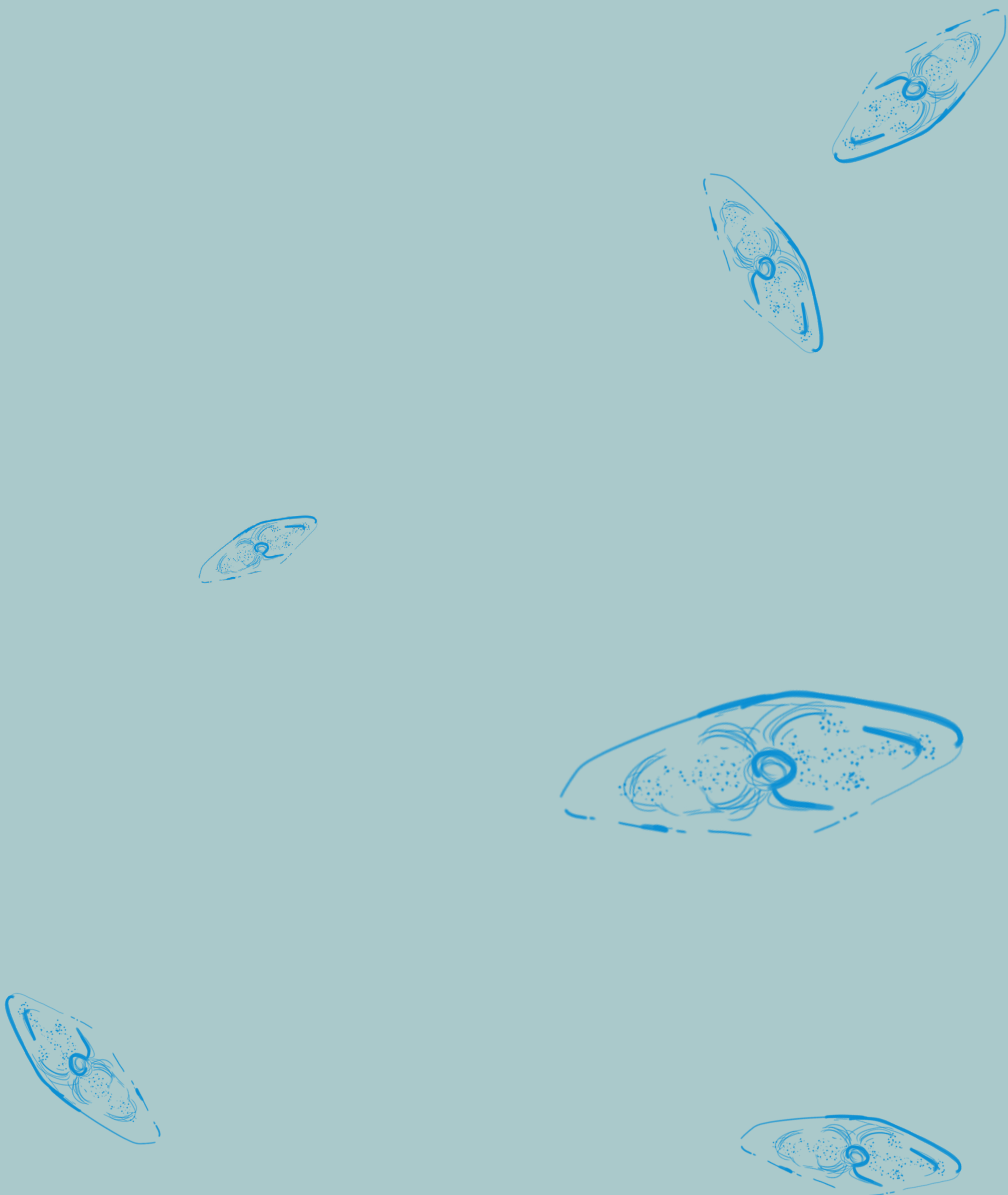
BIODESIGN FOR DARKNESS: THE POTENTIALS OF BIOLUMINESCENCE FOR THE TU DELFT CAMPUS

Vera Smolders



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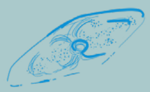

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Acknowledgements

The thesis before you is the result of my graduation project for my master in Integrated Product Design at the Delft University of Technology.

At first, I was hesitant to do a graduation within lighting design because I was worried that I should do something afterwards within the field. Of course, this is not true, and because it is one of my biggest interests at the moment, I did choose to do it. The addition of a living organism caused the project to be even more interesting. I got the opportunity to explore the possibilities and challenges of integrating an alternative living lighting source within lighting design.

This project would not have been possible without the help I received from various people. First of all, I want to thank my supervisory team Elvin and Sylvia for their guidance throughout this project. I appreciate the feedback, questions, support, and the laughs (and cries) during the meetings. I always left them with new energy to keep going because of the enthusiasm you both brought.

Richard, thank you for all the support in the biolab, thinking along with my ideas and testing and especially on your sick day for arranging materials to get my prototype finished!

I also want to thank my friends and family for their support and believing in me, for helping me when I was stuck, design tips and distractions during the project. My parents for motivating me and helping where possible. My zebra friends, for studying together, the mental support and taking coffee and sun breaks to recharge. Lastly, a special thank you to Pim for receiving the majority of my complaints, but also listening to my ideas, struggles and supporting me throughout the process, for explaining me matlab to obtain the right results and for helping me with measurements on the coldest night in December. At least we got to stand in the snow! Thank you for being there and celebrating my achievements with me.

I hope you will enjoy reading this thesis and start to see the possibilities after dark!

Summary

Light pollution is becoming an issue due to the excessive use of Artificial Light at Night (ALAN). This thesis explores the design potentials of bioluminescent algae to integrate more darkness into our urban nightscapes, with a design exploration on the TU Delft campus. The goal is to find out if bioluminescent algae can be used to design for darkness.

This research was divided into a theoretical study, a research study conducting measurements and user experience, ideation and prototyping, and user evaluations. Literature has shown that people's perception of light is crucial for a safe and comfortable environment at night. The perception is very subjective and is influenced by various factors. The research also analysed the characteristics of bioluminescent algae and found that they have the potential to offer distinctive textures and patterns that could improve the nighttime environment.

Through measurements and user studies the current lighting environment was defined and a location for the design was chosen. This research led to the insight that a design at the location near the Aula would have the most significant impact in reducing light usage. The location offers space for an interactive and explorative design. The dimensions simple, dim, and safe showed significance and are used as handles for the ideation phase.

Following the design vision, two concepts were selected that went through prototyping, testing processes in the biolab and user evaluations. The testing process resulted in choosing the sturdy transparent container types that created more light output while interacting. Based on the insights of this research the prototype was translated to a final design. The goal of the design is to show how bioluminescent algae can be integrated for design for darkness, which was validated with the user.

In conclusion, the project shows that the material performs well in dark environments and the promise of bioluminescent algae as a means for design for darkness is recognised. Further exploration and applications are encouraged, since there are steps needed to re-introduce darkness. A meaningful application using the material can be made to promote darkness to help people see the positive aspects of darkness and take steps towards darker nightscapes.

Contents

1

Introduction

1. Introduction

Artificial light at night (ALAN) allows us to go outside and be active for longer and contributes to traffic and social safety. In addition, a lot of economic activities demand lighting at night. Industry, transportation, greenhouses, and advertising are a few of these. Both the direct impacts of lighting from these sources and skyglow caused by ALAN disturb natural patterns of light (Gaston et al., 2015). As a result, many locations that do not need lighting are still being illuminated. In addition to light; people, animals and plants need a period of darkness every day. Darkness is necessary for plants to organise the rhythm of their physiological processes. For example, the amount of light is more reliable than changes in temperature for predicting the start of winter. Temperatures can change abruptly, but on average, light levels drop off quite frequently. Not only for seasonal change but also for a day/night rhythm, periods of darkness are needed to support fitness, healthy growth, and development (Inoue et al., 2017). The fact that they do not use energy for photosynthesis at night supports the development because they have more energy available.

One of the most notable effects for humans is the suppression of melatonin production due to the spectral composition of the light emission, which is the increasing emission of blue wavelengths. These wavelengths are associated with the change to LED lighting (Miguel et al., 2022). Besides the melatonin suppression effects, other health problems have been linked to ALAN, such as obesity, cancer, depression, and cardiovascular illnesses (Fonken et al. 2010) (Lyytimäki 2013). The shifting or interruption of biological rhythms due to ALAN, whether this is in the day/night rhythm or the seasonal rhythm, has a negative impact on practically all animal species (Pottharst & Könecke, 2013) (Lyytimäki, 2013).

Absolute darkness is very difficult to experience in the natural world. Whether it is the ambient glow of sunlight reflected by the moon, the light from the stars or people's impact on the planet, there is always some light present. If experiencing complete darkness in the natural world is challenging, it is next to impossible to avoid visible light in the built environment. Our society actively seeks out opportunities to use light. We make abundant use of light, whether it's to lengthen the day, offer safety and security, or just to improve our lives. Nowadays, turning off the lights has become a more intentional effort than turning them on (Major, 2011).

The current debates around light pollution provide a unique opportunity to re-introduce darkness into urban nightscapes. This is where design for darkness can add value, by looking at the positive aspects of darkness and how this can be incorporated into nighttime lighting design (Stone, 2019). In the Dutch Randstad, levels of light pollution are high, therefore the reduction of light could be of great benefit to the biodiversity in the cities and improve human health. The created urban nightscape would foster a connection with nature through the lighting design focused on enhancing urban life after dark.

An interesting quality some living organisms possess is the ability to produce and emit light, known as bioluminescence. This is seen in living organisms such as fireflies or glowworms, but also in marine organisms. The most common type is generated by marine plankton, dinoflagellates, known as Pyrocystis Fusiformis. Due to its size, the light emission is relatively high compared to other species from the dinoflagellate. During its day cycle, it uses light to create its own energy (via photosynthesis) and emits light when agitated during its night cycle (Valiadi & Iglesias-Rodriguez, 2013). Bioluminescence offers a novel approach to design with light. How to use nature as a source of energy, exploring the potential for alternative and more sustainable ways.

1.1 Project

This graduation project explores the possibilities of creating a meaningful application that brings the unique qualities of the bioluminescent organism combined with lighting design forward with a focus on design for darkness. The outcome of the project is a design that stimulates people to actively discover bioluminescent material's unique experiential and performative qualities through interaction. The context is focused on public space at the TU Delft Campus with a flow of passers-by that can seek this interaction with the material. The aim of this project is to explore if bioluminescence can be a means for the design for darkness approach with a research exploration on the TU Delft campus. Therefore, the main question of this study is: **"What design potentials would bioluminescent algae offer for our campus? "**

1.2 Scope

This thesis consists of several topics that will be discussed, visualized in Figure 1. As mentioned, the research exploration and final design location is narrowed down to the TU Delft campus.

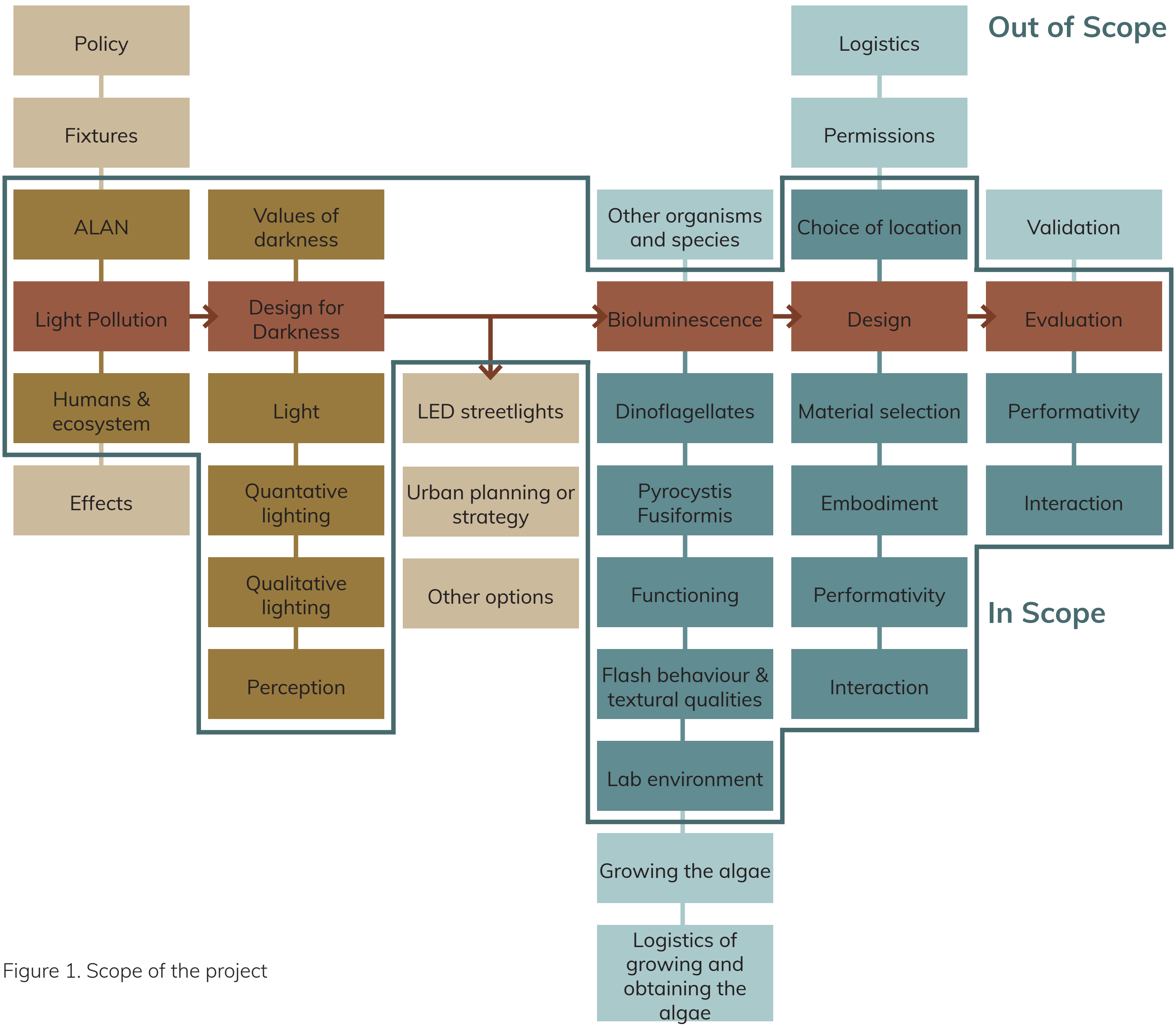


Figure 1. Scope of the project

1.3 Project Approach

This project followed three main phases that describe the design process: a research phase, the ideation phase, and the development of the concept. In the next sections for each phase the design activities that are performed will be explained.

Research phase

The research phase started by creating the design brief that defined the topic of this thesis (Appendix A). A literature study is done to get familiar with the existing knowledge on the different subjects as shown in the scope. The principal elements of lighting and the human visual system are explained; which is necessary to understand the following chapters. Next, the concept of light pollution is introduced, whereafter design for darkness and its important values are discussed. Then the relevant biological background of the organism that contains bioluminescence will be outlined, and we will look at current designs involving bioluminescence. Following the literature, a research study is conducted in two parts; stationary measurements and a user experience study, both on location. These studies are used to create an overview of the light qualities present and to provide an impressionistic description of the lighting in a space by users. Based on these insights, the location of the design and the design handles are determined. This led to the following question: How can a balance be created between darkness and safety?

Ideation phase

The ideation phase started with the design vision, which included the intended interaction vision and user journey. During the idea development, a brainstorming session in two phases was held in which ideas were generated by answering How Might We's. Through the process of discarding, combining, and refining, a selection was made and discussed with an expert from the biolab. Which led to the selection of two concepts: a soft, flexible encapsulation and a rigid swinging encapsulation. In developing the concepts, further prototypes have been made and tested in the biolab on their performativity.

Development of the concept

In the final phase of the graduation project, two designs were developed. Prototypes were made, which were evaluated by X individuals from the TU Delft. This led to new insights into the interaction. A final iteration was made that led to the final design, explaining the construction, materials and intended interaction and performativity. The design was validated based on the vision. Lastly, the final design and values of darkness are discussed, and a conclusion was made on the potential of bioluminescence as a means for design for darkness. Recommendations will be proposed for further development of the design.

2

Literature Research

2. Introduction

This chapter presents a literature review of the scope of the project, regarding light, light pollution, design for darkness, and bioluminescent algae and provides an overview of designs that are currently used in the framework of this topic. It also provides research on algae behaviour to establish a theoretical understanding of the interaction.
The focus of the literature research is to answer the following questions:

- What is light in general, and how does it work?
- How do people perceive light regarding safety and comfort?
- What is light pollution, and how does it affect us?
- How can we tackle light pollution with the design for darkness approach, with a focus on human perception and light impact.
- What is bioluminescence, and how does it behave?
- What kind of designs are currently in place that include bioluminescence, design for darkness and light pollution?

2.1 Light

In this paragraph, different concepts are discussed, to form a better understanding of what light is, compare different frameworks and clarify other key concepts that need to be understood in the context of this thesis.

Human visual system – how we perceive the world

In our day-to-day life, we primarily perceive light indirectly, because of the appearance of objects. The objects around us are visible because of the light that permeates it. However, light also has an impact on how we perceive a space or objects. Although the appearance of things is influenced by the type of light, the shape and texture of objects also have an impact on the light, causing an interplay of light. Not only that but also our own perspective, which is how our brain interprets sensory data, influences light.

We receive stimuli from all around us, and our senses participate in an active process that tries to make sense of this information and become aware of our surroundings. This active process is called perception. Once light reaches the eyes, our brain converts the information to be able to detect the appearance, movement, and location of objects. The part of the human eye that is sensitive to light is called the retina (see Figure 2). The cones in the retina are sensitive to long, middle, and short wavelengths of radiation and provide our perception of colour. The rods, which cannot distinguish colour, are sensitive to movement and light intensity. Besides the cones and rods, it also contains ganglion cells which are light sensitive. These cells influence our biological clock (Philips, 2008).

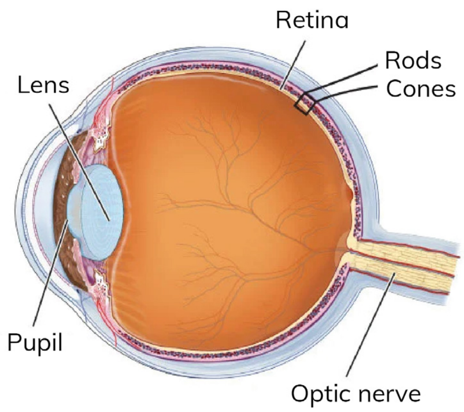


Figure 2. Anatomy of the eye (Retina: Anatomy, Function & Common Conditions, n.d.)

The rods are more sensitive to light than the cones and can therefore see in complete darkness. At very low light levels, the visual perception depends only on signals from the rods. We originally experience extreme darkness when we move from a brightly lit area to a dark one, because the light has suppressed our rod pigment. It can take up to 30 minutes to adjust from light to dark. This is called dark adaption. While it takes less than a minute for light adaption (Philips, 2008).

The eye adjusts to variations in light sensitivity, through a process called adaption. There are three ways this is done: adjusting the iris to change the size of the pupil (to a limited range), adjusting the retina's nerve endings sensitivity, and adjusting the chemical composition of the photosensitive pigments in the rods and cones. The eye's level of adaption, which is controlled by a scene's overall luminance, determines the eye's capacity to detect luminance contrast. For example, a tunnel might appear darker seen from the outside on a bright day. It is because of the eye's inability to adapt to strongly different luminances simultaneously. A scene that, for example has a well-balanced contrast is comfortable and gives satisfaction, because the eye does not have to adjust that much (Philips, 2008).

Quantative lighting

Quantitative lighting revolves around providing the right light levels. This means that it is focused on the visual needs of users. Figure 3 illustrates the different terms: luminance, luminous intensity, luminous flux, and illuminance.

Luminance

The term luminance describes the light that is emitted or reflected from a surface, per unit area in a given direction. It is an indicator of how bright a surface might appear; therefore it is also referred to as brightness (Gansland & Hofmann, 1992) (UQ Architecture, 2018).

Luminous flux and intensity

The total amount of light emitted in all directions by a light source is known as luminous flux. The luminous flux is measured in lumen. The luminous intensity is the luminous flux radiating in a given direction per solid angle, in the unit candela. It is how bright a light appears (Gansland & Hofmann, 1992) (UQ Architecture, 2018).

Illuminance

The illuminance refers to the amount of light that falls on a surface, measured in lumens per square meter, or lux (Lai, 2022) (UQ Architecture, 2018). It is the amount of luminous flux per unit area.

