sensitive to light at night, as they use it to orientate themselves, and many others would still have their communication, reproduction, and safety altered. The effects of artificial light in the natural area could therefore range from an alteration of organism physiology to a change in the structure of ecological communities (Davies & Smyth, 2018).

Wildlife and nature watch/sanctuary and environmental groups

There are multiple stakeholders with an interest in nature and the wider environment in Delftse Hout. Values and interests are tied to preserving the ecological diversity in the flora and fauna present in the area. Many of them actively engage in the promotion of nature in the area: they keep an eye on the environment and note changes, create safe spaces for animals in petting zoos, etcetera. Aside from this, they are personally - and some financially (the petting zoo for example) - interested in realising a pleasant environment for recreational visitors in Delftse Hout. They attempt to combine the preservation of the environment with the needs of visitors. When it comes to introducing more lighting in the Delftse Hout they will most likely act from a defensive standpoint, arguing more lighting is harmful for the environment and should be implemented carefully and with as little intensity as possible. There is plenty of literature accounting for this matter, like mentioned under the stakeholder environment. Therefore, this stakeholder would prefer to keep artificial light at a minimum to refrain from harming the environment. This slightly conflicts with the viewpoint of some of the other stakeholders who argue that more lighting would increase safety - albeit without distinguishing between perceived and actual safety. However, this stakeholder does to some extent agree with this viewpoint since they do value safety. The extent of this group's power comes down to their role and votes in the decision-making process, in which they are equal to most of the other 'active members'. Therefore, the extent of their power is average. The extent of their involvement is average because this innovation aims to alter the environment that they concern themselves with, but some also focus on other areas than the Delftse Hout.

Recreational visitors and organized sports

One of the most present stakeholders in the Delftse Hout are the recreational visitors. Every day they are clearly present in the area keeping busy with a plurality of activities. Within this group there is a relatively large distinction when it comes to their values and interests. All recreational visitors have their own perception of what is important and morally justifiable. When it comes to introducing more lighting in the area one person might see this as 'good' because it increases the level of safety, however another person might see this as 'bad' because of the harm it does to the environment. Thus, the definition of what is seen as a 'good environment' mostly differs per recreational visitor. However, principles such as safety and

wellbeing of nature are seen to be prominent values among this group. These visitors usually do not think about lighting unless it forms an issue for them. These issues mostly concern safety, for example when a crime is committed in the area or when they feel unsafe.

Organized sports are a big activity daily hosted by the Delftse Hout, thanks to its big space and sports facilities. Team members have to travel back after practices or matches everyday going through the park, and they currently do not feel safe doing so. Because sport practices usually end quite late, it is already dark when members have to leave, especially in the winter. The lack of lightning on their way out makes their perceived safety very low. Because many of the organized sports are directed to children, who have to leave the facility at night, parents are worried about their kids' safety, and you never see them walking alone. This group will praise an increase of lightning in the area, so they gain visibility at night when they leave sport facilities. This will improve their feelings of safety.

Where the entrepreneurs and other stakeholders have direct power, these groups of stakeholders have indirect power in the decision-making process thanks to their large level of involvement as regular users and customers in the area. Because the stakeholders who have direct power are in some cases dependent on the recreational visitors' and organized sports members' opinions, they exercise their indirect power through their combined opinion.

Commuters

Apart from the multiple activities it offers, the Delftse Hout is also used as a passthrough area for commuters, mostly by bike, moving between the adjacent cities. In the report from 2020, the issues arising when travelling through the Delftse Hout are evident. Narrow and disjunct roads, cycling lanes shared with cars and pedestrians make commuting already complicated and unsafe. (Stone et al., 2020). This is combined with insufficient and inconsistent lighting throughout the way, even leaving some parts completely in the dark. Thus, commuters' perceived safety is also low. They push for a solution that involves good and consistent lightning across all commuting lanes, so their visibility increases and therefore their safety.

Because commuters are not generally associated with a specific entrepreneur with direct power in the area. Considering that it is a less integrated and unified group of people, their extent of power is small, as well as their involvement in the innovation.

Municipality

The Delftse Hout belongs to the municipality of Delft. The institution could have the power to decide on and implement a lighting solution in the Delftse Hout. However, the message is that there is no budget margin to dedicate to it, which means the municipality has not gotten involved at all in the innovation project. As seen in table 1 the municipality is identified as a passive stakeholder, however through involving themselves voluntarily with the project they would become an active stakeholder. A related factor is that the area of the Delftse Hout does not have an area manager as opposed to other areas. They have not been in close contact with us or with the other stakeholders. Nonetheless, they are interested in someone else bringing improvement to the Delftse Hout, making it as appealing to its citizens as possible, also taking into account that ensuring more customers in the future would bring more expenditure and investment in the area. Even if they did not give an input for the project, according to their policy budget it seems like they also pursue the promotion of sustainable and environmental goals. In relation with the Delftse Hout, they mention the values of values of the landscape and nature (Gemeente Delft, n.d.).

Atelier LEK

Atelier LEK is an independent design studio that specializes in lighting: lighting in public spaces, lighting for the exterior and lighting for the interior of buildings. They have been involved in the area's lighting policies and have a vested interest in the publicity that comes with any solution. They are an emerging company in an emerging market, so projects like these serve to consolidate their position in the urban design world. They have an interest in creating an effective solution, but also in a unique solution pertaining to their expertise with light. A solution that any architect or civil engineer could come up with would reinforce the notion that their company and market is an excess. Therefore, innovation is highly valued to this stakeholder.