Qualitative lighting

Qualitative lighting design is focused on the perceptual needs of the user. Perception-based lighting design needs understanding of optical space-shape-materials-light interactions and its visual effects on appearance, functioning, behaviour, and health. Richard Kelly was one of the first in the field to apply this to create a layered concept of lighting.

Richard Kelly described light "as the key mode through which one understands and experiences the designed environment." (Petty, 2007) He differentiated three basic functions of light: ambient light, focal glow and play of brilliance. These different layers are in interplay with each other and can form a unique experience and, as he argues, perceived visual beauty. These categories provide a simple and structured range of possibilities to address buildings and objects, but also the perceptual needs of the users of the space (Gansland & Hofmann, 1992). His approach is a perception-based lighting design that focuses on spatial lighting qualities and describes how a lighting plan can be framed as a sum of three layers of light (Kelly, 1952).

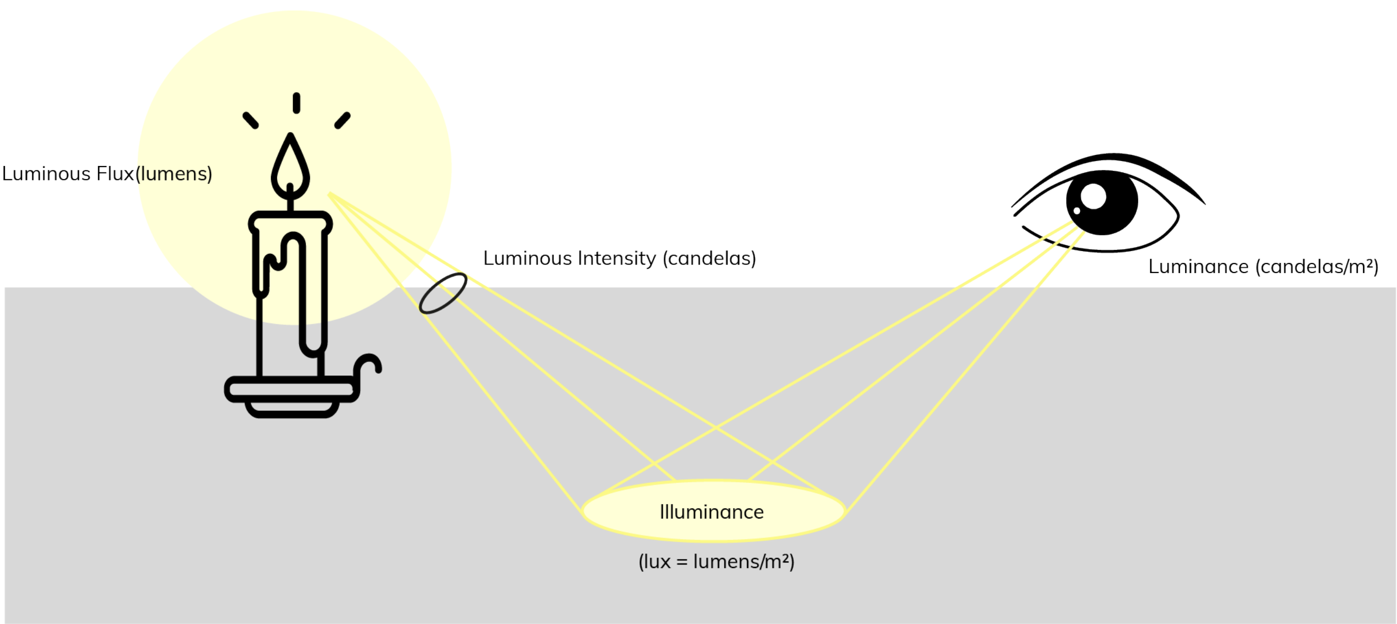


Figure 3. Quantitative lighting explained adapted from (UQ Architecture, 2018).

Ambient luminescence

Ambient light provides the general lighting in an environment. It allows for orientation, being able to work, and communicate with the surrounding people (Gansland & Hofmann, 1992). Kelly describes ambient luminescence as "the uninterrupted light of a snowy morning in the open country. It is fog light at sea in a small boat, it is twilight haze on a wide river where shore and water and sky are indistinguishable. It is in any art gallery with strip-lighted walls, translucent ceiling, and white floor. Ambient light produces shadowless illumination. It minimizes form and bulk." (Kelly, 1952).

Focal glow

Focal glow is used to accentuate significant areas and make them visible so other areas stay in the background. This way the visual environment can be perceived easily and quickly. Focal glow can also be used to highlight in an aesthetic sense (Gansland & Hofmann, 1992). ".. is the campfire of all time. It is also the celebrated limelight of aphorisms because the early English music halls used antiquated projectors which burned a gas resulting from wetting a kind of lime (now commonly known as "carbide"). Focal glow is the follow spot on the modern stage. It is the pool of light at your favourite reading chair." (Kelly, 1952).

Play of brilliance

Brilliance is the effect of light that occurs on glossy or transparent material or surfaces. It is produced by the reflection of the light, or the light being refracted. The light could enhance the environment in an aesthetic sense (Gansland & Hofmann, 1992). "Play of brilliants is Times Square at night. It is the eighteenth-century ballroom of crystal chandeliers and many candle flames. It is sunlight on a fountain, or a rippling brook. It is a cache of diamonds in an opened cave. It is the rose window of Chartres. Night automobiles at a busy cloverleaf, a night city from the air." (Kelly, 1952).

The three light layers described can be optically represented by the light density, light vector, and light texture. Figure 4 is a schematic representation of the integral framework of light, connecting the descriptions of light. In the top row, you can find the physical representation of the light field as a luminance map or panoramic image. These images represent the different orders of their mathematical representatives, which are known as spherical harmonics components. The components can be thought of as a Fourier decomposition on a sphere. These mathematical components thus have direct physical meaning and allow us to describe light as a sum of qualities. Importantly, Pont found these components to be good descriptors of Kelly's layers, and thus that this additive system supports a generic composition approach to lighting design with Kelly's layers (which represent the physico-mathematical components) as the key elements. The golf ball is used to visualize the light qualities in these types of light (Pont, 2019).

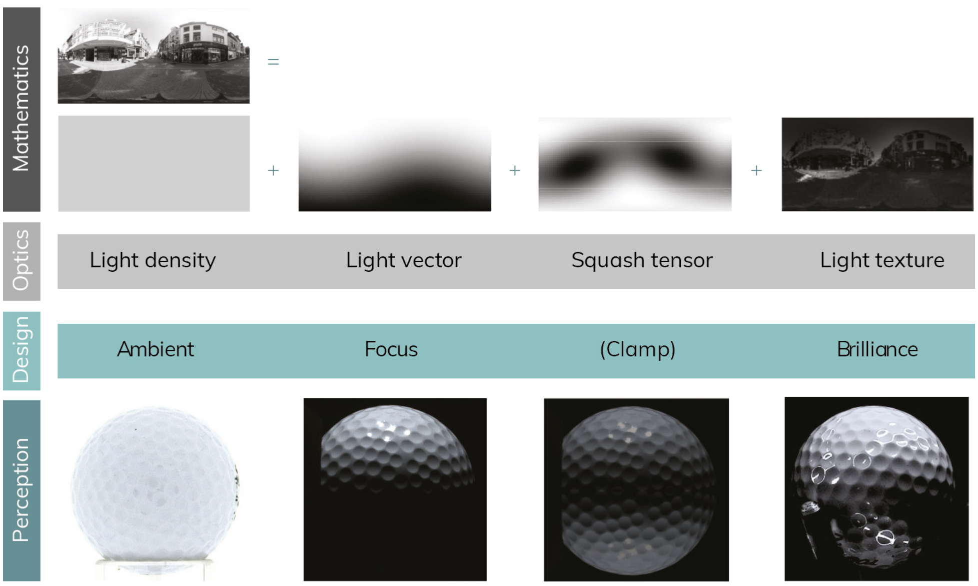


Figure 4. Schematic representation of the integral framework of light adapted from Pont (2019).

Kelly's framework provides clear differentiation between the functions of light; William Lam further defined the qualitative lighting design approach by introducing criteria that describe the requirements placed on a lighting system that are systematic and context related. The criteria are divided into two groups: activity needs, regarding task lighting, and biological needs, the more basic features of how people relate to their visual surroundings (Lam, 1977).

When we perform certain activities within a visual environment, we have activity needs. The analysis of the activity needs is largely identical to the criteria for quantitative lighting. The aim is to arrive at functional lighting that will provide the optimum visual conditions for the activity in question (Gansland & Hofmann, 1992).

The biological needs are more essential than the visual needs, the needs 'sum up the emotional demands that are placed on a visual environment and are applicable in every context'. They are based on unconscious requirements and the emotional evaluation and wellbeing of a situation in a visual environment (Gansland & Hofmann, 1992).

There are three psychological needs that Lam distinguishes. Orientation in a space that concerns the discernibility of routes and destinations, what time of day it is and weather conditions. Discernibility or comprehension influences our feeling of safety and communication, meaning that a space should facilitate contact with other people but allows for private areas to be defined (Gansland & Hofmann, 1992). He states that if designers give priority to the biological needs for visual information that in most spaces the lighting will also provide for most activity needs.

When we look around us, we can observe our environment because of light. Scientifically light is defined as electromagnetic radiation that can be perceived by the eye. Pont (2019) defines light as the light field: "the luminance as a function of spectral energy (wavelength), position, and direction in regions of space free of occluders. The light field as a function of time then also includes temporal variations, if any. In perception research, this concept is known as the plenoptic function (Adelson & Bergen 1991): all optic information available to an observer at any point in space and time". Pont takes this as the starting point for studying different aspects of perception.

Defining light quality

Good quality lighting is essential, because it can affect our ability to perform tasks, our mood and health and wellbeing, and our feeling of safety. It contains several criteria that include the lighting levels, luminance contrast, glare and spatial distribution of light, colour and colour rendering and modelling (Boyce, 2013).

The experience of comfort regarding perceiving the illumination in a scene is described by the lighting quality, which after dark is an underlying contributor to the perception of pedestrian comfort. Table 1 outlines these factors to the experience of lighting quality in urban lighting.

To ensure a sufficient visual performance for a task, the lighting level, illuminance, should be high enough. According to research, increasing the lighting level from low or moderate to high

Table 1. Aspects of lighting quality -adapted from (Kruisselbrink, Dangol & Rosemann, 2018)

Aspect	Component
Quantity of light	Illuminance; Luminance
Distribution of light	Uniformity; Luminance distribution
Visual Comfort (Glare)	Disability glare; Discomfort glare; Veiling reflections
Spectral power distribution of light	Spectrum; Color rendering
Luminaire characteristics	Luminous intensity distribution; Flicker
Directionality of light	Direction; Modelling
Space characteristics	Objects; Reflectances
Dynamics of light	Variability; Rhythm

increases the speed and accuracy with which objects can be detected and identified (Philips, 2008).

Another important term is glare. Glare is caused by light levels that are greater than what the eyes are adapted to and can lead to discomfort and reduced visual performance. The degree of glare reduction is a crucial component of good lighting. Glare can be direct glare which comes directly from the source, or reflected glare which is from a reflected surface (Philips, 2008).
The colour composition of a lamp has a significant effect on the rending of the colour of objects we perceive. In some situations, this is of importance, such as for food and people, but in some, they are of little importance, such as road lighting. Here the priority is on the illumination level and efficiency. (Philips, 2008).

Diffuseness is an important property of light because it affects the way we perceive surfaces and materials. Diffuseness refers to the degree to which light is scattered or spread out as it travels through a medium or reflects off a surface. A highly diffuse surface, for example, will appear softer and more uniform in appearance, while a less diffuse surface will appear sharper and more detailed (Figure 5). The perception of the diffuseness is influenced by factors such as the material and shape of the object, the direction of the illumination and the observer's perspective (Xia et al., 2016a and b).

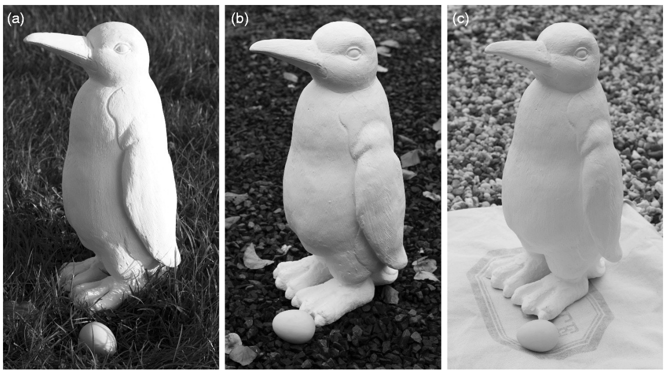


Figure 5. Visualizing three different diffuseness levels: (a) direct sunlight, (b) overcast sky with a dark background, (c) overcast sky with a light background (Xia et al., 2016a).

2.2 Light Pollution

A rather new environmental problem has arisen, simply put, there is too much light during the night. Nighttime lighting has always been seen as necessary and desirable, and to an extent it still is. However, as seen in recent research, this has become a concern (Stone, 2019). The excessive use of artificial outdoor lighting is called light pollution. Light pollution is caused by the increased brightness of the nighttime environment due to the use of artificial light (International Dark-Sky Association, 2013) (Light Pollution | National Geographic Society, n.d.). Falchi et al., (2016) published that around 80% of the world, and 99% of Europe (Rijksinstituut voor Volksgezondheid en Milieu, n.d.), live in places where the sky is considered to be light-polluted. It not only uses a large amount of energy and costs a lot of money but can damage ecosystems and have a negative effect on human health and well-being (IDA, 2013) (Stone, 2019). To prevent further damage to our planet, a change must be made to the way cities are illuminated and light pollution must be taken more seriously.

The IDA (2013) identifies four different elements of light pollution (Figure 6):

- Glare, visual discomfort caused by excessive brightness that can reduce visibility.
- Skyglow, the night sky over inhabited areas that are brightened by light that is sent upwards and scattered.
- Light trespass, light where it is not needed, wanted, or intended.
- Clutter, grouping of light sources that are bright and excessive.

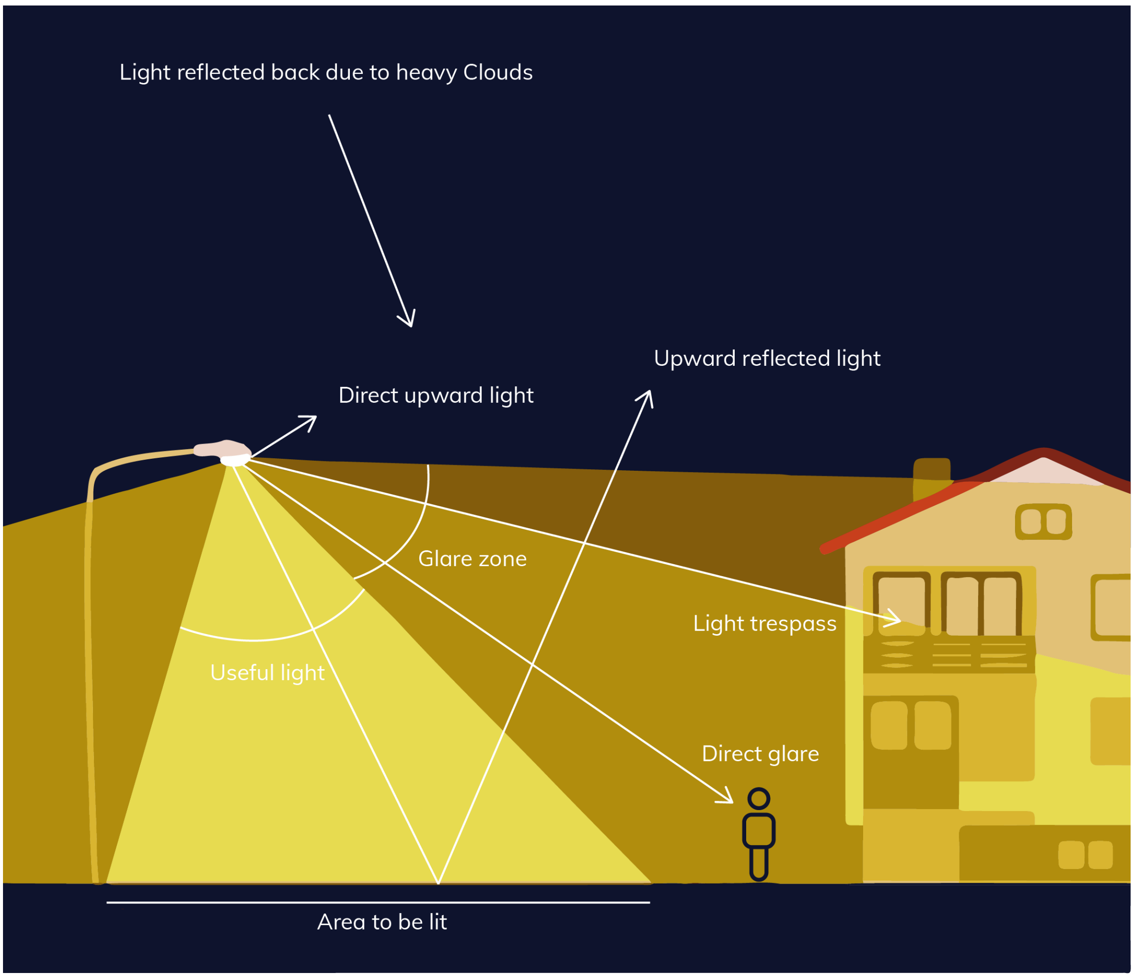


Figure 6. The different elements of light pollution identified by IDA (2013).

One of the most illuminated countries in the world is the Netherlands. Normally, 2500 stars can be seen at night with the naked eye. But only a few can be seen in the cities and towns (Rijksinstituut voor Volksgezondheid en Milieu, n.d.). Since our existing public lighting system is still focused towards producing more light and does not prioritize darkness, light pollution has increased by at least 49% between 1992 and 2017 (University of Exeter, 2021). In the Netherlands, there is no policy on nighttime illumination or protecting the dark. However, some municipalities have drawn up a policy, but this is to save energy regarding nighttime light (Rijksinstituut voor Volksgezondheid en Milieu, n.d.).

Figure 7 shows how much light could be seen at night in 2021. If you look at the Netherlands from above, here zoomed in to the South of Holland, the red and purple areas are very lit. Black and blue areas are less lit. As you can see from the map, it is only dark above water far from the land, this is because of light trespass. The Randstad, the greenhouses in South Holland and the port of Rotterdam are very lit. (Kaarten | Atlas Leefomgeving, n.d.).

The ongoing concerns about light pollution provide the opportunity to bring back darkness into urban nightscapes. This is where design for darkness can add value, by looking at the positive aspects of darkness at night and how this can be incorporated into the design of nighttime lighting (Stone, 2019).

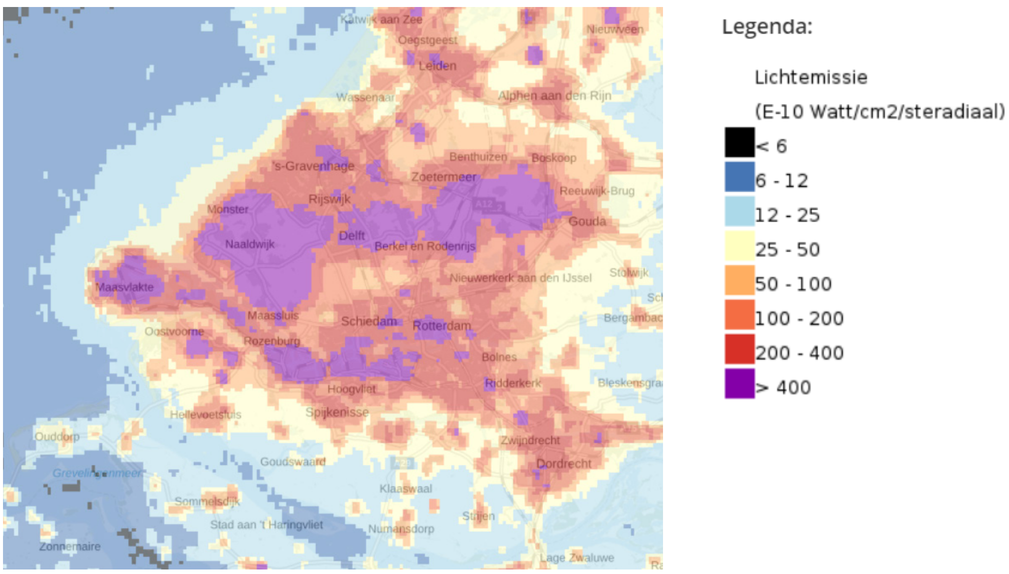


Figure 7. Light pollution South of Holland created from (Kaarten | Atlas Leefomgeving, n.d.).

2.3 Design for darkness

Darkness is an essential part of lighting design, it is about finding ways to make use of darkness, whether that be by using more contrast or by deciding to leave a surface completely dark to give emphasis (Copland, 2017). The discussion about light pollution focuses on the negative aspects of ALAN, and not enough on the positive aspects of darkness, and how to bring back darkness into our urban nighttime scenes.

“Current literature is missing a comprehensive account of the positive value of darkness at night and an understanding of how this can be incorporated into the design of nighttime lighting.” (Stone, 2019).

Since people are surrounded by brighter nights due to artificial lighting, they may experience the natural darkness as unpleasant or unsafe. For example, street lighting is considered a ‘natural’ part of an environment. People are used to these situations that this becomes normal, they are likely to suffer from shifting baseline syndrome. This is caused by a lack of experiencing a light pollution free night sky (Lyytimäki 2013). Soga and Gaston (2018) state that the shifting baseline syndrome entails a gradual change in the accepted norms for the state of the natural environment as a result of a lack of knowledge, experience, or memory of its prior state.

This suggests that as the natural environment continues to deteriorate, our baseline standards will also decline. In figure 8, Lyytimäki (2013) suggests a cycle of the shifting baseline syndrome that can be connected to the nocturnal nature, explaining the deterioration of our standards.

Stone (2018) argues that the baseline can be pushed back by creating darker nightscapes with a design for darkness approach. It aims to promote an understanding of the tangible and symbolic benefits that can be attained by balancing light and dark. It is about learning the value of darkness and experiencing it as a quality to reconnect with natural rhythms and the night sky full of stars rather than as something to be feared or despised.

“Experiencing darkness – or alternatively, purposeful illumination within a darkened space – could allow moments where people glimpse past the lighting that now mediates our urban lives and see a nighttime space oriented otherwise. In doing so, we could be forced to confront our (often unquestioned) expectations and perceptions of lighting, and possibly plant the seeds for a new version of darkness to permeate through our cities.” (Stone, 2019, p.109)

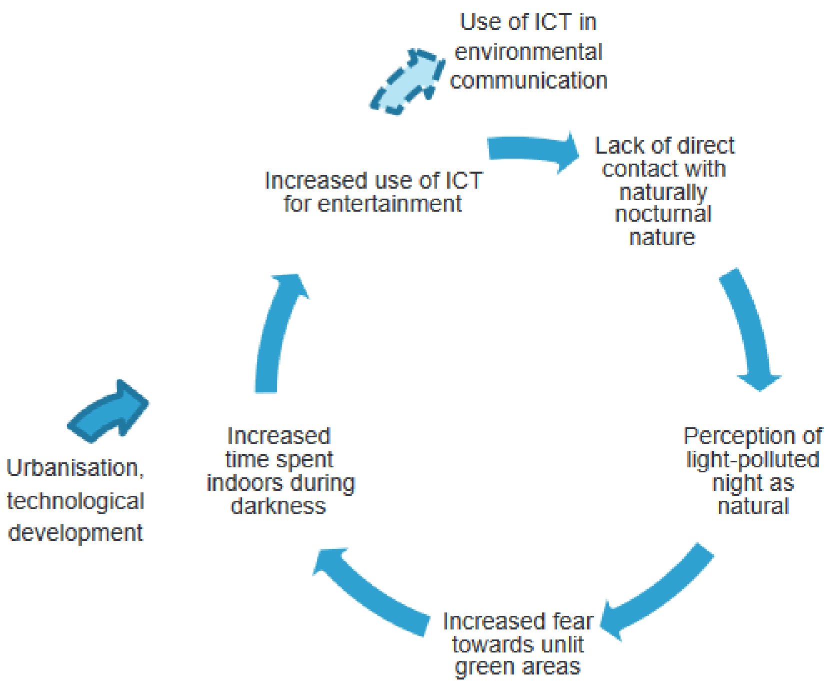


Figure 8. A suggested cycle of the shifting baseline syndrome (Lyytimäki 2013).

Therefore, the value of darkness needs to be understood. Stone has distinguished nine values by recasting the effects of light pollution as valuations of darkness, see Table 2. He then converts these into prima facie obligations, this way, there is a moral reason to act and strive for the values (Stone, 2019). The values are explained on the next page and can be used to validate the concepts created in the process.

Table 2. The values of darkness as prima facie obligations from Stone (2019).

Value of darkness	Prima facie obligation derived from value
Efficiency	The responsible use of lighting where and when needed; money-saving
Sustainability	The responsible use of lighting where and when needed; energy-saving and preserving non-renewable resources
Ecology	The protection and preservation of species and biodiversity; habitat conservation efforts
Healthiness	Promoting and fostering human health; physiological well-being
Happiness	Promoting and fostering happiness; emotional wellbeing
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

Efficiency
Using excessive amount of light during the night when it is not needed wastes energy and can be seen as unnecessary. The preservation and introduction of darkness becomes a symbol of economical use of lighting sources, only using light when and where it is needed. In cities and urban settings this can be very useful, conserving resources and improve economic efficiency by valuing and using darkness effectively.

Sustainability
Sustainability concerns the decrease in energy consumption and tackling climate change. This can also be linked to the use of ALAN. From this angle, integrating darkness is a way to encourage sensible energy use and reduce CO2 emission.

Ecology
Species and ecosystems are impacted by ALAN, particularly in urbanised areas. Regular amount of daylight and darkness are necessary for species and habitats. As a results, the re-introduction of darkness is related to maintaining species, biodiversity, and nighttime habitats.

Healthiness
From the literature research, it became clear that human health is affected by the use of ALAN. The ability to access and experience darker night can therefore be considered as beneficial for personal health. Darkness would then appear as a physical quality that one should attempt to foster. This will result in us as humans getting familiar with darkness and the natural night sky, and the positive effects on our health.

Happiness
The focus on experiences over material possessions, preference for routinely small moments of pleasure, the enjoyment of (natural) beauty and the calming and beneficial effect of being under the night sky are a few ways that can enhance happiness. Darkness can therefore be thought of as having the capacity to improve psychological health generally.

Connection to nature
As mentioned before, natural nighttime settings are becoming harder to find because of artificial lighting's impact on the nighttime environment. Thus, encouraging dark nights to be seen as a means of maintaining the natural nighttime circumstances.

Stellar visibility
Related to the connection to nature is that the stellar visibility also decreases. The main characteristic of natural nighttime conditions is starlight, which is frequently mentioned as the main factor that is in danger of disappearing. For access to the night sky, dark skies are necessary.

Heritage and tradition
Around the world, different cultures and traditions have made use of the night sky and plays a key role. Since nighttime darkness is a need for continuous access, losing the night also signifies the heritage and tradition. Dark nights enable the night sky to be preserved, which in turn preserves this heritage for current and future generations.

Wonder and beauty
It is important to appreciate the night sky's aesthetic appeal, which is naturally linked to the preservation and promotion of darkness. By turning off the lights, one would be able to appreciate the wonder and beauty of the starry night sky to a far greater extent, enhancing the fundamental benefits of darkness.

To integrate darkness effectively in our nightscapes, a consideration of how people perceive light, and its qualities is essential. Specifically, when people perceive a light environment as safe and comfortable to be at night.

2.4 Perception of light and perceived social safety

The perception of pedestrian comfort after dark highly depends on the lighting quality. The concept of light and darkness is not just related to actual safety but also to the perception of safety. Darkness creates a feeling of insecurity because it limits visibility and recognition from a distance (Painter, 1996). According to Boomsma and Steg (2012) safety refers to the state of being protected from harm or danger, both in terms of actual physical protection and the perception of being protected, regarding actions taken by others in public.

The allowable range of contrasts is determined by the eye's adaptation state during visual tasks. When the environment is stable, the eye remains in a constant state of adaptation, while an unstable environment results in continuous and fatiguing adaptation due to excessively low or high background luminance (Gansland & Hofmann, 1992). Hence, dimmer and layered lighting, with less sudden contrast, may be more comfortable for people and their perceived safety.

Zoning can be an effective tool to create functional and visually appealing spaces. It involves dividing a space into different zones or areas which are based on their function. The primary objective of zoning is to provide a balance of luminances within each zone that is suitable for the current visual task. For instance, when transitioning from a bright city centre to darker urban areas, light levels can be lowered in steps or zones, which takes dark adaptation into account (however, it should be noted that pedestrians, bikers, and car drivers adapt differently to their surroundings). The brightness ratio between the visual task and its surroundings is critical to achieving this balance. The surrounding areas should be lowered to avoid detracting from the task at hand, and the visual task should be the brightest in the surroundings to draw attention to it. To create a comfortable and functional lighting environment, it is important to preserve a defined range of contrast (Gansland & Hofmann, 1992).

Depending on the shape of the light from the source, it shouldn't be either too high or too low, since a strong spot produces high contrast, whereas glow-in-the-dark materials will produce soft contrast. Bonato and Gilchrist (1994) found that a target begins to appear bright under different illumination conditions when it is about 1.7 times brighter than a surface that would appear white in those same lighting conditions, regardless of whether there is a nearby white surface for comparison. The "luminosity threshold" is the brightness level that illustrates two characteristics of surface greys: it remains constant regardless of variations in lighting level or surface reflectance. In the end, it all comes down to balancing the contrast, which is crucial for visibility.

Emotional responses and the perception of lighting are closely related. For instance, people feel more comfortable walking towards an area that is brightly lit. However, if the contrast between brightly lit areas is too high, it can cause confusion, which is why there should be lower light levels in between, forming a "bridge" in the view (Gokhale, 2013).

Moyer (1992) investigated the links between perceived lighting characteristics based on light direction and brightness and human emotional responses. The combination of light entering the eye, the brain interpreting the information, and the lighting design of a space determine how people see and feel about a space by altering the brightness present in the space. For example, when two objects are lit with a focal spot, the eye jumps between these objects, resulting in an unpleasant spotty effect that can lead to gloom if it causes an adaption shift (Gokhale, 2013).

According to Dean Dal Ponte of the Hubbell Lighting company, “a common misconception is that areas with higher light levels are safer, but to add more light to increase safety may actually have the opposite effect’ (Blander, 2021). A study was conducted to assess the impact of different lighting attributes on people’s feelings of safety (FoS) in public spaces. Observers rated the attributes while the FoS ratings were simultaneously measured and analysed. Interestingly, the results showed that higher levels of illumination did not necessarily lead to a corresponding increase in FoS. Instead, the analysis indicated that FoS was highest at low illumination levels of 5-10 lux, with only a slight increase in FoS beyond this threshold at higher illumination levels (Svechkina, Trop & Porto, 2020).

Outdoor lighting, the availability of illumination in an area during the night, provides a sense of safety for many people, although it has not been proven to be actually safer. Maybe a soft uniformity of light from various sources, rather than too much lighting or brightness, is what makes us feel at ease. Uniform light refers to an area illuminated evenly and consistently, without noticeable changes in brightness or intensity. There is a relatively equal distribution of light across the space, creating a visually balanced and pleasant environment (Blander, 2021).

As Philips’ Seitinger suggests, successful lighting design is not just about delivering light but also choreographing darkness to create a good perception of a space. That way, you can increase value and quality for users (Blander, 2021). According to research, darkness, disorder and being alone or with perceived threatening others are cues that indicate a potential risk and increased fear of personal safety. However, ambient atmospheres and comfortable environments can boost our capacity and confidence to perform tasks and form connections with others (Philips lighting research, 2016). Attractive lighting design can also affect people, making a space feel more welcoming and enjoyable.

In addition to light qualities, light also has affective or emotional characteristics, which is referred to as the ‘light atmosphere’. Vogels (2008) suggested that a lighting atmosphere can be categorized into four categories: cosiness, liveliness, tenseness, and detachment. Although the concept of atmosphere does not produce a value judgment, it helps to evaluate a space’s expected affective effect. Louwers (2019) found that the dimensions of tenseness, liveliness, and detachment were present in dynamic lighting patterns. The light atmosphere can play a crucial role in shaping our experiences and perceptions of a space and is therefore an important consideration in lighting design and architecture.

When making lighting decisions for public spaces, it is essential to consider factors such as assisting for wayfinding, providing correct ground illumination that focuses light where it is needed, and not having a negative effect on nocturnal species. By taking these appropriate factors into account, we can facilitate safety in the right way (Ward, 2022).

Please note that in all research mentioned above, the state of adaptation is not considered. Once dark adapted, we can see much more in the dark, and much less light will be needed to perceive an environment as bright. This can be related back to the shifting baseline syndrome; people are not used to darker nights since they are constantly surrounded by ALAN. Our eyes can get used to the darkness, but we rarely experience it.

2.5 Benchmarking lighting design

The benchmark includes current lighting designs that support design for darkness. Conventional and artistic design solutions will be examined for darkness design. By analysing the light qualities, for instance, low light level designs, atmosphere, and interaction.

Atelier Lek created a fixture for cycling path RijnWaalPad. It is a high-quality express cycle path that links two cities and making cycling easier. Atelier LEK was tasked with creating a lighting design that would enhance the bike path's quality and make it easier to recognise. They made a LED fixture consisting of three modules, making each volume smaller and minimising the peak luminance and the glare (Atelier LEK | Onafhankelijk lichtontwerp - Rijnwaalpad, n.d.). In figure 9, the path is shown. Here it can be seen that in addition to the functional lighting on the cycle route, there is additional lighting on the sides which provides a subtle accent and recognition. The functional lighting is soft and has a low lighting level.

Figure 9. RijnWaalPad.

Another cycling path that shows a great example of a darkness design solution. The Viruly path near the Delftse Hout, was renovated and in addition to a wider cycle path, they integrated light on the ground next to the path, see Figure 10. Because this part is already quite dark the light level is deliberately low. The lower light level works great for our dark adaption, going from well-lit city to darker urban areas, making it possible to watch the night skies.

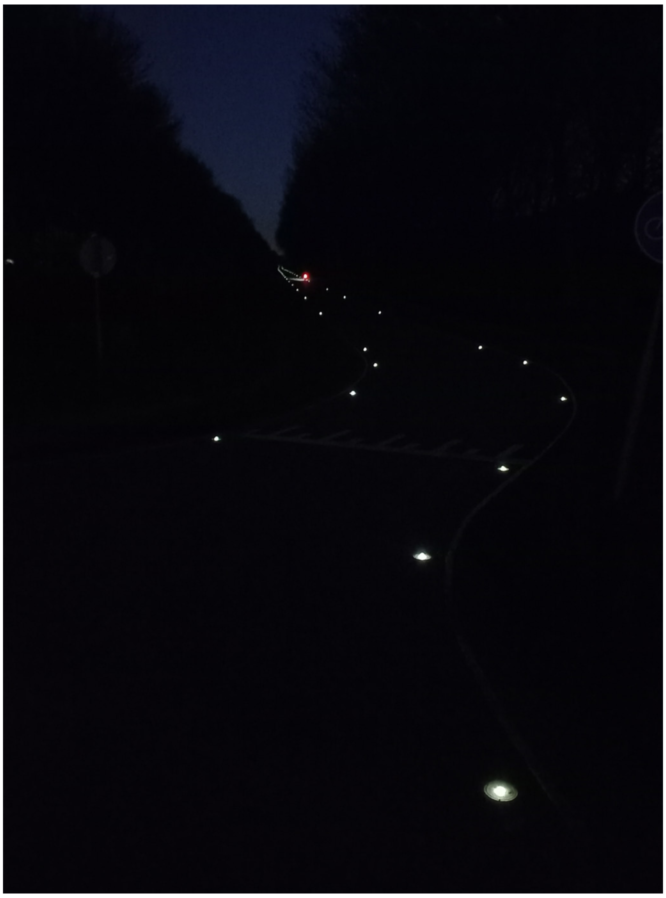


Figure 10. Viruly pad.

The Smart Highway project, Figure 11, contains several sustainable roads by Daan Roosegaarde and Heijmans Infrastructure. The smart roads interact with traffic by using energy, light and information. The Van Gogh bicycle path features light-emitting stones that glow in the evening. During the day, the stones will charge because of the (sun)light and will glow at night. Glowing lines works with the same principle, enhancing the lines next to the road. These approaches focus on soft lighting for way finding and therefore not disturbing the surrounding environment by lighting the sky (Studio Roosegaarde, 2017).

Figure 11. Glowing lines (top) and Van Gogh bicycle path (bottom),

Another project from Studio Roosegaarde is DUNE, Figure 12, an interactive landscape of light that will respond to passing visitors. This makes the visitor a part of the artwork, which enhances the interaction between themselves and the landscape and creates a kind of relationship. The responding lights will also create a type of way finding, since passers-by or people walking the same route can see the movement from a distance (Studio Roosegaarde, 2017).

Figure 12. Project DUNE, an interactive landscape.

The Queen Elizabeth Olympic Park lighting scheme was designed by Spiers + Major and delivered by Michael Grubb Studio, see Figure 13 (Michael Grubb Studio - Queen Elizabeth Olympic Park, London, UK, 2022). The challenge was creating lighting that would support the park's playful design and make users feel safe and secure. The use of lighting in the Queen Elizabeth Olympic Park brings the area to life an creates an intimate atmosphere. Light and darkness transform the space, which is done by a dappled light from moon-like spheres. To give the scene a sense of depth of field and give it an aerial perspective, the interior of the sphere is painted with a colour that changes in shades from blue to green gradually along the length of the promenade. People are encouraged to move around and explore the space by the intriguing atmosphere created by the illuminated focused pools and the dappled effect (The Importance of Darkness in Lighting Design, 2022).

Figure 13. The Queen Elizabeth Olympic Park.

Rudolf Teunissen is a light designer from Rotterdam and founded the company Daglicht en Vorm. Characteristics of his designs are the usage of light to create a new space to be experienced. Their vision is that light connects people with their environment, and they explore how it can add value. One of their projects was a light concept for a playground in Slinge shown in figure 14, similar to broken light, where it was important that at night the parc was a pleasant place to stay. The light concept provides an own experience in the evening. The light creates a friendly ambience where the contrasts draw patterns that recall the movement of water or the shadow of trees. What seems dark at a distance gives plenty of visibility close by. This play of light gives the space an extra dimension and is seen as friendly and characterful (DAGLICHT EN VORM – architect and light, n.d.).

"It is important that light art is seen as enriching public spaces. It ultimately allows you to create atmosphere in certain areas" (Lichtkunst als openbare verlichting en verrijking van de openbare ruimte, n.d.).

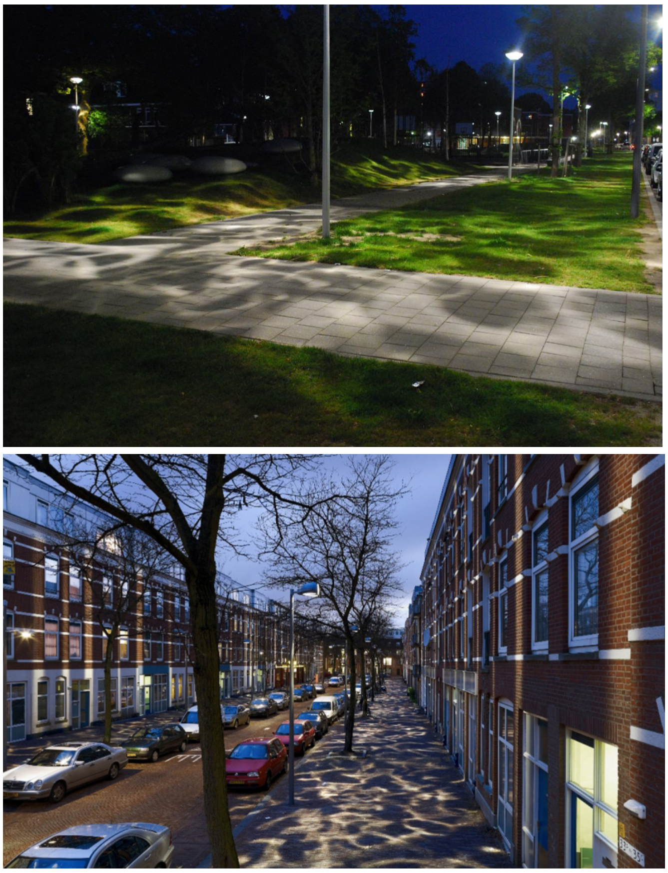


Figure 14. Playground in Slinge (top) and Broken Light (bottom).

In any location, whether at home, an office or a public area, lighting design plays a key role in establishing a cosy and welcoming atmosphere. The discussed different lighting designs show that by balancing light and dark, ambience through patterns can be employed to create a pleasant atmosphere that enhances the space its aesthetic and promotes a feeling of safety and security. There is an added value in experience through perception.