Aside from typical corporate values it seems that personal values from the company's designers are incorporated. These include environmentalism; well-being both for nature and humans; as well as balance, care, and temperance with regard to implementation. The extent of their power is largely defined by the fact that they have been called in as specialists. They have absolute intellectual authority in this project, as well as the cooperation and trust of the ODH. Although they are not responsible for the execution of the project, they will evaluate the end-product and the process leading up to that. This makes the extent of their power large.

Lighting manufacturers

It is questionable at this stage of the project if lighting manufacturers are relevant stakeholders at all. This hinges on a few factors, namely: if lights are bought as a solution; the size of the involved company; the size of the order; the appearance of their namesake; the distance to Delftse Hout. It all depends on the solution.

For a large lighting manufacturer, like Philips for example, this project is insignificant unless it can provide them with marketing potential. Although they would gladly sell materials, they are not expected to seek further involvement.

Small to medium-sized manufacturers are expected to seek involvement outside of sales, if they are based relatively nearby.

Chapter 3 - Problem Definition

To be able to come up with a suitable and implementable solution for the problems, stated in chapter 1, and the stakeholders, stated in chapter 2, a problem definition should be indicated. This chapter highlights an overview of all the actual problems, a statement and demarcation of the problem, a justification of the chosen problem and (re)design requirements. This chapter will also show a connection to the sustainable development goals of the United Nation. This chapter connects to the empirical investigation of VSD. The empirical investigation focuses on the human context the artefact will be used in (Friedman et al., 2013).

In the report 'Light Touch - A Vision for the Delftse Hout at Night' several hotspots, places where the problems are most prevalent, are highlighted. These areas include:
1. Highway underpasses
2. Cycling route 'Aan het Verlaat'
3. Cycling route 'Along highway and sports fields'
4. Sportpark 'Brasserskade'.

Image 1: Hotspots

An overarching problem for all these areas is the lack of funding to combat the underlying issues with the area's light management. These underlying issues, which are covered in chapter 1, are the actual safety of visitors, the perceived safety of visitors, the detriments to nature. However, this results in another underlying issue, namely the effects on businesses in the area. The poor perception of safety has a harmful effect on the local businesses, whose customers are anxious to visit during night and twilight hours. This has become a bother for entrepreneurs because many of their businesses rely on darkness and unaltered nature. At the same time, the customers that visit these businesses for their spot in nature are arguing that nature should yield to their desire for lighting.

When considering all the actual and potential problems which were identified in the preceding stages a certain demarcation can be identified. This demarcation is a result of the different core values, all stakeholders involved, attached to the concept of introducing lighting in the Delftse Hout. As listed in chapter 2 there is a wide array of stakeholders who all have a different view on implementing lighting in the Delftse Hout and the way in which this should be done. However, in all these divergent opinions, two general trends can be seen as valued by the involved stakeholders: the first one being perceived safety and the second one being the environment. From this the demarcation arises on which our solution, explained in the next chapters, will be substantiated. This is a demarcation between safety and nature. In the end, the goal will be to come to a solution which accommodates the needs of all stakeholders to some extent. In other words, the goal is 'to find a way in which more lighting can be implemented in the Delftse Hout area to increase perceived safety, without causing harm to the natural environment'. The following steps in the report will be focused on three concepts: 1) lighting to improve perceived safety in the area; 2) lighting which integrates best in the natural environment; 3) combining the first two concepts in such a way that they do not interfere (too much) with each other. Completing these three steps should result in an outcome which accommodates the values and interests of the stakeholders and other parties involved. Resulting in better business for the entrepreneurs and their customers, a safer experience for recreational visitors and all these goals are reached without harming the environment.

Chapter 3.1 - *Problem Specification*

To narrow the solution down, the chosen hotspot will be the cycling routes going through the Delftse Hout. This hotspot is clearly designated within the 'Light Touch - A Vision for the Delftse Hout at Night' report, so the area where the solution has to be implemented is also demarcated. As stated in the report, the priority is on making the path along Aan het Verlaat and the Middelweg better. This crosses the dark core of the park, has insufficient to nonexistent lighting, and has an inconsistent fragmented route. Therefore, our main objective is to give the cycling routes in the Delftse Hout an effective, consistent, and eco-friendly light, which aims at a symbiosis between improving perceived safety and integrating best in the natural environment. However, the improvement of the route also considers making a more direct lane and extending the Middelweg towards the east. Be it shorter or longer in the end, it will need from us a correct lighting design. Image 2 gives an idea of the location and structure of the path and its possible extensions. The red line shows the existing cycling lanes, and the yellow line shows a proposal to extend the cycling lanes. To be able to eliminate the problem, the underlying issues have to be taken into account. For this cycling route the most relevant underlying issues consist of the perceived safety of the commuters, the effects on the businesses, especially the ones that operate in the dark, and the detriments to nature.
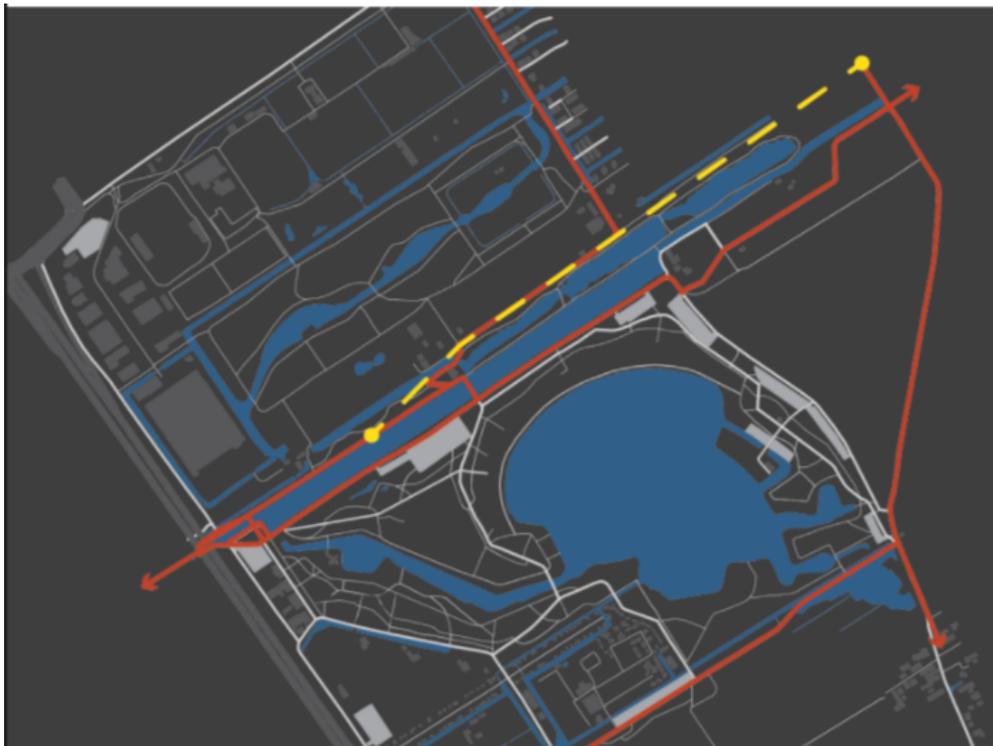