2.6 Bioluminescence

Bioluminescence is a phenomenon observed in more than 10.000 species, which is the emission of light by a living organism. Bioluminescent organisms are mainly found in marine environment and can be found in organisms as diverse as bacteria and large vertebrates like angler fish and sharks (Marcinko et al., 2013). Although bioluminescence occurs frequently in marine environments, a few species on land and in freshwater environments contain the spectral characteristic, such as fireflies, fungi, worms, and beetles, see Figure 17(Haddock et al., 2010).

Bioluminescence is the result of a chemical reaction that happens within the cell. On a molecular level, the reaction is similar in most organisms, a molecule known as luciferin can emit visible light in an energy-intensive reaction, which is catalysed by the luciferase enzyme, which triggers the oxidation of the luciferin (Fleiss & Sarkisyan, 2019).

The organisms' spectral characteristics are primarily limited to blue-green wavelengths, ranging from 450-500 nm, which travels through ocean water most effectively and making them easily visible (Haddock et al., 2010) (Valiadi & Iglesias-Rodriguez, 2013).

There is a clear benefit in visual communication between organisms through bioluminescence. It can for instance be to attract, defence, offence and communicate. In most cases bioluminescence is used to scare of predators, frequently in an effort to attract higher order predators, act as a form of camouflage or startle a predator (Haddock et al., 2010).

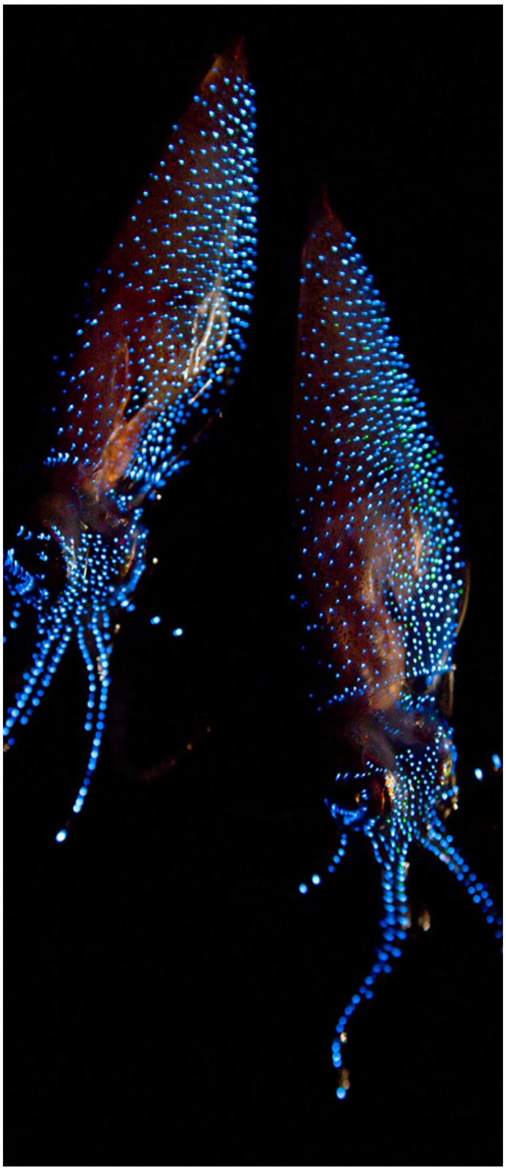


Figure 16. Firefly squid (Get up close and learn about firefly squids, the mystical phenomenon of Toyama Bay, z.d.).

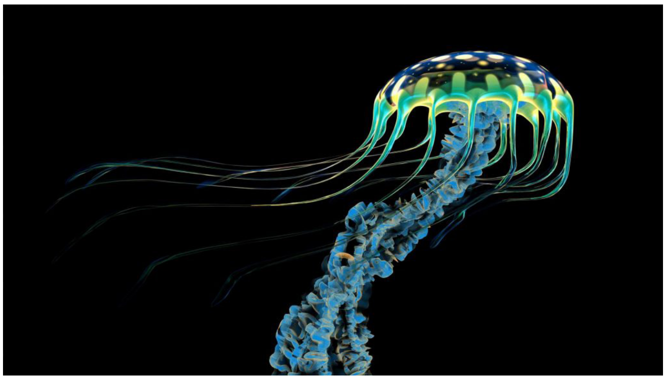


Figure 15. Jellyfish (Beneath the Glow | Feed Magazine, 2018)

Figure 17. Glowworms (Meneguzzi, 2023).

Dinoflagellates

The majority of the ocean's surface bioluminescence is caused by dinoflagellates which are usually considered algae. Disturbance of the water at night leads to bright blue light displayed in Figure 18, especially when their populations are dense (Valiadi & Iglesias-Rodriguez, 2013). The bioluminescence appears when agitated mechanically due to shear stress, as brief flashes of light and low intensity glow (Wilson & Hastings, 1998). Due to their shear stress dependency, they can interact with predators. This is known as the burglar alarm. In response to the movement of approaching predators the culture will be stimulated and emit light. Additionally, the predators will be illuminated, making them visible to others. This is the most widely accepted explanation, but it requires a high concentration of the bioluminescent population to function, so the selective advantage at a lower concentration may be due to another function, such as aposematic warning or startle response. (Hanley & Widder, 2017).

Marine dinoflagellates are single-celled, planktonic organisms and conducts photosynthetic metabolism. Dinoflagellates all have the same basic characteristics; each species has its own distinctive and defining characteristics. According to Baker et al. (2008), there are at least 18 luminous genera, which include Gonyaulax, Noctiluca, Protoperidinium and Pyrocystis. The Pyrocystis genus are particularly intriguing because they have a relatively high intensity light emission (Seliger et al., 1969). Because Pyrocystis species are an important part of the marine phytoplankton, they supply a substantial amount to earth's oxygen. They can consume large amounts of carbon dioxide by converting it into oxygen through photosynthesis (Swift and Durbin 1972).

Within this project, the focus will be on the species Pyrocystis Fusiformis, see Figures 19 and 20. This species is in comparison to other species quite large and is non-motile, meaning that they cannot move through their environment on their own. (Classification-Pyrocystis Fusiformis, n.d.).

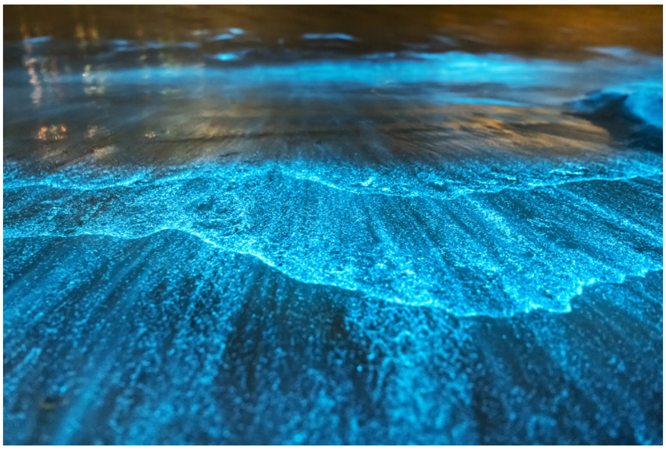


Figure 18. Bioluminescent algae in the sea.

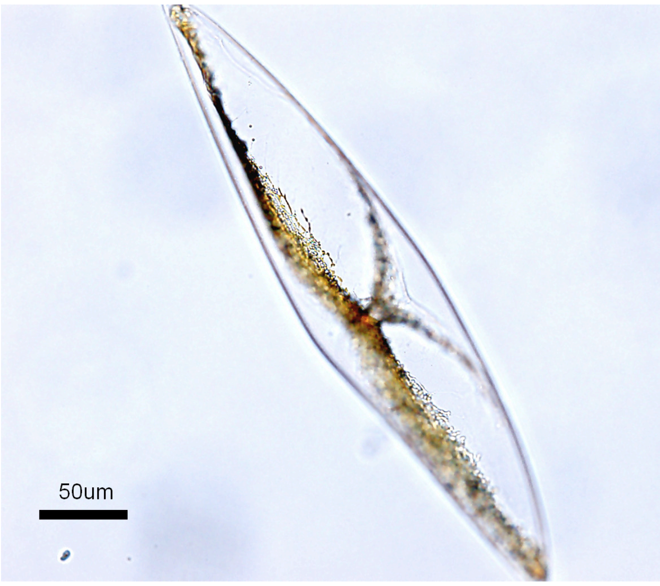


Figure 19. Pyrocystis Fusiformis (Reproduction - Pyrocystis fusiformis, n.d.).

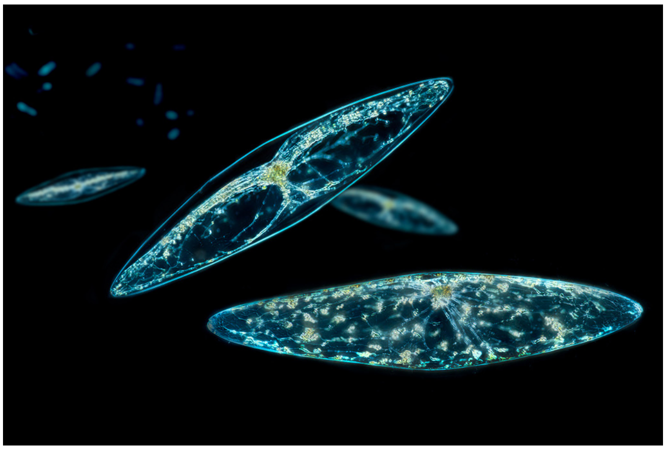


Figure 20. Pyrocystis Fusiformis emitting light (Reproduction - Pyrocystis fusiformis, n.d.).

The fusiformis is regulated by the circadian rhythm that is tied to a day and night cycle of around twelve hours. During the day the luciferins are rebuild due to photosynthesis. In the night phase (dark) the luciferins are oxidized and emitting light (Widder & Case, 1981) (Wilson & Hastings, 1998). Photoinhibition of bioluminescence ensures minimal energy is wasted during the day (Valiadi & Iglesias-Rodriguez, 2013). This means that during the day, the cells will not illuminate, such a non-luminescent cell is called a “photo phase”. A luminescent cell is called a “scoot phase”. (Fleisher & Case 1995).

The fusiformis will begin to illuminate when the flow conditions are right and there is enough mechanical force. When a force is exerted on the outer cell membrane (step 1), the dinoflagellate is stimulated, see Figure 21 (Maldonado & Latz, 2007). The shear stress sets off a chain reaction of cellular processes, the calcium influx (2 and 3), the hyperpolarization of the vacuolar membrane (4), the proton release into the cytosol (5), the drop in pH (6), which results in the acidification of the scintillons. In the organelles known as scintillons, the luciferin substrate and the luciferase enzyme are found. When the acidification occurs, the luciferase is activated, causing the luciferin to be oxidised. The reaction is completed, resulting in a flash of blue light (7) (Valiadi & Iglesias-Rodriguez, 2013) (DeSa & Hastings, 1968). The acidification of scintillons is necessary because the chemical reaction that generates light is pH dependent, so when the pH will drop the bioluminescence chemistry is activated.

A culture tends to lose some of its sensitivity after being agitated by a large shear force, when it is followed by a lower intensity agitation. Von Dassow et al. (2005) describes this effect as the loss of sensitivity of the organism. An increase in shear stress is needed to give a similar bioluminescence output (Van Dortmont, 2020). The research points out that the bioluminescent response is influenced by both the force applied and the rate at which the flow stress changes. If there is a slower rate of increase in flow stress, the dinoflagellates will become less sensitive which results in a reduction in overall light output (Von Dassow et al., 2005).

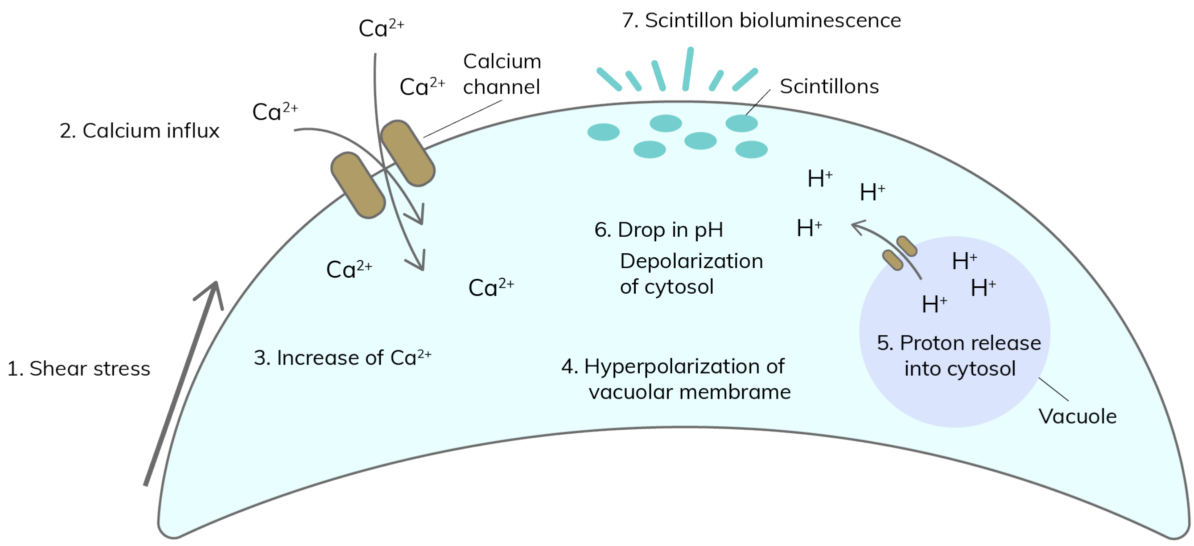


Figure 21. Schematic overview of the bioluminescent pathway adapted from Lambert (2015).

Flash form behaviour

There are micro and macro flashes present when fusiformis emits light. The scintillon present in a fusiformis cell produces a microflash of light. The macroflash, which is seen as the entire cell lighting up, is the accumulation of the microflashes. Macroflashes are defined by their intensity and form. The emission strength of a macroflash is dependent on the amount of scintillons that participate in the flash and the emission strength of the microflashes they produce. The form of the macroflash is defined by the rise and decay time. This is influenced by the response of multiple microflashes, which can be synchronous or asynchronous, as well as the rise and decay time of individual microflashes (Widder & Case, 1982).

Widder and Case (1981) researched the bioluminescent behaviour and described two different flash characteristics. The two types of macroflashes are the first flash (FF) and the subsequent flashes (SF). The first flash is a short and intense flash response to the initial stimulation, it is relatively bright and rises quickly in 10 ms and experiences a short biphasic decay which is 90% complete 200 ms after the flash's onset. During a first flash the scintillons will synchronically respond with a microflash. The following flashes have a rise time of about 150 ms and has a longer monotonic decay. The decay is 90% complete after about 500 ms from flash onset, making them much dimmer but longer lasting. During this subsequent flash a smaller number of active scintillons react, thus asynchronously, producing a dimmer flash.

After some time, cells can recover from exhaustion, see Figure 22. After an interval of 10s to 1 min the total light emission of the second flash will be roughly 10% as intense as the first flash. Recovery developed steadily up to 12 minutes for periods longer than 3 minutes, at which the second flash's total stimulated light intensity reached, on average, 20% more light and occasionally 40% more than the first. The rise time of the second flash is only 70% of its initial time at this point. Because the second flash follows a 12-minute pause, the flash's decay is prolonged, resulting in a longer overall flash duration which causes the increase in the total stimulated light. After 30 minutes, the second flash's rise and fall times seem to have returned to their original values, and the first flash's characteristics seem to have fully recovered (Widder & Case, 1981).

The recovery for exhausted cells is however much slower. The first flash requires 30 to 60 minutes recovery in unfatigued cells and 6 hours in fatigued cells. After a 6-hour period the exhausted cell will only produce 60% of the total light output; after 24 hours the output is 90%. This indicates that the number of flashes is not proportional to the availability of bioluminescent material. The exposure to light is essential for recovery because it expedites the process. Recovery can also occur without the light phase, suggesting that storage can also produce bioluminescent material and that its production is not solely dependent on photosynthesis during the light phase (Widder & Case, 1981).

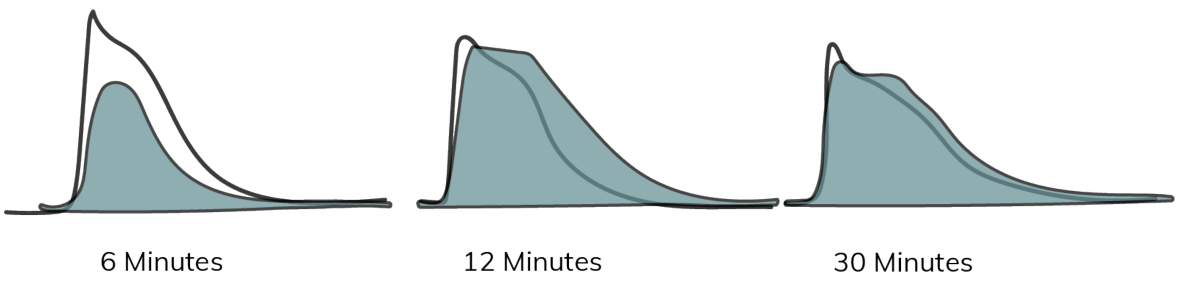


Figure 22. The recovery of the first flash (Widder & Case, 1981).

Van Dortmont (2020) researched the behaviour of the P. fusiformis light over time. He looked at different types of agitation, such as rotation, pulse, and vibration, and how this effects the changes in luminance, what the relation is between input and output and the sensitivity of mechanical stimulation. Next to that he also looked at the textural qualities that appear with these types of agitation and the spatial distribution.

Increasing the rotational speed results in a higher amount of light produced over time, but also a faster and greater drop in intensity. At 90 RPM, the decay is more gradual than at 120 RPM, resulting in a more consistent light output. The addition of a pause interval in a rotational sequence can extend and increase the total light output but will result in a visually less consistent output over time. The direction of agitation also plays a role in light output, with alternating direction increasing output by more than 200% compared to constant or one-way paused rotation at the same speed. This increase is due to the shear force caused by the sudden change in direction, which triggers a larger part of the culture and results in a brighter light. Counter rotation further increases shear force, resulting in a more gradually and consistent fading light (Van Dortmont, 2020).

The response of fresh culture is almost instantly compared to a culture that has been agitated, there will be a delay in the response to a stimulation. The delay depends on what kind of stimulation there was before, depending on intensity and duration (Van Dortmont, 2020). Due to loss of sensitivity over time, which will increase with larger shear forces, it is important to consider the order of agitations to utilize the bioluminescent potential and therefore enhance the light output. Lower intensity agitations should be at the beginning to maintain the sensitivity, because the response is lower after the culture is exposed to large shear forces as a result it will show no response to a lower intensity (van Dortmont, 2020).

Although the type of agitation affects the textural qualities, the amount of texture can be changed by varying the agitation's speed or intensity. In general, a faster rotation speed results in a reduction in the texture that can be seen as dots of light but will start to merge together. Rotation will result in a uniform glow with little visible texture because the cells are clustered together. Pulse agitation creates a texturized pattern that is evenly spread, this tends to create more dots instead of liner lines and motion blur (see Figure 23). With vibration agitation the light is more texturized, where each individual algae can be seen, it creates a high scattered light (van Dortmont, 2020).