Image 2: Cycling routes in the Delftse Hout

This problem is chosen because of its urgency and the effect it has on the underlying issues. These issues can only be resolved if they are tackled on a larger scope. Since this cycling route attracts a lot of visitors and is right in the middle of the Delftse Hout it also may be the only way to tackle as many of the underlying issues as possible. In this hotspot the lack of a good lighting design has very real serious consequences, as it minimizes traffic safety and the visibility needed to notice any dangers in the road. The World Health Organization, WHO, states that "Seeing and being seen are fundamental prerequisites for the safety of all road

users." (WHO, 2004). Inadequate visibility is one of the most important risk factors for road crashes. Two-wheelers are even more affected (WHO, 2004). Therefore, the required action is urgent, and the potential benefits of our intervention are very high.

Chapter 3.2 - *Design Requirements and Goals*

As a public project, the requirements for this design are more stringent than those for products placed on the consumer market. After all, it needs to take the values of the society into account. In this case there are five values that are identified as important: health and safety, environmental, economic, and function and technical. The reasoning behind these are as follows:

- Health and safety - the design should provide enough (effective) light to make a substantial positive change in both the perceived safety of the users of the cycling lanes and their real safety against the dangers of the path arising from bad visibility and lack of space. As is shown in chapter 2, safety is a key concern for many, if not all, stakeholders. The project design should not only be structurally safe for visitors to be near and/or use, but also explicitly carry this social value throughout the design process, making clear its VSD as defined in Van den Hoven (2013) and Friedman & Hendry (2019).
- Environmental - an important value consists of the environment in the Delftse Hout. The biodiversity should not be harmed in a substantial way which would lead to a decrease of it. This is important for many businesses located in the area, but also for the wellbeing of the environment itself. This requirement relates to the Sustainable Development Goals, which will be discussed in chapter 3.3.
- Economic - since there is little to no budget to execute this project, the economic side should be kept in mind through every step. The solution should be able to be incorporated without costing an arm and a leg. What also has to be kept in mind is where the money to execute the solution is coming from.
- Function and technical - the final design of this project should be one that functions properly and is technically correct/complete. This would ensure quality and functionality of the design. This will be tested through the characteristics of note in Appendix B.

The incorporation of the project could lead to some unwanted but possible side effects, these could consist of the following three side effects. Firstly, damaging the environment in the Delftse Hout. If the environment is consistently not taken into account, it could be damaged permanently and irreversibly. This could, for example, lead to a damaged and unhealthy landscape, which is less attractive for visitors. This connects to the second unwanted side effect, namely having a negative outcome for the businesses in the area. Lastly, more criminal/unwanted actions could arise because the design may allow for more shadows in the area. In combining these factors, the goals for our innovation project emerged. They have been grouped and presented in the following goal tree diagram:
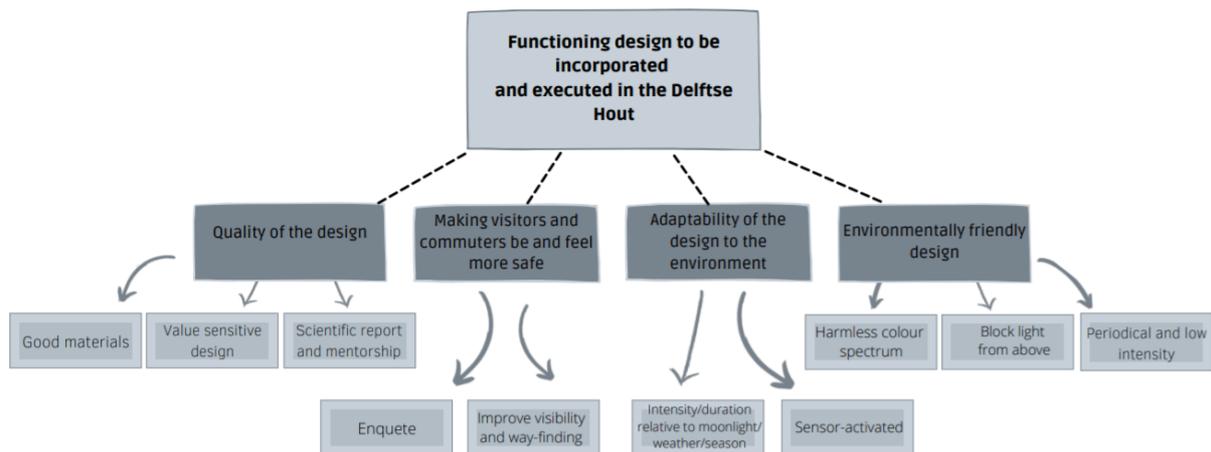
Image 3: Goal tree