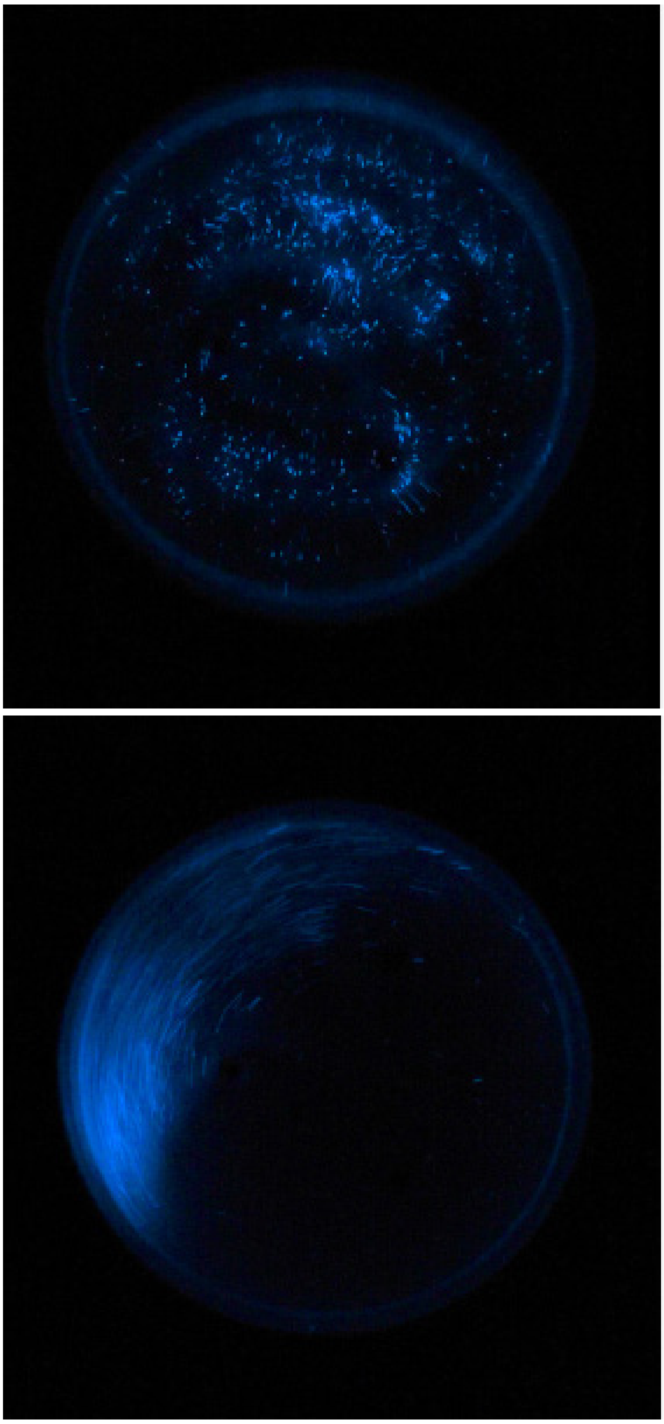


Figure 23. The differences of scattering in pulse agitation (top) and rotational agitation (bottom) derived from Van Dortmont (2020).

A different kind of application comes from research by Li et al. (2022), the research tries to fabricate a soft biohybrid that is integrated with bioluminescent dinoflagellates. The biohybrid would be stimulated by mechanical stimulation, integrated magnets or as robot.

A culture of Pyrocystis Lunula is encapsulated by a transparent and soft elastomer chamber (PDMS). It should be noted that the material is highly permeable to gas exchange, which ensures the survival of the organism. A shear stress was applied to the dinoflagellates, which activated their bioluminescence, because of the biohybrid device being deformed, by for example bending, stretching, compression and other stimuli. The device is transparent which allows for photosynthesis and viewing of the bioluminescence.

Next to that the research looked at the intensity of the bioluminescence and how the elastomer chamber affects this. They fabricated two similar chambers, one smooth and one with pillars on the inner surface. They looked at the characterizations of the light intensity under various loading conditions. Due to the enhanced fluid motion created by taller pillars, light intensity increased as pillar height increased. The chamber with pillars produced more light than the chamber without pillars under the same loading conditions.
The biohybrid device was also tested with contactless stimulation caused by mild air flow. The beams were on a fixed underground. The air flow, ~45 L min−1, deformed the cantilevers and stimulated the biohybrid device. (Li et al., 2022).

How to grow in a lab

The dinoflagellates can be grown in a lab environment; however, the interference of organisms is critical for the start of a culture. Therefore, proper equipment is needed to create a sustainable living environment that allows growth and will maintain the culture for further testing.

The Pyrocystis Fusiformis can reproduce itself asexually, this means that they can reproduce at a much faster rate and keep the genes. The growth however is dependent on several combined effects, such as light, temperature, nutrition, and salinity. The growing conditions can be optimized but the growth rate will only go to a certain limit. Pyrocystis Fusiformis divides every 4 to 5 days, when conditions vary this will lie between 5 to 14 days (Swift and Meunier, 1976).

Light

Dinoflagellates derive energy through photosynthesis, meaning that they require light. During the light phase the energy is derived from a light source. This light source needs to meet requirements on several aspects such as the duration of light, the intensity of the light source and the spectrum.

Since the dinoflagellates are controlled by a circadian rhythm they need a constant light of approximately 12 hours, followed by a dark phase of 12 hours. The light cycle can be expanded to 14 hours, which will result in the generation of more energy (Van Dortmont, 2020).

Swift and Meunier (1976) showed that the stimulable bioluminescence of the species P. fusiformis the capacity was saturated at 0.15 μmol m^{-2} s^{-1}. The division rate of the cells was saturated at 30 μmol m^{-2} s^{-1}. The cell numbers will not further increase due to light intensities that are higher than 5 to 10 μmol m^{-2} s^{-1}. It also showed that under lower light intensities the P. fusiformis maintained the high division rates, but it was at the expense of their cell size.

To reach the light intensity of 5 to 10 μmol m^{-2} s^{-1} a LED light source of 400 lumens is recommended for cultivation in a lab environment. To enhance growth an 800-1600 lumen LED light source could be used (Van Dortmont, 2020).
Since the dinoflagellates are autotrophic organisms, they can absorb only certain wavelengths. The best match that fits the absorption spectrum is a cool white LED. These also have the benefit of being energy efficient and do not produce a lot of heat, which could affect the organisms (Van Dortmont, 2020).

Temperature

P. Fusiformis is commonly found in regions where the surface temperatures fluctuate between 16 to 24 degrees (Rivkin et al., 1982). The algae are best placed in a temperature controlled environment between 18 and 20 degrees. To enhance the rate at which they grow the temperature can be between 22 and 24 degrees, but higher than 24 degrees will decline the rate and eventually they will die (Van Dortmont, 2020).

Medium
The culture is best kept in a liquid medium to be able to grow. The liquid medium consists of seawater with nutrients for the dinoflagellates. The recipe that is used is the L1-SI liquid medium. In the lab the liquid medium is made with artificial seawater because this is seen as more reliable, because the exact composition of natural seawater is not known and could therefore miss certain elements (Van Dortmont, 2020).

Storage
The algae cultures are best kept in sterilised Erlenmeyer flasks, this way they can be stored in smaller volumes. The Erlenmeyer's are sealed with a non-absorbent cotton wool to allow gas exchange to be possible but block possible contamination. An autoclave should be used to sterilise the vessels and medium. The cultivation will quickly be over once stronger microorganisms enter the medium. The cultivation of dinoflagellates is more difficult because the four different mediums need to be made and put in the autoclave otherwise it will precipitate.

To allow for proper gas exchange in the Erlenmeyer flask used it should be filled to ¼ or ½ of its maximum volume. Due to the tapered shape the surface area will be optimal (Van Dortmont, 2020).

Handling the culture
Since the culture has a great risk of contamination, once it is sealed with the cotton wool it is important to only open the flasks when necessary. If it does need to be opened, it is important to work as sterile as possible, because this will limit the chances of contamination (Van Dortmont, 2020).

2.7 Benchmarking bioluminescent design

The benchmarking process involves analyzing current designs that incorporate bioluminescent organisms. This allows for insights to be gathered on the possible ways to integrate the bioluminescent organisms into product and lighting design. This is done by reviewing the designs on the encapsulation design, the required interaction (to activate the organism) and the application area.

The use of bioluminescence in design has gained more attention, but it is still relatively new material to use. People try to develop day-to-day (product) solutions with bioluminescent organisms such as bacteria or algae.

The company Glowee has a new illumination philosophy and is working on street furniture integrated with bioluminescent bacteria. The bacteria are held in transparent containers from glass. These bacteria glow because of the continues flow of oxygen. Their new street furniture, shown in Figure 24, mainly contains information sheets on a glass plate that are backlight by the bacteria (Glowee, n.d.).

The lamp Ambio, see Figure 25, from Teresa van Dongen is another example of a design solution with bioluminescent material. The user can pull the weight down and the liquid will start glowing because of the swinging movement and therefore getting oxygen to emit light. She used the material as an alternative energy source. The material is held in a transparent container made of glass with a plug for gas exchange (Ambio - Teresa van Dongen, 2014.).

Although there are some other products that use algae, they frequently serve unclear purpose but aesthetics, such as the necklace from Bompass and Parr (2016), see Figure 26, and the Bio-Orb (PyroFarms, n.d.), they can be shaken to observe the light. The BioGLo is a product functioning as lamp where air bubbles activate the algae and observe the characteristics (BioGlo - The Bioluminescent Aquarium, 2019). Another example is the Living Lighting dress from Victoria Geaney (Geaney, n.d.), here the algae are inoculated in a dress of wool that is dipped in agar.

Figure 24. Glowee street furniture.

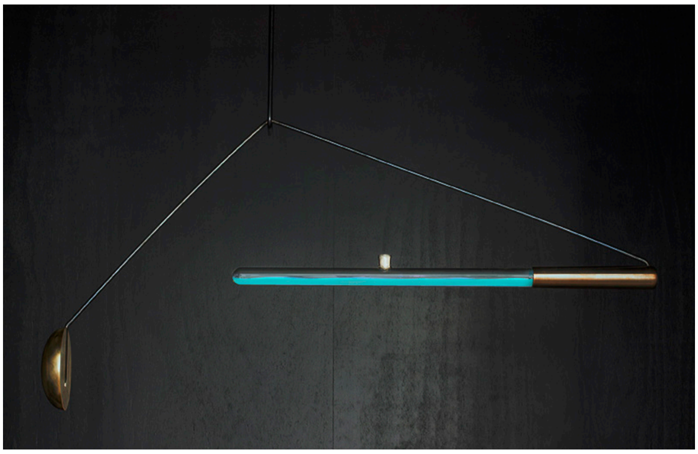


Figure 25. Ambio by Teresa van Dongen

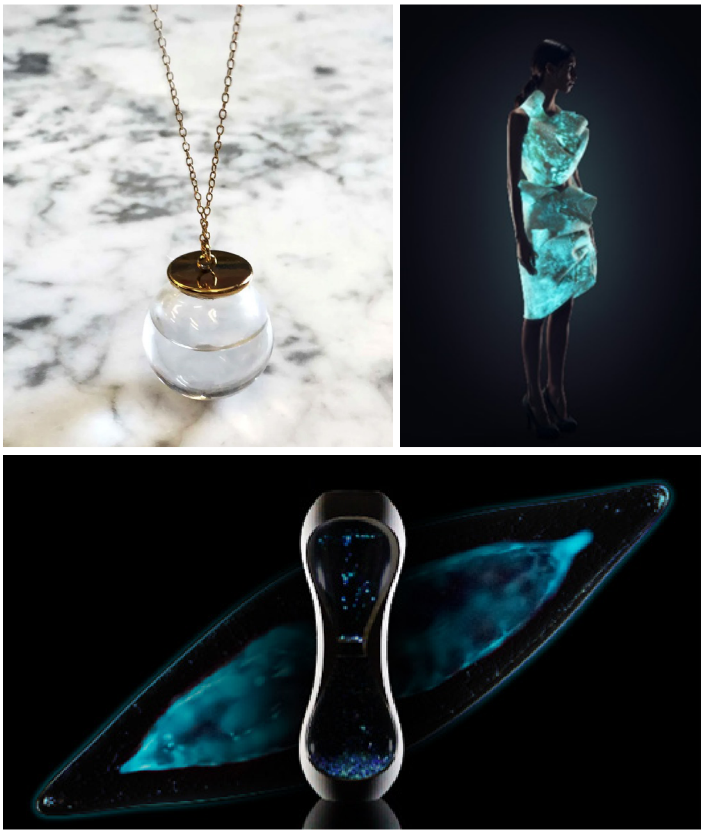
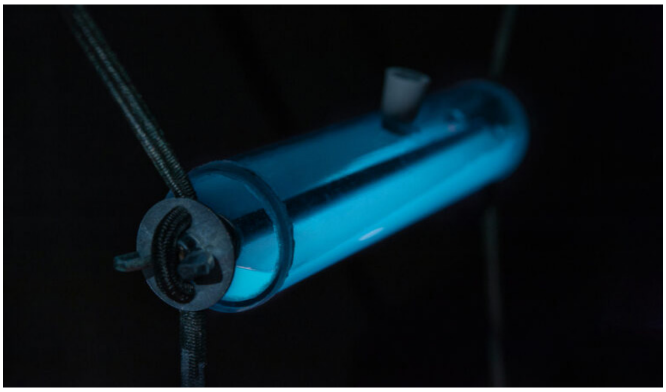


Figure 26. Necklace (top left), Living Lighting dress (top right) and BioGlo (bottom).

Currently, there are also projects done in exhibition design, see Figure 27. The ability to explore the behaviour of the bioluminescent dinoflagellates through movement, stimulating interactions that would occur in the organisms' natural habitats, is a common theme of these interactive exhibition setups. An example is from Studio Roosegaarde called the Growing light, here they use transparent polymer bags that are placed in the floor filled with dinoflagellates. The force created as visitors walk over the tiles will cause the algae within them to be activated, simulating walking through them on the beach (Studio Roosegaarde, 2017). Another example is Bioluminescent Field by Nicola Burggraf. Many tiny flasks containing bioluminescent dinoflagellates are scattered throughout the dark space. When visitors enter the installation, the vials attached to the rods, causes the algae to light up. The algae in this installation serve as a sensor that reacts to visitor movement (Burggraf, 2010).

Figure 27. Exhibition design Growing light (top) and Bioluminescent Field (left).

At Delft University of Technology they are also working with bioluminescence during graduations or courses. From one of the courses the project Performative Living Light (Karana, 2020) was conducted, where they used bioluminescence to change the interaction people have with daily objects. In Figure 28. you can see on the bottom a bench that would glow up when the seat is out of balance. On the top is a part of an installation where visitors could walk through and find their way. By moving weights, the containers would light up. It is a playful way to turn on the light. Both projects used bioluminescent bacteria, which respond differently than algae.



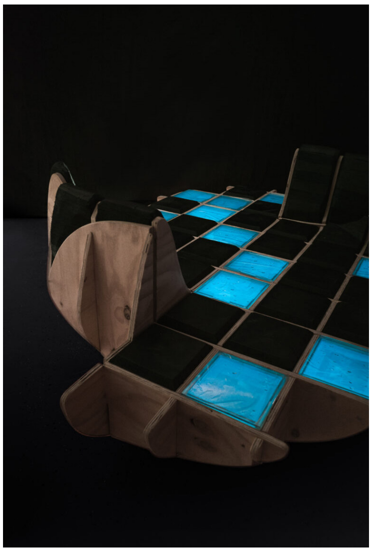


Figure 28. Performative Living Light

The encapsulations are made from clear glass or transparent plastics. This contains the culture and lets all emitted light to pass through. Most encapsulations are made to be sturdy and allow for repeated user stimulations because living cultures are sensitive to contamination. Often, the design's encapsulation only contains the liquid culture, and the designers do not provide specifics about introducing a new culture to the old one to keep them alive.

A different kind of application comes from the research by Li et al. (2022) mentioned above. They fabricated a soft biohybrid structure that is integrated with bioluminescent dinoflagellates to construct soft robotics. It is a way to create robust and power free biohybrid that is soft and mechanoluminescent. The device is transparent which allows for photosynthesis and viewing of the bioluminescence. The biohybrid would be stimulated by mechanical stimulation so the robot can create optical signals, illuminate the surrounding area, and visualise mechanical perturbations as shown in Figure 29.

This research would offer new interactions for designing with a liquid culture. With such a soft biohybrid it is possible to also add interactions as squeezing, flexing, compressing, pinching and others.

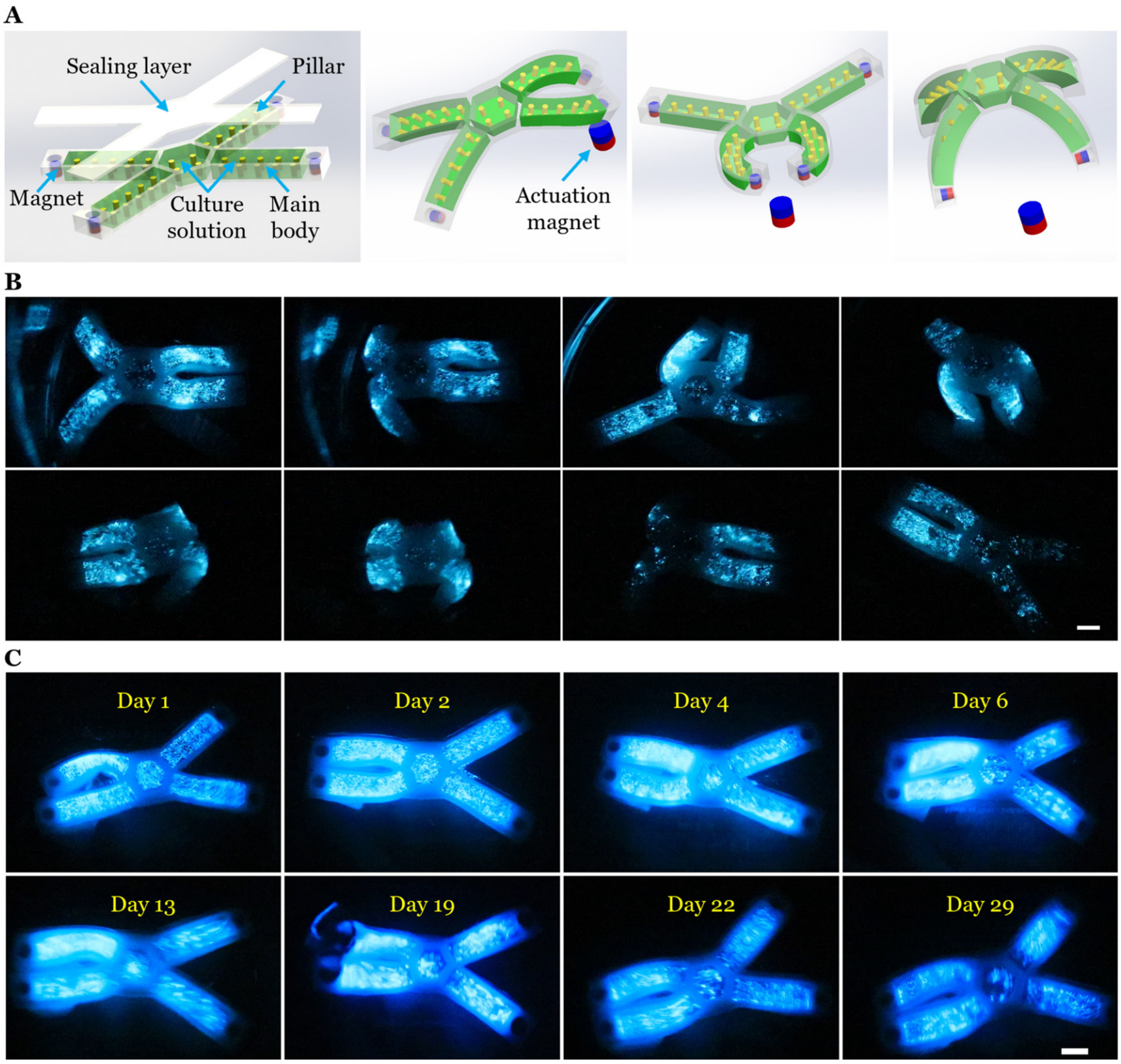


Figure 29. An untethered magnetically controlled soft mechanoluminescent robot with a closed system by Li et al. (2022).

2.8 Conclusion literature research

From the literature study it became clear that light pollution damages ecosystems and negatively affects us as humans. Because of the excessive use of Artificial Light at Night (ALAN) we are surrounded by increased brightness at night since light is unconsciously seen as better. The four elements of light pollution, glare, skyglow, light trespass and clutter causes 99% of Europe to live in light-polluted places. To prevent further illumination and bring darkness back into our nightscapes this thesis will focus on the design for darkness approach, where the values of darkness play a role.

From the nine values of darkness, with the focus of bioluminescence as a material, they can all be applied in a way since the values are sometimes closely related. Efficiency, the material can promote efficient use of lighting and darkness in cities. Sustainability, the material is a source of nature that can produce light; therefore, it is a different energy source. By using the material, we can explore the potentials for alternative and sustainable ways of lighting. Ecology is promoting the decrease in usage of ALAN, to witness their light, which impacts species and ecosystems. Healthiness, with the material we want to actively involve people in the environment, discover the material and getting familiar with darkness. Happiness, the emotional wellbeing will be enhanced through the captivating material; experiences, moments of pleasure etc. Connection to nature by supporting the natural settings and involving the user with a living material. By using the material as a light source, other light sources should be dimmed or removed resulting in a better sight of the natural night sky, supporting heritage, tradition, wonder and beauty; also, in the material itself.

Working with bioluminescent algae as a light source will create a dark acupuncture concept. Dark acupuncture aims to confront people with space in the urban environment that are explicitly left dark. With this approach, people will be forced to think differently about our expectations and perceptions of nighttime lighting, and it will possibly help in our acceptance towards darker urban nightscapes (Stone, 2019). This is because bioluminescent algae will not function as a functional light and need to be activated to provide light.

This thesis will focus on the framework from Pont, which also includes Kelly's three layers of light. The framework is used to describe the light from a perceptual based angle and from a more mathematical and optic angle. It is a synthesis of mathematical, physical, perceptual, and design descriptions of light. Looking at the compositions of each description in the different fields represented, the descriptions are the same. This way, it is possible to prove what the current lighting condition is, based on measurements and analysis and how this is perceived by users. Based on those insights we can determine design opportunities for the ideation phase of the project.

A few of the qualities of light will be analysed during the project. The set is reduced due to the time scope of the project and the materials available. The qualities that will be analysed are:

- The illuminance
- The ambient light also called the light density
- The focus light also called the light vector
- Diffuseness
- The contrast measure

The range of contrast is of importance for our dark adaptation. Dimmer and layered light, creating thus a low contrast environment, and using patterns to generate ambience improves the space aesthetics and supports people in their perceived safety and security. Because once you are dark adapted you can see much more in the dark and thus resulting that there would be less light needed to perceive an environment as bright.

As perception plays a significant role in the study of light, it is essential to examine how individuals experience the existing light conditions. The dimensions from Louwers: tenseness, liveliness, and detachment, will be used to assess the light among other dimensions.

Working with bioluminescent algae means that you need to consider their circadian rhythm. It regulates the algae, meaning that during the day they are recharging their energy and at night they can transform the energy into light. Therefore, a transparent container is needed for the light to reach the cells to conduct photosynthesis and for users to see the response to their interaction. To light up, there is a shear force needed. The interaction and stimulation of the algae can then cause them to flash. The type of agitation, the duration and the force needed all influence the organism: the textural qualities of the algae, creating between little visible texture to highly scattered texture. Due to loss of sensitivity the recovery is highly dependent on these factors. Therefore, the order of agitation is important; the intensity of the agitations should be from low to high intensity. Next to that it can help to create intervals between agitations to let them rest. For the design it is especially important to consider the sensitivity of the algae. Thus, it is important to recognise and consider the livingness of the organism and use this as a design quality.

3

Research Study

3.1 The research study

The purpose of the study is to learn how people perceive the lighting on campus in relation to the qualities they believe to be important. This study focuses on the qualities of lighting in an environment since the qualities influence the perception of a person. To support the study measurements and analysis were done on the light qualities on campus. The study contains examining specific aspects of light in four places on campus. The aspects, or qualities, are illuminance, ambient and focus light, diffuseness, and contrast measure.

To acquire knowledge about the user experience of the present lighting on campus, semantic differential scales will be used to examine their experience of light qualities. The semantic differential scale enables the conversion of qualitative data into quantitative values, facilitating their analysis and comparison.

Research Questions

This study focuses on analysing the specific qualities and the user experience of the lighting environment. At the same time, the aim is to confirm what spots on campus are the darkest and what are the lightest to determine where a design can have impact in regard to the design for darkness approach.

Therefore, the following research questions can be formulated:

- What light qualities are preferred on lighting atmosphere perception in four spots in Mekelpark?
- Which spots in Mekelpark are the lightest and the darkest, where lightest refers to the highest illuminance and darkest to the lowest illuminance?
- In which spot would the impact of a design be the biggest regarding design for darkness and user experience?

Data from two studies are presented: stationary measurements and a user experience study; an impressionistic description of the lighting in a space. In study 1, the focus is on measurements taken in four determined places in Mekelpark. The aim is to confirm, where the dark and light spots are, to determine where the next study should take place. In Study 2, the focus is on the user experience of the light environment. The hypothesis raised by study 1 that users perceive spot D as darker and unsafe and A as light and safe is evaluated. The results are used as a basis for designing lighting interventions that aim to integrate more darkness and improve the perceived safety in such a darker spot.

Ethical approach

Several measures have been taken to protect those that partake in the design process. According to the ethical guidelines of the Delft University of Technology, the following documents have been created and followed to ensure the ethicality of this project:

- Data Management Plan
- HRX checklist for Human Research
- Consent form

The study was approved by the HREC, the documents provided can be found in appendix B.

Context TU Delft Campus

For this project, the TU Delft Campus is chosen as context, specifically Mekelpark. Mekelpark is centrally located and connects the different faculties that are present. The campus features an extensive bicycle and pedestrian network. It has a green and park like character, therefore a large part of the campus can only be reached on foot, by bike or public transport.

Mekelpark is used to for lots of different things. You can walk over the designated paths, hangout on the grass, do some sports, or get a meal from the food trucks. There are free zones that can be reserved for large groups to gather, study, relax, or hold meetings.

At night, there are clear light and dark spots in Mekelpark due to the lighting present which is not evenly distributed along the length of the park. The light sources differ as well as the colour temperature of the light. Furthermore, some parts are busier than other parts. These factors are used to determine four spots in Mekelpark to conduct the studies, because they show a clear difference in conditions. The four spots are shown in Figure 30. from a top view of the TU Delft campus.

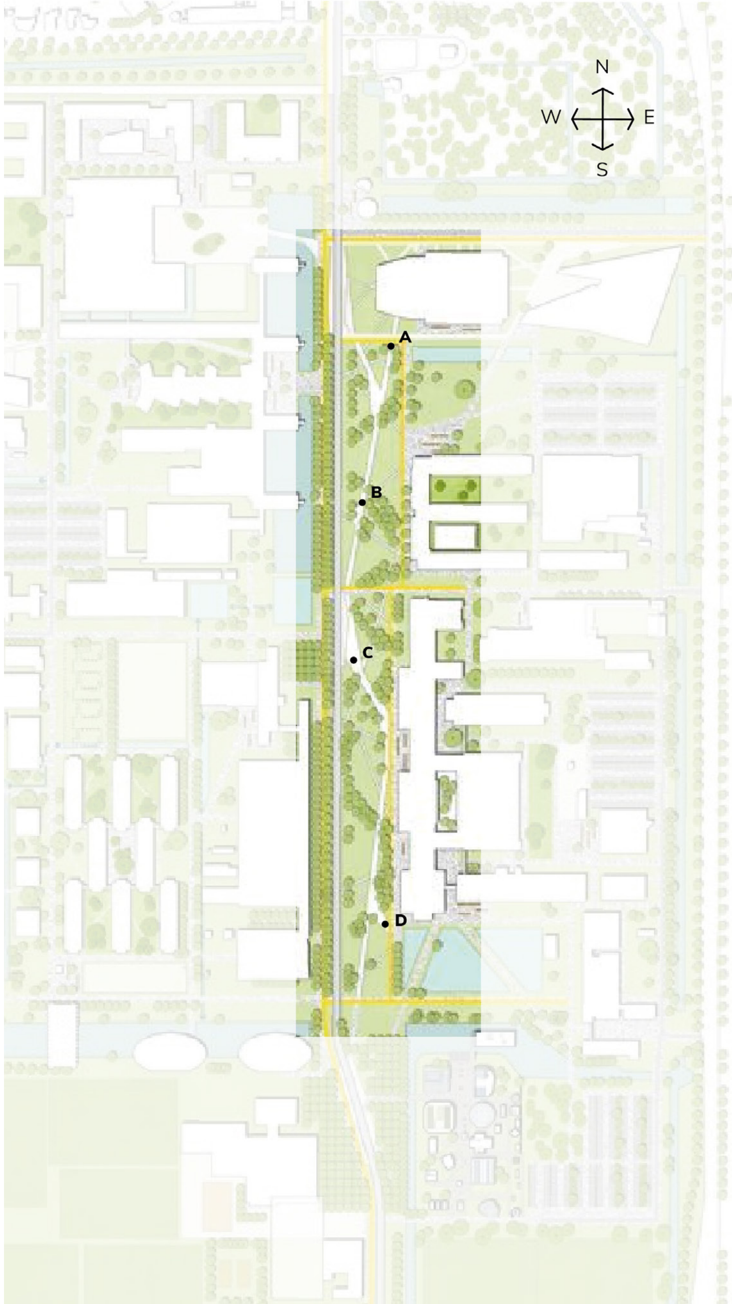


Figure 30. The four spots on campus.

3.2 Study 1

In the first study, the qualities of the light environment are measured in Mekelpark. The overall goal of this study, to determine the light qualities present in Mekelpark, provides a basis for, and leads to a hypothesis for study 2. The first study aims to collect data to determine the dark and light spots present.

Material and setup

The study was conducted at the pedestrian path in Mekelpark in four determined spots at the campus of the Delft University of Technology, The Netherlands (see Figure 30). The test site consists of several lampposts, light from buildings and bus stops.

The study was conducted after sundown (around 20:30) in the middle of December 2022. During this the weather conditions were dry and cold, with temperatures below zero. Being on campus meant that there was occasional traffic during the measurements.

Procedure

Lighting and spatial configurations within the nighttime scenes of four places in Mekelpark were measured.

The cubic measurements are done with a light meter. On top of the camera, a cube is placed, on each side of this cube the meter is placed to make a measurement. There will be six measurements of which the luminance, ambient and focus can be determined. From the ambient and focus the diffuseness can be determined (Xia et al., 2016).

For the other measurements a photo reflective sphere, or chrome ball, was used. The chrome ball can be used to capture lighting information from the environment you are in. It reflects all the light from every direction and captures this, this results in a relatively accurate representation of the light at that specific moment in time (Dror et al., 2004). To capture this, a photo is made with a camera, a Nikon D3400. From this, the contrast measure can be determined, which is discussed below.

To analyse the spatial distribution of light on the photo reflective sphere the following steps are undertaken, see Figure 31 for the set-up:

Setting up the imaging system

Place the photo reflective sphere (A) in a location. The photo reflective sphere is put on a 3D printed part (B) to hold it stable on top of the tripod (C). Position the camera (D) so that it can capture an image of the sphere and the light reflected in it. On top of the camera, place the cube (E) for the light meter (F) measurement. Determine what is north, south, east etc. and in what direction your camera is pointing. Pictures on the north and south side were taken.

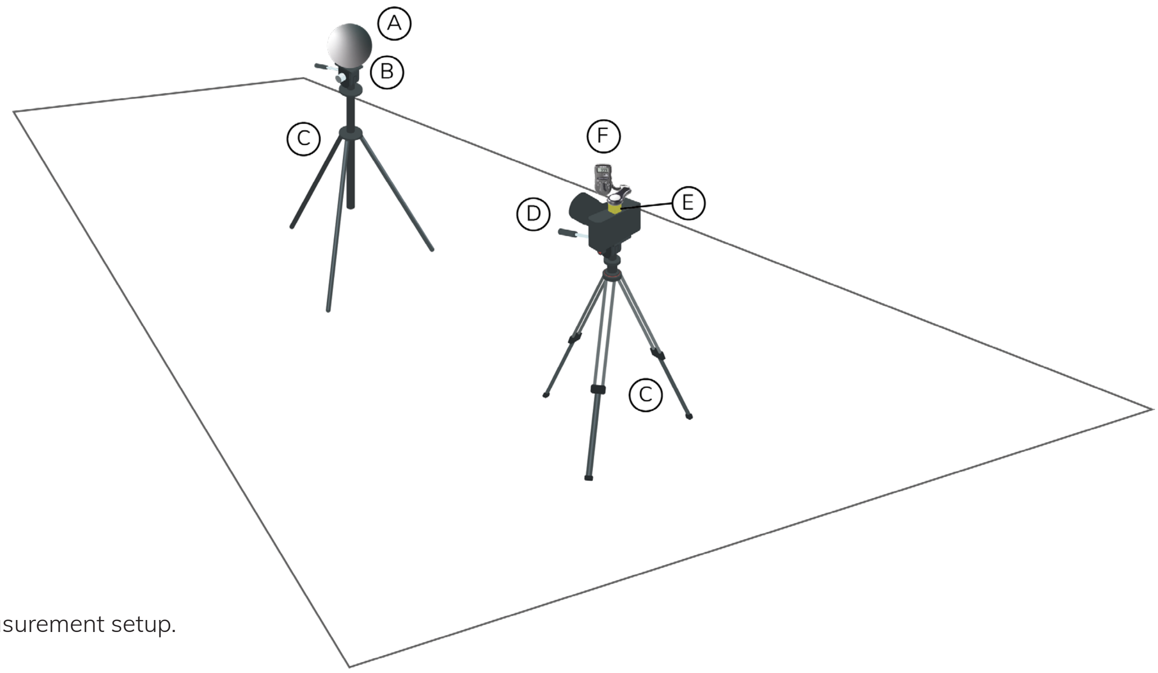


Figure 31. The measurement setup.

Measure the illuminance
Use the light meter to measure the illuminance in all six directions. Use the cube to direct the light meter. Make sure that you and the people helping are not in front of the light meter since this will alter the measurement.

Capture the image
Use the camera to capture an image of the sphere and the light. Make sure that the image is properly exposed and in focus. Different shutter speeds were used to be able to capture the sphere both in light and dark places. The shutter speeds were: 0.2, 0.5, 1, 5 and 10 seconds. RAW imaging is used to avoid automatic modulations.

Pre-process the image
Use image processing software to pre-process the image. To analyse the photos from the photo reflective sphere, first, the sphere needs to be unwrapped into a rectangle. The sphere is isolated, and then a filter is used to obtain a rectangle. In photoshop a plug-in from flaming pear called flexify 2 was used to be able to do this. Figure 32 illustrates what will happen after using the filter.

Figure 32. Use of filter flexify 2.

Extract the light intensity data
Use image processing algorithms provided by MATLAB to extract the pixel intensity from the input image.

Analysis of the intensity data
Use statistical or mathematical techniques to analyse the data and extract information about the direction and intensity of the light at different points on the sphere. This may include plotting data in a graph such as a histogram. To analyse the data retrieved from the measurements, excel and MATLAB are used.

Using illuminance measurements in the six directions, determining 1) the ambient light, also called the light density, 2) the focus, also called the light vector and 3) the diffuseness. This cubic measurement is introduced by Xia et al. (2016), where they provide an approach to be able to analyse images of natural scenes and compares this with Cuttle's method. Both methods showed that they can accurately measure the diffuseness. Cuttle's method provides a simple calculation suitable for a quick and local estimation.

Diffuse light has a wider range of angles from which the light originates. The method combines six reflectance observations made with a light meter. The six measurements are made on each side of the cube as seen in Figure 33.

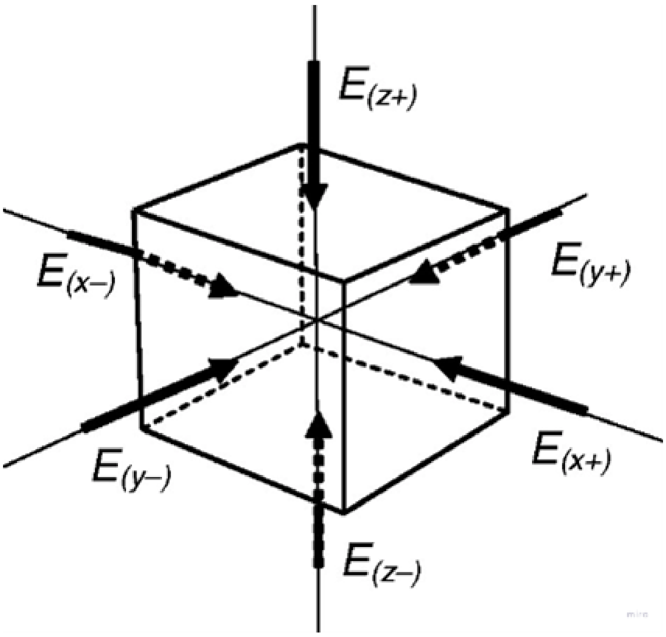


Figure 33. The cubic illumination is specified by six illuminance values (Cuttle, 2014).

Looking at Cuttle's method to determine the diffuseness, first the illumination vector is calculated, which represents focus. The vector can be calculated as:

$$Evector = \left(\mathrm{E}(+\mathrm{x}) - \mathrm{E}(-\mathrm{x}), \mathrm{E}(+\mathrm{y}) - \mathrm{E}(-\mathrm{y}), \mathrm{E}(+\mathrm{z}) - \mathrm{E}(-\mathrm{z})\right) \quad (1)$$

The scalar component represents the light density or ambient light. The scalar component is calculated as:

$$\mathrm{Escalar} = |\mathrm{Evector}|4 + \bar{\mathrm{E}}\mathrm{symmetric}$$
$$= \frac{|\mathrm{Evector}|}{4} + \frac{\{\min(\mathrm{E}(+\mathrm{x}), \mathrm{E}(-\mathrm{x})) + \min(\mathrm{E}(+\mathrm{y}), \mathrm{E}(-\mathrm{y})) + \min(\mathrm{E}(+\mathrm{z}), \mathrm{E}(-\mathrm{z}))\}}{3} \quad (2)$$

Where min stands for the minimum value. The diffuseness can then be calculated as follows:

$$(\mathrm{DCuttle})\mathrm{Normalized} = 1 - \frac{\left(\frac{|\mathrm{Evector}|}{\mathrm{Escalar}}\right)}{4} \quad (3)$$

The results will be between 0, which corresponds to fully collimated light, and 1 which corresponds to fully diffuse light.

To analyse the photo reflective sphere, the image is cropped and unwrapped, as mentioned before, this is called a spherical illumination map (Dror et al., 2004). A histogram of a spherical illumination map is a graphical representation of the distribution of light intensity values across a spherical surface. It shows the number of pixels in this surface with a particular light intensity value, with the intensity values plotted on the x-axis and the frequency of occurrence plotted on the y-axis.

By using MATLAB, the light intensity in the image can be analysed. The first step is to convert the image to grayscale if it is a colour image. Next, the image's pixel intensities range is divided into a set of equal-sized bins or intervals. The number of pixels that fall within each interval is then counted, and these counts are plotted as bars in the histogram. The histogram's x-axis represents the range of pixel intensities, while the y-axis represents the frequency or number of pixels with intensity within each bin. The resulting histogram provides a visual summary of the distribution of pixel intensities in the image, which can help understand the overall brightness and contrast of the image. For example, a histogram with a peak at low intensity values may indicate that the spherical surface is mostly shadowed, while a histogram with a peak at high intensity values may indicate that the surface is mostly lit. By analysing the histogram of a spherical illumination map, a better understanding of the light distribution on the spherical surface is created.

From the histogram, the contrast measurement can be calculated. This is done by determining the quartiles from the histogram. Quartiles are values in the histogram located at the 25th, 50th, and 75th percentile. The 50th percentile is also called the median; it is the centre of the histogram. To calculate the quartiles from the histogram a normalized cumulative distribution function (CDF) is created from which the values of the quartiles are extracted. First the total number of data point in the histogram will be determined, this will be the denominator for the CDF. Next the value for each quartile is calculated by dividing the quartile value (e.g., 25%) by 100 and multiplying it by the total number of data points. Then the data point that corresponds to the CDF value can be located on the histogram, this will be the quartile value. The contrast measure is then calculated as follows:

$$Contrast\ measure = \frac{(quartile\ max - quartile\ \min)}{(median)} \qquad (4)$$

The results of the contrast measure will vary from 0, no contrast to 1, a lot of contrast. Several shutter speeds were used to capture the light in the sphere in both the darker and lighter spots. The histograms from each shutter speed in one direction in a location are combined into one histogram to compare.

3.3 Results of study 1

Cubic measurement

The light measurement results with the light meter are shown in Figure 34. The figure shows the illuminance in six directions on four different spots, where the camera was pointed at the photo reflective sphere. The camera took pictures of the sphere on two sides, north and south, in each spot, see the Mekelpark map in 3.1 for reference.

The measurements of each location, meaning for example A1 and A2, are similar. This can also be seen for the other spots B, C and D. There are no huge differences between the north and south side. Location A2 has a high measurement value for the northside compared to A1. Spot B and D are both on the darker side compared to A and C.