The goal tree that is pictured in image 3 connects to several stakeholders. Firstly, 'making visitors and commuters be and feel more safe' portrays the values of multiple stakeholders, namely the ODH, the entrepreneurs, the recreational visitors, the commuters, and the organized sports. The two branches on the far right portray the values of the nature and activity entrepreneurs, the environment, and the wildlife and nature watch, sanctuary, and environmental NGOs.

Chapter 3.3 - *Sustainable Development Goals*

When it comes to responsible innovation a yardstick which is often used to measure the effects of new inventions and designs are the Sustainable Development Goals (SDGs) as introduced by the United Nations (2015). These SDGs are the global agenda regarding the sustainable development of multiple international sectors; they were introduced in 2015 and are set up to be reached by the year 2030.

For the design of lighting in the Delftse Hout area the SDGs will be introduced as a yardstick as well. The most relevant SDG's will be introduced, and a reflection will be given on how the solution design could include them.

Seeing the values accompanying the design of lighting for the Delftse Hout area there are two SDG's which particularly seem to have the same goals. These are the SDGs: 11) Sustainable Cities and Communities and 15) Life on Land. SDG 11 is arguably best applicable to the lighting design project; on the U.N. website it is described as follows: ''Make cities and human settlements inclusive, safe, resilient and sustainable'' (United Nations, 2015). Standing out in this description are the terms 'safe' and 'sustainable', these incorporate the dichotomy between the stakeholders as discussed in the previous chapter. The goal here is to create an environment of cohabitation for humans as well as nature. Flora and fauna should become a more integrated part of cities and other areas where humans are commonly present. The Delftse Hout is a good example of such an area. It is a natural environment open for civilians to partake their daily activities in or travel through on their route to other locations. When implementing more lighting in the area this increases safety, while doing so sustainability will be considered as well as preserving the flora and fauna and thus making a connection to SDG 11.

Then there is SDG 15, described on the U.N. website as follows: ''Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss'' (United Nations, 2015). Here the goal is mainly focused on the environment itself and how the impact humans might inflict upon it should be reduced. In this description the sustainable use of terrestrial ecosystems and halt of biodiversity loss are most depicting for the Delftse Hout lighting project. When implementing more lighting in the Delftse Hout this should be done in a way which doesn't inflict harm upon the environment, thus using the terrestrial ecosystem in a sustainable manner. The same goes for putting a halt to biodiversity loss; here too there should be made use of lighting which doesn't inflict harm to certain species of flora and fauna vulnerable to more lighting at night.

Chapter 4 - Solution (Re)Design

As explained in the previous chapters, the problems identified in the Delftse Hout have to do with safety and perception of safety for visitors, the waste light in the area, and the lack of budget. The solutions can therefore be separated into advice and lighting solutions, which will be discussed in this chapter. Additionally, the working principles of these solutions will be discussed and a multi criteria analysis will be conducted to choose a specific solution.

Chapter 4.1 - *Advice*

In order to implement any lighting solution, it is important to keep non-technical factors such as permits, funding, and policy and awareness in mind. Each of these factors can be complete reports unto themselves, so we will only give a short description of them here below as well as a framework on how to get started on one factor we find most important for our core stakeholders.

Option 1
This option would consist of advice focusing on getting permits from municipalities to execute ideas and projects.

Option 2
In this option the factor of funding would be highlighted. This solution would focus on how the ODH, and the entrepreneurs could set up successful subsidy proposals.

Option 3
This option regards broadening the support of the stakeholders, for example the visitors and municipalities, through policies and awareness.

To evaluate the solutions above, they will be ranked on one key aspect, namely usefulness of the advice. Here we find option 2 to be the most useful, because the lack of budget is a crucial part of the issues. The solutions would not be able to be implemented without solving this problem.

Chapter 4.2 - *Lighting*

Lighting has already been found to be a solution for the problems mentioned in the previous chapters. Within lighting, there is a vast amount of creative solutions that can provide light for visitors to travel safely while also inspiring the community to be more mindful of the environment. To take the environment and natural stakeholders into account, there are also several characteristics of light that can be researched. It is only a matter of finding the right combination of characteristics from the following categories that yields the best results. Through a brainstorm session with Atelier Lek several possible ideas were created. The design process combined the design guidelines in Appendix C. Following this brainstorm session some ideas were combined and relevant ideas were chosen for this report. These will be discussed below.