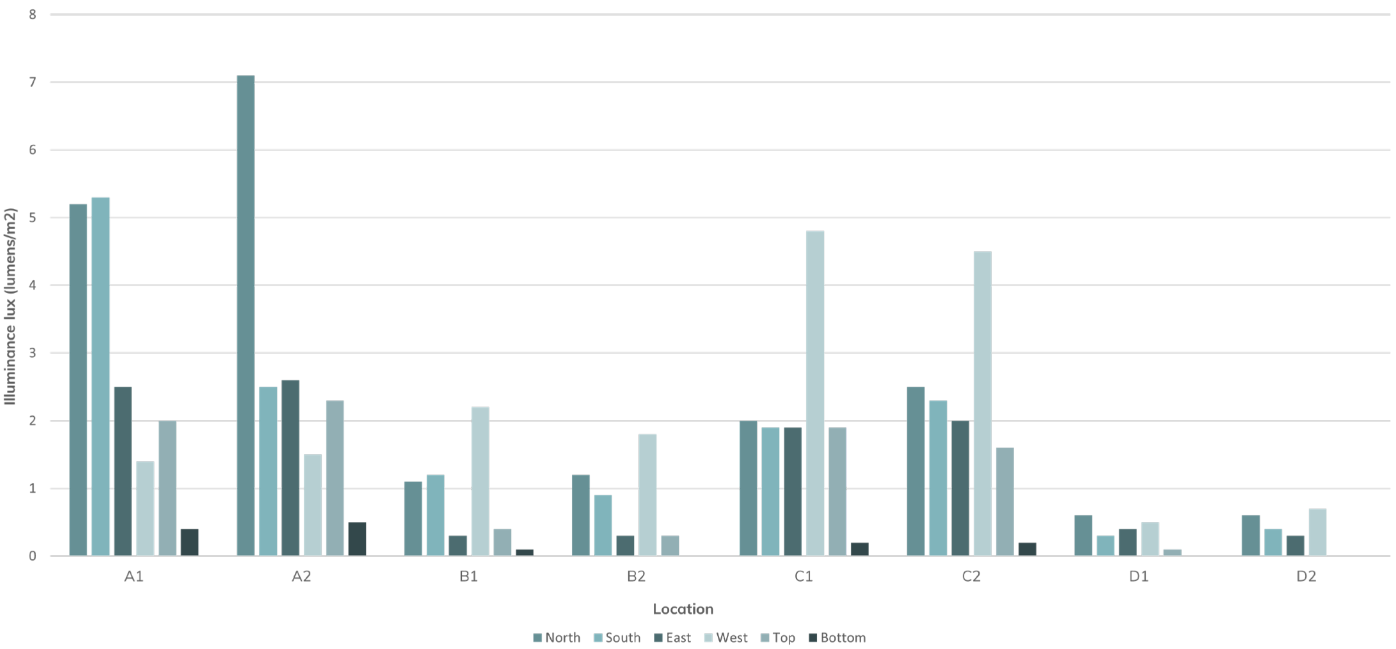


Figure 34. Illuminance measurements at each location.

The top values of the illuminance are plotted in Figure 35. The top values show us the light level in the vertical plane in the positive direction. From this plot it can be seen that in spot A it is the lightest and in spot D the darkest. Spot C is also on the high side of the graph.

EScalar is plotted in Figure 36, which represents the light density and shows what the strength is of the average lighting. It can be determined that in location A1 and A2 that there is more light present in the area, which makes it brighter. In D1 and D2 the value is low, this lower light density means that there is less light present, making it darker.

From the illuminance measurements the light density and vector were determined to be able to calculate the diffuseness. The results of the diffuseness were plotted with the corresponding location, shown in Figure 37. In location A1 the light was the most diffused compared to the other locations. In spot B the light was more collimated compared to the other locations. From the results it can be seen that A2, B1 and B2 are around the middle, and the other locations are more on the high side.

Something interesting to note here is that from Figure 34, in A1 there the north and south are much higher the other measurements; this means that the light comes from two opposite sides. This is also called a ‘light clamp’. Within that pair the values do not differ that much but compared to the others they do. Diffusivity metrics and measurements done with the cube (‘1st order approximation’ in a mathematical sense) are not sensitive to a light clamp. In the framework, however this would be reflected in the next (second) order, namely the ‘squash tensor’. By using a dodecahedron configuration, the squash tensor can be estimated and then it is able to measure such a squash or clamp.

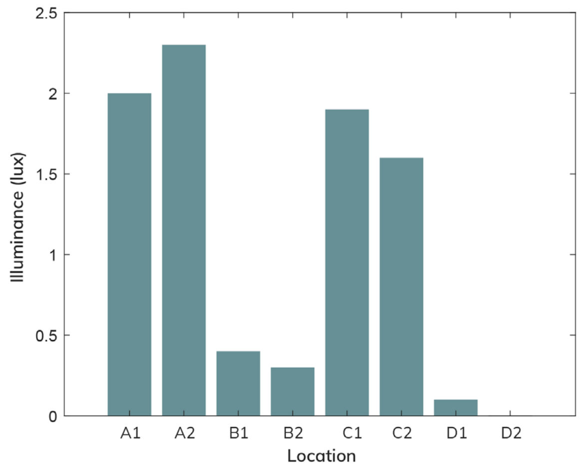


Figure 35. Illuminance top values at each location.

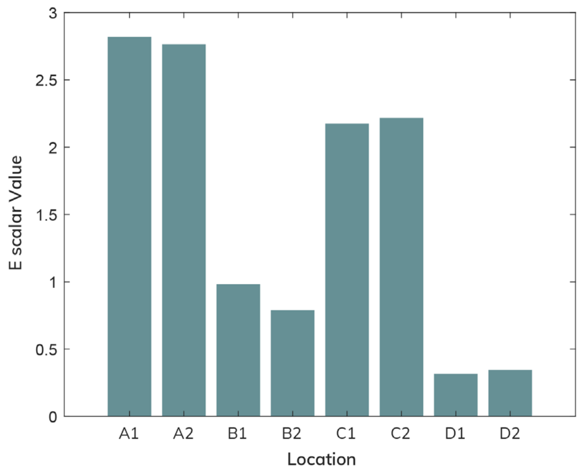


Figure 36. EScalar value at each location.

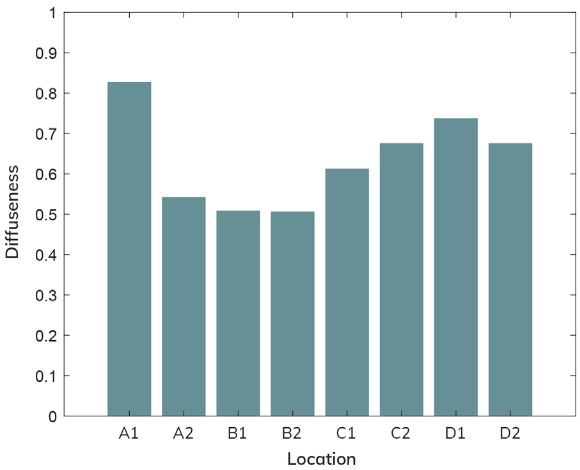


Figure 37. Diffuseness at each location.

Photo reflective sphere

In Figure 38, the light vectors are visualized, this is the average illumination direction. It shows the direction the light is coming from and the strength of the light. The length of the vector represents the magnitude, thus the longer the vector the higher the magnitude of the vector.

In each location photos were made at different shutter speeds; Figure 39 provides an overview of these photos. A combined histogram of each location (with the different shutter speeds) was made to be able to compare the probability of the pixel values, this can be seen in figure 40. On the x-axis is the pixel value, where zero represent black pixel values and seven represents the white pixel values. On the y-axis is the frequency of occurrence, or probability of each pixel value. From the histograms, it can be seen that there are high peaks on the left side of the graphs, this indicates that the image is mostly composed of dark pixels. With a longer shutter speed, it can be seen in the graph that the probability of the pixel values moves to the right. Location C1 and C2 show the most similar graph for one spot.

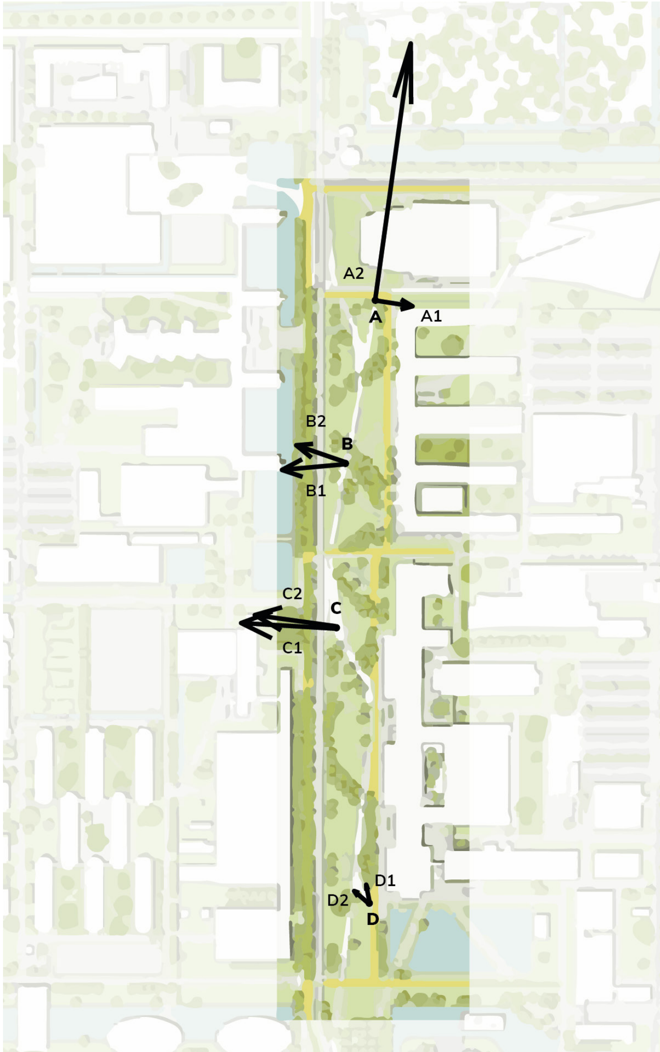


Figure 38. Light vectors

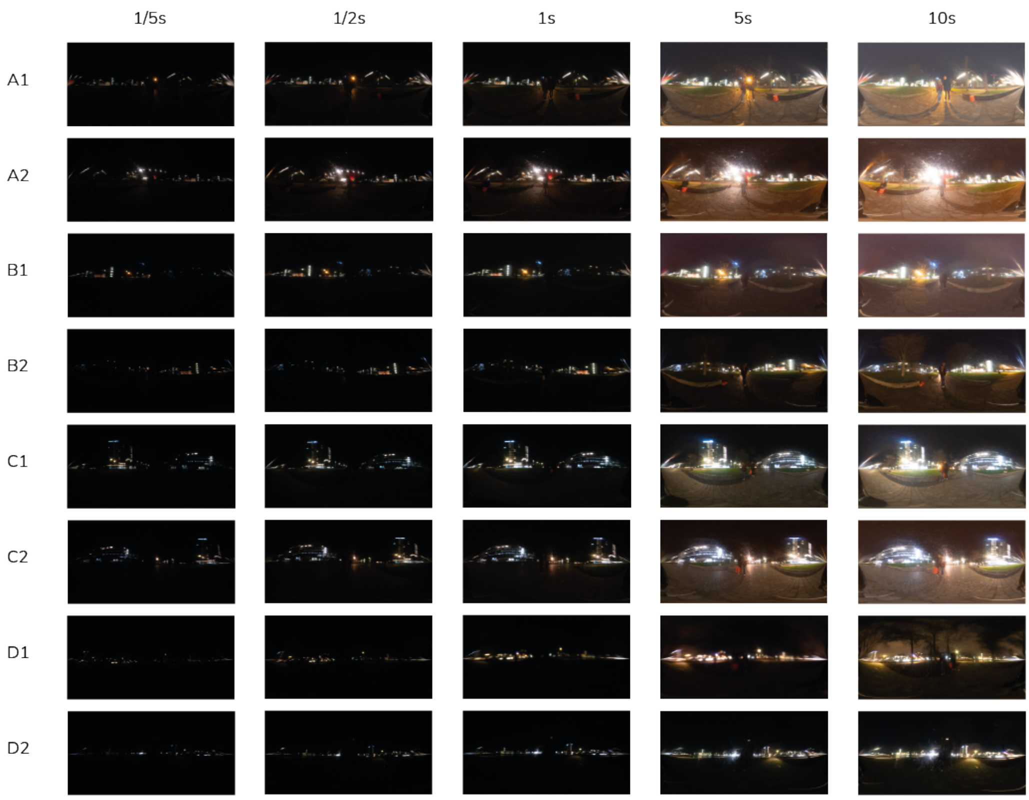


Figure 39. Overview of the spherical illumination maps in each location at different shutter speeds.

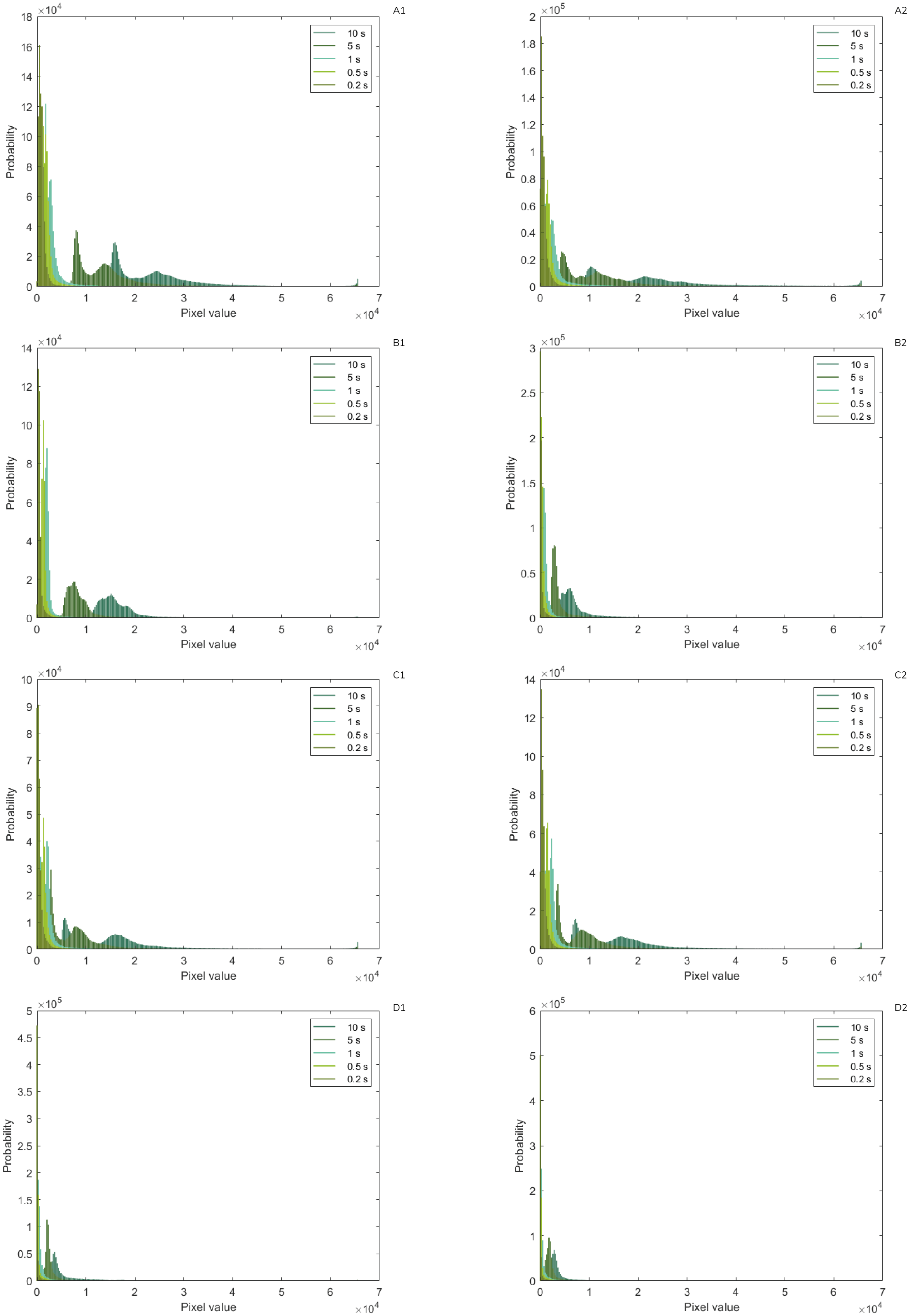


Figure 40. Probability of pixel values in each location with multiple shutter speeds.

The contrast measure was calculated for each location with the shutter speed of 1 second, the results are shown in Table 3. It shows the difference between the black and white pixels in the pictures from the histograms. As mentioned before, 0 means there is no difference in contrast and 1 means there is a high difference in contrast and thus in luminance. In location A2 it can be seen that there is a high contrast compared to location B1. Most of the locations are moderate contrast.

Table 3. Contrast measure in each location of shutter speed 1 second.

Location	A1	A2	B1	B2	C1	C2	D1	D2
Contrast Measure	0.5450	0.8000	0.2222	0.4000	0.6667	0.6667	0.6667	0.5000

3.4 Discussion of study 1

Cubic measurements

Illuminance

The illuminance values provide a clear overview of the light in the environment. Since the measurements were done twice in each spot, slight differences occurred. Together with the visualised light vectors and the pictures of the photo reflective sphere it can be determined why there were differences measured.

The light vectors in figure X. visualise the average illumination direction, where the light comes from, direction, and which magnitude they have. The results show that the vectors point in the directions of the buildings present in Mekelpark.

In location A2 it can be clearly seen that the light vector is pointing on the map towards the Aula, when looking at the corresponding pictures of the location it can be stated that this light vector is in fact coming from the Aula, where there are multiple spots hanging on the side of the building. In A1 it can be clearly seen that the light is coming from the building TNW, Applied Physics.

In location B1 and B2 the light vectors point towards the building of 3mE, Mechanical, Maritime and Materials Engineering. Looking at the corresponding pictures it can be determined that the light is due to the staircase and a study hall of this building.

In location C1 and C2 the light vectors point towards the building EWI, Electrical Engineering, Mathematics and Computer Science. Looking at the corresponding pictures it can be determined that the light is due to the lower floor levels.

In location D1 and D2 the light vectors point in the direction of the park and buildings. This is mainly due to the light of the buildings surrounding spot D.

Light density

The light density is in location A1 and A2 the highest, therefore there is more light present in that area and thus a lot of light exposure. In the images and light vectors, it can be seen that this is coming from the Aula building and TNW, Applied Physics. D1 and D2 are low values meaning that there is less light exposure and thus making it darker. Light density is an important consideration, as it can affect the visibility and aesthetic of a space. For example, in photography, high light density is often desired to achieve bright and well-exposed images, while in lighting design, the light density should be adjusted to create a comfortable and inviting space. It is also important to consider that excessive light density, or glare, can cause discomfort, reduce visual performance, affect the health of the people that are exposed to it and cause light pollution.

Diffuseness

The values that were calculated for the diffuseness provide a range between 0,50 and 0,83, which generally indicates that the diffuseness of the light sources is moderate to high. The values that are above 0,70 can be considered high diffuseness. This means that in location A1 and D1 the diffuseness is considered high. In the other locations it is moderate.
The diffuseness is a measure of the quality of light in terms of how evenly it is distributed within a space. Thus, a light source that produces a high degree of diffuseness will illuminate an area evenly and without harsh shadows. It should be noted that there are several factors that can affect the diffuseness, including the light source, the location and the orientation of the light source, and the presence of diffusing materials. For example, a light source that is positioned close to a surface will produce more direct and less diffuse light, while a light source that is positioned farther away or behind a diffusing material will produce more diffuse light.

Photo reflective sphere

Pixel value probability

The pixel value probability for different shutter speeds was displayed in histograms. A comparison of the shutter speeds and locations indicates that spot A and C are the lightest, while B and D are the darkest. The histograms further support this by showing that as the shutter speed increases, the pixel value probability shifts towards the right side, towards the white pixels.

Contrast

The contrast measure is calculated from the histograms. The contrast measure tells us the difference between two values, in this case the difference in an image. When analysing the pictures that correspond to the location, it can be seen that in A2 the light coming from the Aula produce a lot of direct light. Therefore, the resulting contrast calculated, which is on the high end, corresponds.

Hypothesis for study 2

Finally, it is important to consider the user experience when evaluating the measurement results. For example, a high contrast lighting might be useful in certain contexts, but it can also cause discomfort or eye strain. From the results and literature research a hypothesis for study 2 can be formulated.

“The hypothesis is that spot D, being the end of the campus and having fewer people present, is perceived as darker and less safe than spot A due to its visual environment, which is characterized by light spots surrounding it and more people present.”

The results indicate that of the four spots in Mekelpark, spot D has the lowest light level. Spot B is also dark, but since this spot is surrounded by two light spots, the visual environment appears lighter and may be perceived as lighter and safer.

Based on the findings of study 1 and the literature research, study 2 will be conducted in the brightest location A and the darkest location D. If a design will be placed in either of these places the design will have a different story and interaction. In location A, it is about dimming the light of the surrounding buildings and outdoor lighting, it could be more of an active interaction and experience.

In D it is about adding light through an artefact, that be constantly on, creating more a passive experience and creating a safer place.