Solution 1 - Phosphorescent trail
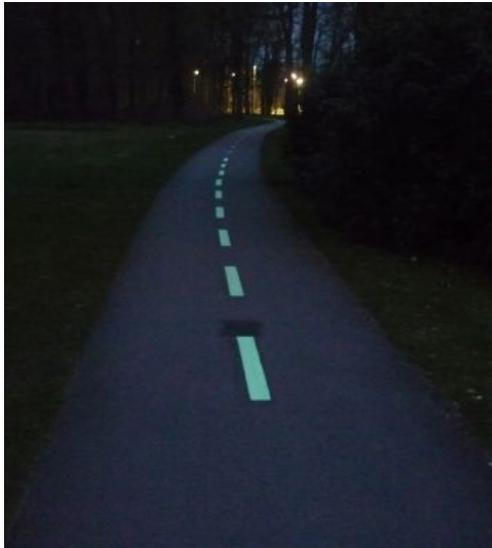
Image 4: Phosphorescent trail

This solution consists of painting a phosphorescent trail that would act as road markings along the bike path. An idea that made headlines in 2014 when Dutch designer Daan Roosegaarde attempted to implement this in an area by Oss. The paint needs to charge during the day with enough sunlight in order to illuminate properly at night. Problems from the 2014 trial mainly occurred due to the paint washing away due to rainfall.

New trials in France are currently underway that may have better results. Paint would be cheaper than lampposts, consume zero electricity, and wouldn't contribute as much to light pollution. A notion that should be made is that marks do not illuminate paths fully.

Solution 2 - LED strips in trees
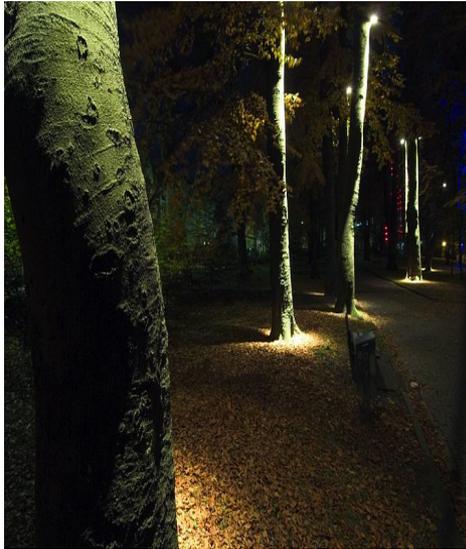
Image 5: Lighting in trees

This solution consists of LED light strips placed on the trees which are activated by motion sensors. These lights would be programmed to light spectra that do not harm the environment and take the moon cycle into account for its intensity. This solution would look more natural than metal posts every 10 meters or so. Light would shine down and illuminate the entire path and can be programmed to only turn on when bikers are riding through it. Strips can either hang parallel to the road or across every 10 meters. Care is needed to make sure strips are secure.

Solution 3 - LED posts

Image 6: Lighting posts

This solution consists of posts with LEDs as a lighting source that turn on or off based on the detected motion. A very generic solution within cities and parks, LED posts are reliable and can be designed to emit the least amount of light necessary in the proper direction.

Solution 4 - Reflective posts
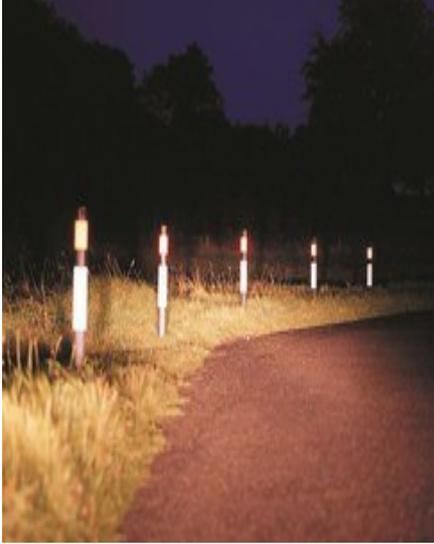
Image 7: Reflective light

This solution relies on the bikers for light. Reflective posts would be placed in intervals and would collect the light from the bikes and concentrate it onto the boundaries of the paths, thereby improving safety.

Solution 5 - LED bar

Image 8: LED bar

This solution is comprised of a low, downward-facing LED bar along the bike paths that illuminates the road surface; as well as a hub that manages the lights' behavior. This management will include responses to motion sensors that are placed along the route intermittently so that the system will only illuminate areas that are in use, leaving areas without traffic unlit. Aside from this the hub will manage the light intensity and color so that it dampens the fluctuations in the moonlight intensity and color, making it so the lighting conditions on the path are always like that of a full moon. This means that the light is in antiphase with the moon and will burn at its brightest when the moon is at its dimmest and it will be off on a night with a full moon and clear skies.

Chapter 4.3 - *Working principle*

A solution is only as good as the extent to which it fulfills its design requirements and connects to its problem definition. The main objective is to give the cycling routes in the Delftse Hout an effective, consistent, and eco-friendly light, which aims at a symbiosis between improving perceived safety and integrating best in the natural environment. The design requirements have been included in chapter three of this report, and in short, they are: *health and safety, environment, and economic aspects.* The following sections will go over these requirements and assess each solution's effectiveness.

Health and safety
Health and safety requirements relate to perceived safety (PS) and actual safety (AS) in the multi criteria analysis from chapter 4.4.

Solution 1 promotes safe travel through clearly demarcating the bike lane. This helps users to navigate in the dark and to stay on the road. The phosphorescent lighting does as good as nothing to illuminate the area around itself, meaning that this solution would constitute a conscious decision to sacrifice road safety for the preservation of darkness. Therefore, it scores a 2 on PS and a 3 on AS.

Solution 2 promotes safe travel as well as perceived safety in the area on and around the bike paths. It contributes to safe traffic by virtue of illuminating the road so that users can see it and each other. Aside from this, it also illuminates the peripheries where pedestrians might otherwise be vulnerable in the dark. A hiatus in its performance with regards to this design requirement could be the exploitation of its motion sensors - by remaining motionless for a certain amount of time for example - which could give criminals an opportunity to ambush those who perceive their surroundings as safe. Therefore, it scores a 4 on PS and a 4 on AS.

Solution 3 promotes health and safety in the same way as solution 2 and all but one of their vulnerabilities are shared. Solution 3 would feature a more robust construction, making it more durable and therefore better able to withstand vandalism. Therefore, it scores a 5 on PS and a 5 on AS.

Solution 4 promotes health and safety by more efficiently using light introduced into the environment by cyclists. It would aid the visibility of oncoming traffic and illuminate the area slightly. This would, however, exacerbate issues with users who deem bike lights unnecessary. Like solution 1, this solution forgoes potential further promotion of this design requirement in favor of environmental and economic performance. Therefore, it scores a 3 on PS and a 3 on AS.

Solution 5 promotes health and safety through diffuse, low-intensity illumination of the road. The intent is to adjust to the conditions surrounding the lights so that it blends with natural light in terms of its spectral range and in terms of its intensity. Cyclists should see a clear, lit bike path, but not lit to the extent that the surrounding area would be too dark to observe without taking their eyes off the road. Therefore, it scores a 5 on PS and a 5 on AS.

Environment

Environmental requirements relate to low impact on nature (LIN) and low impact on wildlife (LIW) in the multi criteria analysis from chapter 4.4.

Solution 1 promotes the preservation of the environment by limiting the amount of light introduced. Many supplies of phosphorescent pigment also state that it is non-toxic. The demarcation of road markings with phosphorescent paint is considered to be a safety improvement with minimal environmental impact. Therefore, it scores a 4 on LIN and a 4 on LIW.

Solution 2 promotes the preservation of the environment by providing reactive lighting - meaning that the system will standby in waiting for passersby before turning itself on. The system will shut itself off after a certain amount of time since the last measured movement and selectively turn on and off lights depending on the location of movements. Aside from this reactive lighting system, its construction will blend into the trees. This will reduce the impact on the look of the area as well as minimize harm to nature when installing the system. However, the lights need to be connected to the trees which might harm them slightly. Therefore, it scores a 3 on LIN and a 4 on LIW.

Solution 3 promotes the preservation of the environment in a similar fashion to solution 2, but its installation and looks are not as friendly to the environment. This solution will require digging and the posts will be more of an eyesore than the more inconspicuous mounting method of solution 2. The reactive lighting system is included in this system too. However, this solution will not take the moon cycle and wildlife light spectra into account. Therefore, it scores a 3 on LIN and a 3 on LIW.

Solution 4 promotes the preservation of the environment by providing an alternative solution to introducing permanent artificial lighting infrastructure, instead opting to reuse the light from bike lights. This solution will far more accurately affect areas in use and leave those not in use unaffected, even though this is a passive system. Therefore, it scores a 4 on LIN and a 4 on LIW.

Solution 5 promotes the preservation of the environment by adjusting its output to always optimally fit into the environment. By creating conditions like those of a full moon on the path the animals and plants surrounding the area will not have a type of light unnatural to them introduced into their habitats. It is expected that this is preferable to conventional lighting, although research into this interface between man and nature is lacking. Therefore, it scores a 3.5 on LIN and a 3.5 on LIW.

Economic

Economic requirements relate to costs (C), durability (D), and ease of implementation (EI) in the multi criteria analysis from chapter 4.4.

Solution 1 is a relatively cheaper solution when taking the other solutions into account. The costs to implement this solution would consist of the paint itself, and the labor hours. However, phosphorescent paint is slightly more expensive than regular paint used on cycling lanes.

These trails also have to be painted over every couple of years. Therefore, it scores a 5 on C, a 3 on D and a 5 on EI.

Solution 2 is economically feasible because of the cheapness of LED strips. A quick browse on the internet reveals that these go for as low a 1 euro/meter. The expenses for this solution would mainly consist of installation, casing, and system engineering. These are expected to surpass the budget for prototyping. Therefore, it scores a 3 on C, a 3 on D and a 2 on EI.

Solution 3 is as expensive as normal park or streetlights, with the cost of reactivity added on top. This is also expected to surpass the aforementioned budget. These lights are also already designed to be durable. Therefore, it scores a 2 on C, a 4 on D and a 2 on EI.

Solution 4 is a relatively cheap solution to the issues raised by the ODH. It would consist of rust-resistant steel piping embedded in the soil, with reflectors attached to them. This is similar to reflectors along highways, and these can be adapted for use in this context. Therefore, it scores a 4 on C, a 4 on D and a 4 on EI.

Solution 5 is relatively expensive. The casing for the LEDs as well as the extensive amount of sensors and/or online data-collection required to quench this system its thirst for information about the lighting conditions make up a large portion of the costs, but development is expected to prove most costly, more than these two already costly aspects to this solution. Therefore, it scores a 5 on C, a 4 on D and a 2 on EI.

Chapter 4.4 - *Multi Criteria Analysis*

To evaluate the solutions above a multi criteria analysis (MCA) will be conducted, meaning that the solutions will be ranked on several key aspects. These aspects partially extracted from the goal tree and partially from the stakeholder interests. The criteria are low impact on nature; low impact on wildlife; costs; perceived safety; actual safety; sustainability and ease of implementation. The importance of these criteria is weighed by multipliers. The importance of the criteria derives from which aspects are frequently seen as important by the majority of stakeholders. All the solutions will be ranked on a score of 1 to 5 on each criterion by the following principles. Low impact on nature and wildlife will be ranked high, a high impact will get low rankings. Higher costs will get lower rankings. Higher safety, both perceived and actual, will get higher rankings. Higher sustainability and easier implementation will get higher rankings.

	Multiplier (0-1)	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Low impact on nature	.9	4	3	3	4	3.5
Low impact on wildlife	.9	4	4	3	4	3.5
Costs	.7	5	3	2	4	2
Perceived safety	1	2	4	5	3	5
Actual safety	1	3	4	5	3	5
Durability	.5	3	3	4	4	4
Ease of implementation	.6	5	2	2	4	2
Total		**19.6**	**19.8**	**20**	**20.4**	**20.9**

Table 2: Multi criteria analysis

Taking the multi criteria analysis into account, solution 5 ranked the highest score. This solution will be elaborated on in the rest of this chapter and report.

The lighting design in Solution 5, consisting in a low, downward-facing LED-bar along the bike paths, has been found to offer the best combination of values. When it comes to keeping a low impact on nature and wildlife, this is accomplished by regulating light to accommodate the environment. It is directed to the lane and blocked from above, so waste light is minimized and flying animals are not confused by it. It is also adaptable to the moon cycle for its intensity, so it does not shine too bright when there is already enough light. Moreover, emitted light has the least harmful color spectrum to reduce the disturbing of local fauna. Several forms of wildlife react differently on different light spectra. Therefore, more research will be done in the following chapters on which light spectrum should be used in which area and at what time.

And finally, it would also only activate when a biker is passing through, reducing the periods of time that artificial lights disturb the dark.

The costs for implementing this solution would be considerable, as with every innovative lighting solution this would have to be designed, manufactured, and installed. These aspects all bring costs with them. However, as it was stated before thanks to this project the designing costs are minimized, and this is found to be the best option to invest in as a potential solver of the hotspot's problem. Electricity costs would also have to be accounted for, although LEDs are cheap sources of light.

We believe a consistent and automatic lighting throughout the bike lanes which directs the bikers and does not cause blinding effects will considerably increase the perceived safety of the users. It makes a big difference from completely dark and hard to follow paths as they were. The actual safety of the bike lanes will also be highly improved, as the LED strips along their extension will offer the rider much more visibility and wayfinding. This way possible dangers such as a change in the lane or the presence of other vehicles or pedestrians, which are recurrent issues there as we previously identified, will be detected.

As for sustainability, the LEDs should be able to run for a long time without a problem. With a compact and reinforced design, the installation should suffer no quick harm and only require low periodic maintenance. The implementation requires some time and effort because of its long extension and mainly due to the process of designing and programming the light in adaptation to the environment, which only means that this value, amongst others, is thoroughly considered through the stages.

Chapter 5- Solution Implementation

The previous chapter discussed several solutions to solve the stated problems in the first three chapters. This chapter will put a focus on option 2, advice on funding, and solution 5, LED bars.

Firstly, an advice will be given on how the ODH, and the entrepreneurs could set up successful subsidy proposals. Additionally, a detailed plan will be drafted to successfully implement LED bars in the Delftse Hout. This plan will focus on the design of the solution, the prototyping, which will be done in collaboration with another group of students in the context of the Light Challenge, and the actual implementation.

Chapter 6 - Solution Evaluation

This chapter will highlight the effect the solution has on the stakeholders. Firstly, a post-test evaluation will be conducted. This will consist of a list with the stakeholders and their (dis)satisfaction with the solution. Secondly, the lessons learned for future problems in the same context will be drawn. Lastly, a scientific and critical reflection will be added.

The post-test evaluation will include an examination of how successful the values were implemented within the solution, which connects to the technical investigation of VSD. Technical investigation regards the effect of technical properties or an artefact on human values (Friedman et al., 2013). Additionally, a possible way to conclude the (dis)satisfaction of the stakeholders is through surveys and interviews.

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Appendices

This attachment to the report serves to provide the reader with extra documentation.

Appendix A - Interview

This appendix contains the interview notes from the interview with the problem owner on September 23, 2020.

1. How did you come to the conclusion that the Delftse Hout needs lighting innovation?

Loads of kids who are sporting, survey among the stakeholders → safety and light had the

highest priority. People realize that nature also lives here, which is one of the main priorities.

The light should be there when it's needed (example when kids come from their sports). It should react to movement (is the dream). Gemeente Delft doesn't have a focus/ money for this project.
Finding ways to find a budget.

2. What steps have already been taken to achieve the 'responsible lighting strategy'? Please summarize the current lighting strategy and give us an assessment.

I don't think anything has changed. There was a project a couple of years ago (2019/2020). In general, a kind of conflict between safety (more light) and including nature/ sustainability (impact of lighting). A lot of entrepreneurs have the essence to preserve nature and biodiversity. But their clients consider a lack of safety. This leads to a conflict. How can this meet and how can you find innovative solutions? This can be a way of looking at a problem from a different angle and finding a solution that can fit everybody.

3. How are you personally involved in the development of Delftse Hout?

Manager of the ondernemersvereniging. Project leader of the entrepreneurs. The board picks some activities each year (safety, quality of water, collectivity with tricheon).

4. Do you expect the area's development to continue to expand the recreational possibilities or do you expect it to be steered toward a more natural, primal environment?

There will be a lot of houses in the area of Delft. The citizens will need recreation (more crowd). We are all aware that nature is a very important aspect (biodiversity, etc.) This also kind of leads to a conflict.
Delft doesn't have a clear vision, because of lack of money. This area also doesn't have an area manager.
There is expected to be more people without harming nature.
Housing plans in → look at the woonvisie delft from 2019

5. What people visit the area and what do they do there? Any remarkable trends?

There are different kinds of groups here:
Elders, student, fishers, swimmers, people from the Hague, recreating purposes, sports, BBQ

6. Are there people that have to go through the Delftse Hout without a choice (e.g., Commuting)?

There is a lot of traffic. It is a shortcut to Nootdorp.

Bicycle lane from the Hague to Delfgauw → want to make it more accessible, because right now the road is very narrow. Therefore, this may lead to more commuting

The question is what innovations are needed (is lighting the only thing).

There is not that much attention to this area, but it is still managed like years ago.

For now, to be realistic it is important to choose one part. Where can we make the biggest leap in improving the lighting/quality. A focus on the project that also inspires us. Focus on a location where we think there is something to gain.

Entrepreneurs from the area want to get the certificate.

Lighting is crossing over boundaries. Therefore, there are other influencing factors. → This leads to wanting a policy focusing on the boundaries and the overlapping lighting from the surroundings. Why is this allowed (this area is the most lit in all of Europe).

7. What other parties are involved in our project?

All 120 entrepreneurs are interested in the lighting (but Jaap represents them), province of Zuid-Holland and Iris.

8. How do you think that Delftse Hout is perceived by the public? Do you think this image is correct?

Scary in the evening (for example the kids who are doing sports are brought here and picked up by buddies to escort them through the area (because their parents don't want them to travel alone at night).

There are some activities that make people feel unsafe (drugs, doing balloons). They usually don't disrupt anybody. The lighting will probably eradicate them.

→ Entrepreneurs 'it does not get the attention it deserves)

Healthy spot to recreate

9. Do you aim to change the view the public has regarding the Delftse Hout through lighting innovation?

Yes, safety & public image

10. Has Atelier LEK done any similar projects for other municipalities? If so, please elaborate.

In every project this conflict plays a part. There is a conflict between the intentions of some people. That's why sometimes people want camara's. Lighting isn't always the solution to the problem.

Next step would be cameras and lighting → leads to kind of a big brother / privacy concerns.

But camera's also give an uneasy feeling, because why would there be any camera's if it is safe.

There is a need for more tools to handle these problems.

11. (If the answer to question 1 is yes) In your experience, what are the best ways of introducing innovative lighting in natural areas?

In the projects we try to reframe the assignment. Trying to focus on the quality in the area and focus the lighting on the positive aspects.
Otherwise, it could lead to competitions between people who are involved.
Putting much more attention on the factors that are positive than the negative aspects.
The designs are trying to encourage good behavior

12. In your experience, what kind of light is the best for a place people feel safe in?

The research about that is very limited. There started to be a focus on this in the last couple

of years. There is much more attention to healthy parts of lighting and more focus on the effect

on nature (bats, moths, etc.) → this has an effect on the food chain (domino effect).

Wageningen university, red spectrum lighting had the least amount of impact. Different animals react differently to lighting. Least amount of lumen, the better.
Modes of dilation in your eyes. At night you don't see colours as much, but you see depth. Green lighting may help with this.
Thinking about stands of the moon.

13. How do you see the communication, and how do you want to be kept updated on the project?

Help whenever you have questions and meet on a regular basis.

14. It seems that this discussion has been going on for more than a decade. What is stopping you from taking action?

More or less because of the survey (in 2017 & 2020) among the entrepreneurs. They want to do something, but they don't have the budget.

15. How is the Light Challenging a part of our project? What is in Heerenveen? Is it worth the trip? Maybe hitch a ride w/ begeleider?

Cycle of events that they organize for the participating groups. There are masterclasses that have to do with all the questions we have asked. Kick-off is on the 29th of September by a lighting artist. 5th of October.
These masterclasses have specific *onderwerpen.*
Competition with the market, universities, and municipalities (problem owners). This integration of the 3 important pillars makes an interesting field to work in.

→ The idea is that the result is a practical working prototype

In January the prototyping starts for the lighting project

Coalition with the haagse hogeschool would be perfect for the prototyping → internship format?

Overlap to hand over the project.

Appendix B - Characteristics of Note

Lumen output - the total quantity of visible light

Diffusion - light from a full moon has been shown to illuminate approximately 0.1 lx. This is in comparison to modern streetlamps, which illuminate 1-40 lx depending on how close to the lamp is measured. By diffusing the light, you can get a less intense shine.

Efficiency - how much of the energy put in is released as light

Color temperature - many studies show that wildlife reacts differently to different wavelengths of light. Picking the right color temperature may both preserve the environment and give visitors visibility.

Heat mitigation - Because light is being produced from electricity, fixtures may become hot and in need of methods to cool them down.

Lumen depreciation - how long the source of light will last.

Appendix C - Design Guidelines

<u>Light production:</u>
Laser - created when an electrical current is passed through special glasses, crystals, or gases, this method can produce light of a single wavelength that travels straight.

LED - short for light emitting diode, LEDs have become increasingly more common in all fields. These emit light in all directions and are by far the most energy efficient.

Phosphorescent lights - this can best be applied in the form of paint. After being exposed to light, this material can glow at night.

Reflection - drawing light from the bike lamps traveling the path

<u>Implementation:</u>
Light blocked from above

Motion sensor - the lights turn on when someone travels through the area

Programming - take the moon cycle and light spectra that do not harm the environment into account

<u>Form:</u>
Light strip in trees - while not as robust as other solutions, this one will stay out of reach and be difficult to tamper with.

Light posts - low posts that illuminate from around waist height.

Light poles - poles that hang overhead and shine light from above.

Trail - Light that shines from ground height, projecting light onto the trail boundaries.