Therefore, it is interesting to compare these two places regarding the user’s perception on the qualities of the lighting.

3.5 Change in lamps

While conducting the survey for study 2 it was noticed that the lamps on campus changed. Throughout the campus all the lamps were changed to the same model, motion activated streetlighting. Next to that, they added atmospheric light to accentuate some trees in spot B, which was quite a dark spot before. The change of lamps went unnoticed because the measurements were done before the Christmas break and the survey was done after the break. Within this time (+/- 2 weeks) it is very much possible to change the lighting. It is good to know that the TU Delft is taking actions regarding lighting and trying to save energy with motion activated light.

In Figure 41 the change in lamps can be seen. The clear difference can be seen in the pattern on the ground, there was a big shadow, and now it is evenly lit.

Due to the change in lamps, a recalibration of the measurements is done. This is to determine the deviation between the measurements.

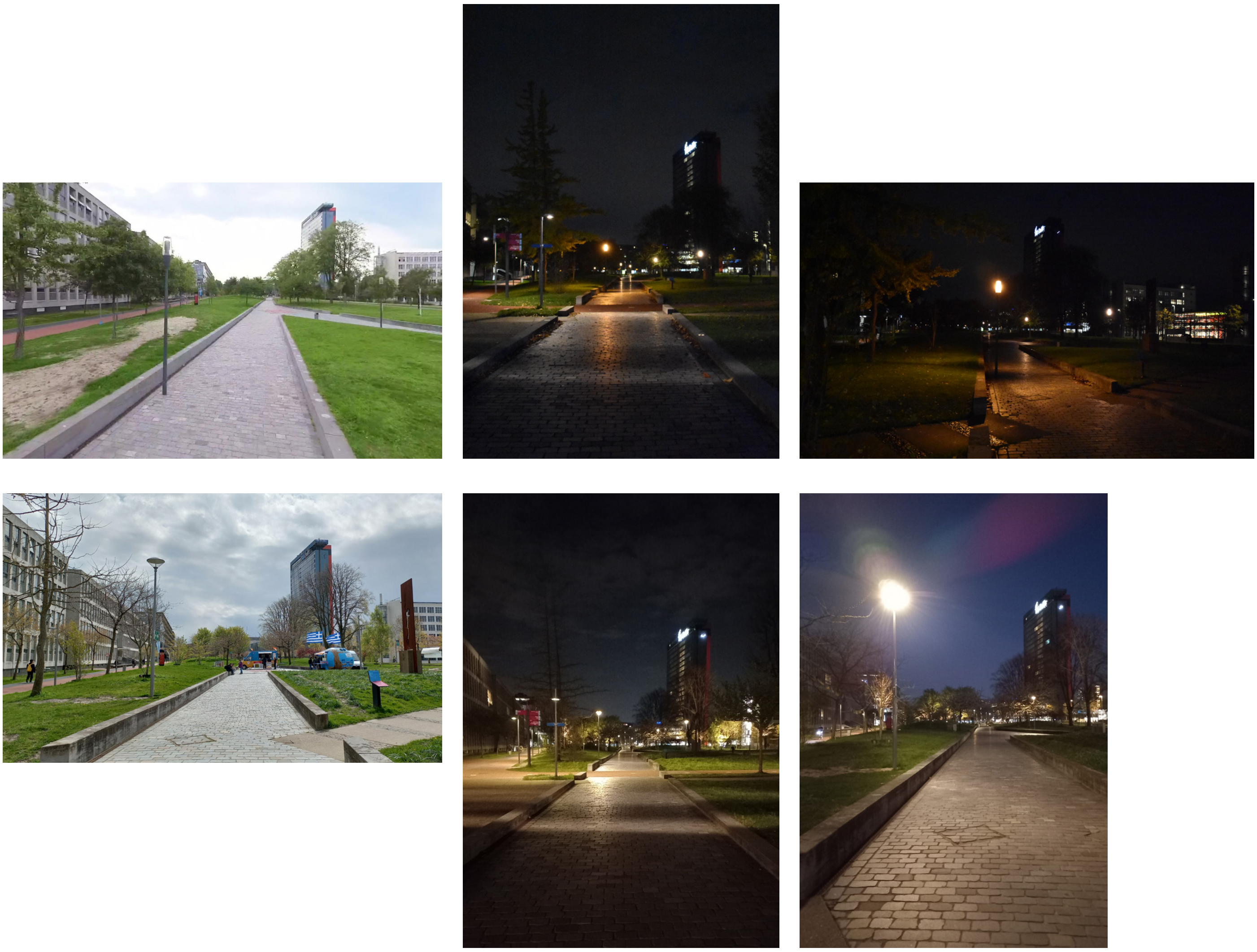


Figure 41. The different street lanterns before the Christmas break (top) and after the break (bottom).

With the light meter new measurements in all directions on all four spots were done. In Figure 42 the recalibration results can be seen where the illuminance values are compared to the old measurements. There is a slight difference comparing all the measurements, but they follow the same trend within one location. Looking at the Escalar value (light density) in Figure 43, A and C show a difference, the values are lower than before meaning that the strength of the overall light has decreased.

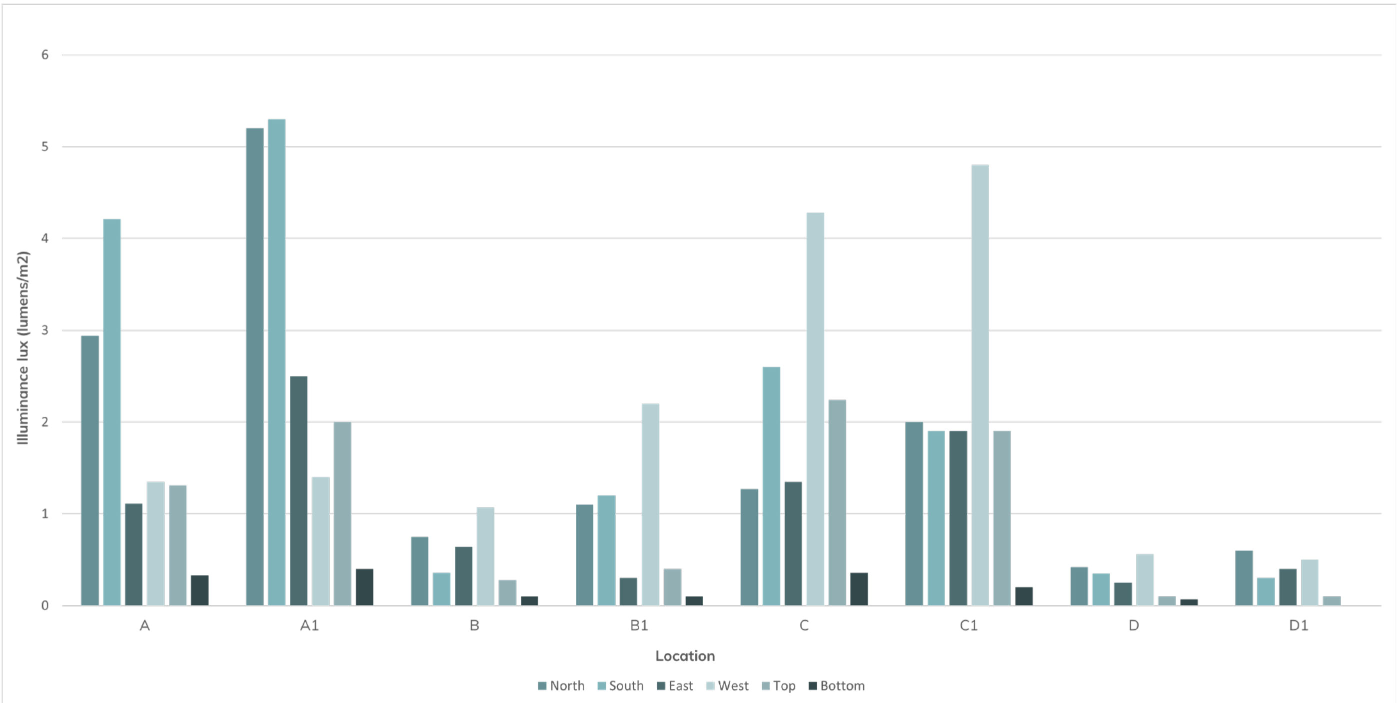


Figure 42. New measurements; A, B, C and D, next to the old ones; A1, B1, C1, and D1.

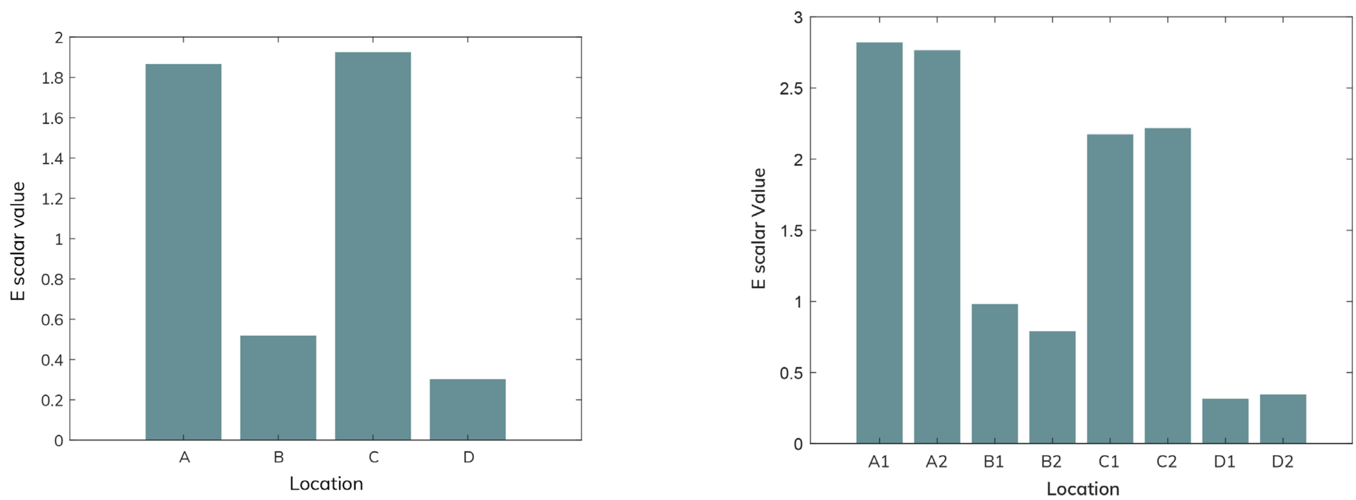


Figure 43. Recalibration of E scalar, next to the old plot.

3.6 Study 2

Goal

The overall goal of the second study is to gain knowledge on how people experience the current lighting that is present in the two determined spots in Mekelpark by study 1. The focus lies on collecting ratings by observers on the lighting environment. Additionally, it will be checked whether the hypothesis created from study 1 is supported in study 2.

Materials and setup

Looking into how people react to different qualities of a lit environment, the semantic differential scale can be used. The semantic differential is a measurement scale by making use of sets of bipolar scales. Adjectives with polar opposite meanings describe the extremes of each rating scale. Each response scale is used to ask participants to rate a variety of environmental characteristics. The listed dimensions in Table 4 can be used to describe scalable elements of the luminous environment (Tiller & Rea, 1992) (Evensen, 2014).

From these response dimensions several were adapted for this study. Since social safety is a great factor in design for darkness, this is considered when testing. The perceived personal danger scale created by Blöbaum and Hunecke (2005) was used for inspiration together with several other studies on this topic (Haans & de Kort, 2012) (Svechkina et al., 2020) (Van Rijswijk & Haans, 2018).

A semantic differential scale with seven points was used. In Figure 44 are the response dimensions shown with the corresponding scale.

The scales are rated on the question:

- I find the light quality...

To fill in the survey a phone is used to be able to see the survey at night. To not hinder their perception of the environment, the device has a low brightness, blue-light filter and the background of the survey is grey.

Table 4. Semantic differential response dimensions adapted from (Tiller & Rea, 1992) (Evensen, 2014).

Clear	-	Hazy
Visually warm	-	Visually cool
Eye discomfort	-	Eye comfort
Bright	-	Dim
Focused	-	Unfocused
Colourful	-	Colourless
Nonspecular	-	Specular
Focused	-	Blurred
Glare	-	Non-glare
Pleasant	-	Unpleasant
Lazy	-	Energetic
Tense	-	Relaxed
Boring	-	Interesting
Simple	-	Complex

	1	2	3	4	5	6	7	
Tense	O	O	O	O	O	O	O	Relaxed
Detached	O	O	O	O	O	O	O	Connected
Dull	O	O	O	O	O	O	O	Lively
Visually cool	O	O	O	O	O	O	O	Visually warm
Complex	O	O	O	O	O	O	O	Simple
Unpleasant	O	O	O	O	O	O	O	Pleasant
Uncomfortable	O	O	O	O	O	O	O	Comfortable
Blurred	O	O	O	O	O	O	O	Directed
Boring	O	O	O	O	O	O	O	Interesting
Dim	O	O	O	O	O	O	O	Bright
Colourless	O	O	O	O	O	O	O	Colourful
Unbalanced	O	O	O	O	O	O	O	Balanced
Ugly	O	O	O	O	O	O	O	Beautiful
Unsafe	O	O	O	O	O	O	O	Safe

Figure 44. Response dimensions.

Findings pilot testing

The response dimensions and question formulation were altered after pilot testing. The response dimensions were altered to create a clearer understanding of the words on a scale. The questions were changed to one question as shown above, to not confuse the participant rating the scales when moving to a new dimension.

Participants

The participants that were selected for this experiment were invited due to their connection with the TU Delft campus, by either living on campus or nearby, being a student, or passing by. Aside from the pilot session 11 participants aged 23 to 63 that took part in this study.

Procedure

The survey took place in Mekelpark in the two pre-determined spots. Participants were received at spot A or D. Here a brief explanation of the goal of the project was given and they were asked to read and, if they agreed, fill out the consent form.

After consent was given the participants would rate the dimensions on the 7-point scale and provide an open comment if that applied to them.

3.7 Results of study 2

For each response dimension the mean results are plotted in a bar chart, shown in Figure 45. The standard error is also plotted for each dimension, showing the range of how much the results would change if the study was conducted again.

The focus of the analysis will be to compare the mean results of location A and D and determine which of the two has a higher or lower value on the given dimension. The plot shows that for the following dimensions there is a difference:

Complex – simple	where D is higher than A.
Blurred – directed	where D is lower than A.
Uncomfortable – comfortable	where D is higher than A.
Dim – bright	where D is lower than A.
Colourless – colourful	where D is lower than A.
Detached – connected	where D is lower than A.
Unsafe – safe	where D is lower than A.

The differences that are found can be tested with a t-test. For the indicated dimensions it is expected to have significant differences, since the differences in the plot are much larger than the standard error.

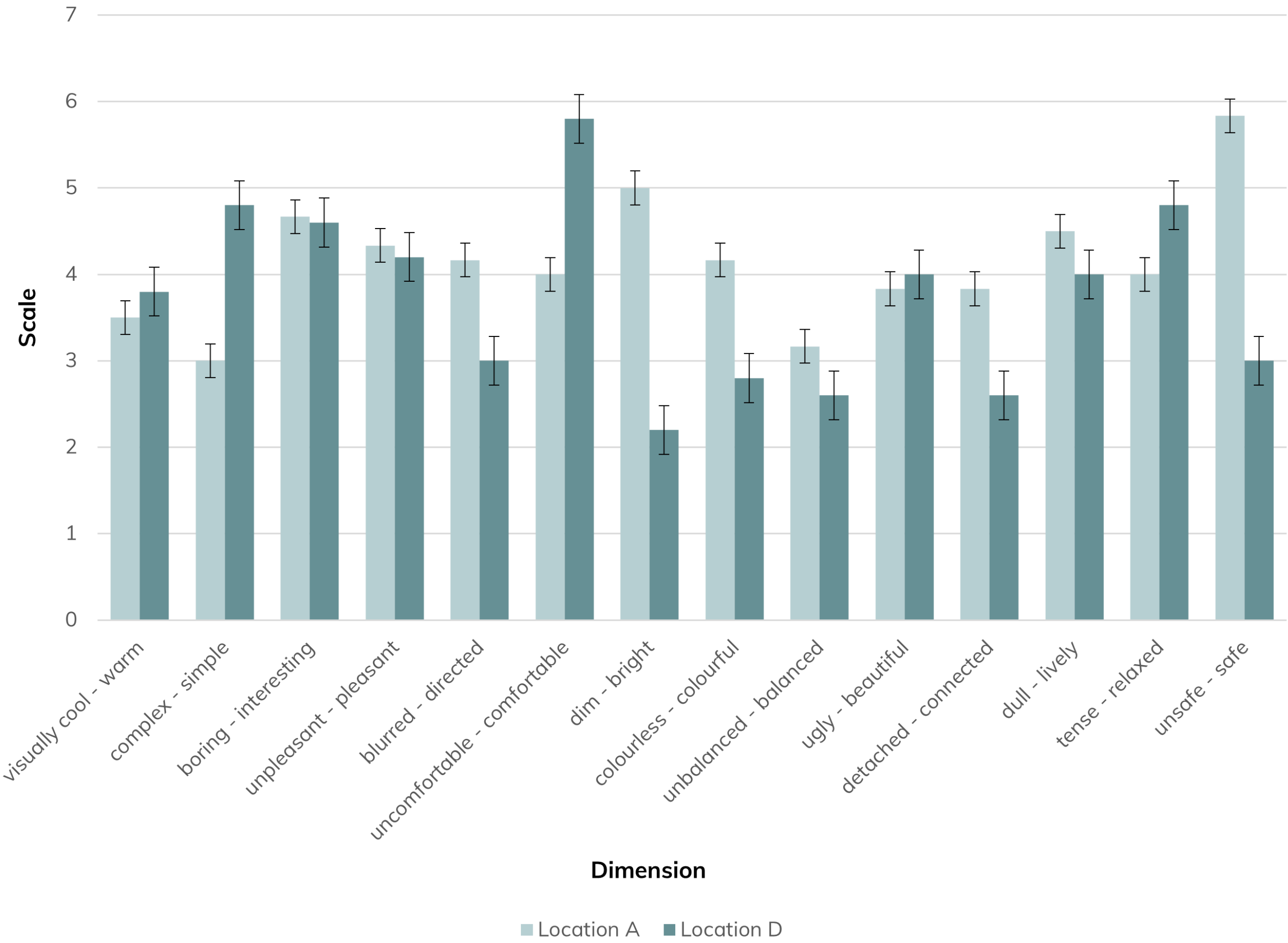


Figure 45. Mean results with standard error.

A two-sample t-test with unequal variances was conducted to compare the mean results of location A and D for each dimension mentioned above.

Complex – simple

There was a significant difference ($p = 0.046$) between the means of location A ($n=6$, $M=3$, $SD=1.26$) and D ($n=5$, $M=4.8$, $SD=1.3$), conditions; $t(9) = -2.31$, $p < 0.05$). Indicating that location D scores higher on the complex – simple dimension than A.

Blurred – directed

There was no significant difference ($p = 0.303$) between the means of location A ($n=6$, $M=4.16$, $SD=1.6$) and D ($n=5$, $M=3$, $SD=1.87$), conditions; $t(8) = 1.09$, $p < 0.05$).

Uncomfortable – comfortable

There was no significant difference ($p = 0.105$) between the means of location A ($n=6$, $M=4$, $SD=2.19$) and D ($n=5$, $M=5.8$, $SD=0.83$), conditions; $t(7) = -1.85$, $p < 0.05$).

Dim – bright

There was a significant difference ($p = 0.021$) between the means of location A ($n=6$, $M=5$, $SD=1.67$) and D ($n=5$, $M=2.2$, $SD=1.64$), conditions; $t(9) = 2.79$, $p < 0.05$). Indicating that location D scores lower on the dim - bright dimension than A.

Colourless – colourful

There was no significant difference ($p = 0.165$) between the means of location A ($n=6$, $M=4.2$, $SD=1.83$) and D ($n=5$, $M=2.8$, $SD=1.09$), conditions; $t(8) = 1.52$, $p < 0.05$).

Detached – connected

There was no significant difference ($p = 0.189$) between the means of location A ($n=6$, $M=3.8$, $SD=1.8$) and D ($n=5$, $M=2.6$, $SD=0.89$), conditions; $t(7) = 1.45$, $p < 0.05$).

Unsafe – safe

There was a significant difference ($p = 0.022$) between the means of location A ($n=6$, $M=5.8$, $SD=0.98$) and D ($n=5$, $M=3$, $SD=1.87$), conditions; $t(6) = 3.05$, $p < 0.05$). Indicating that location D scores lower on the unsafe – safe dimension than A.

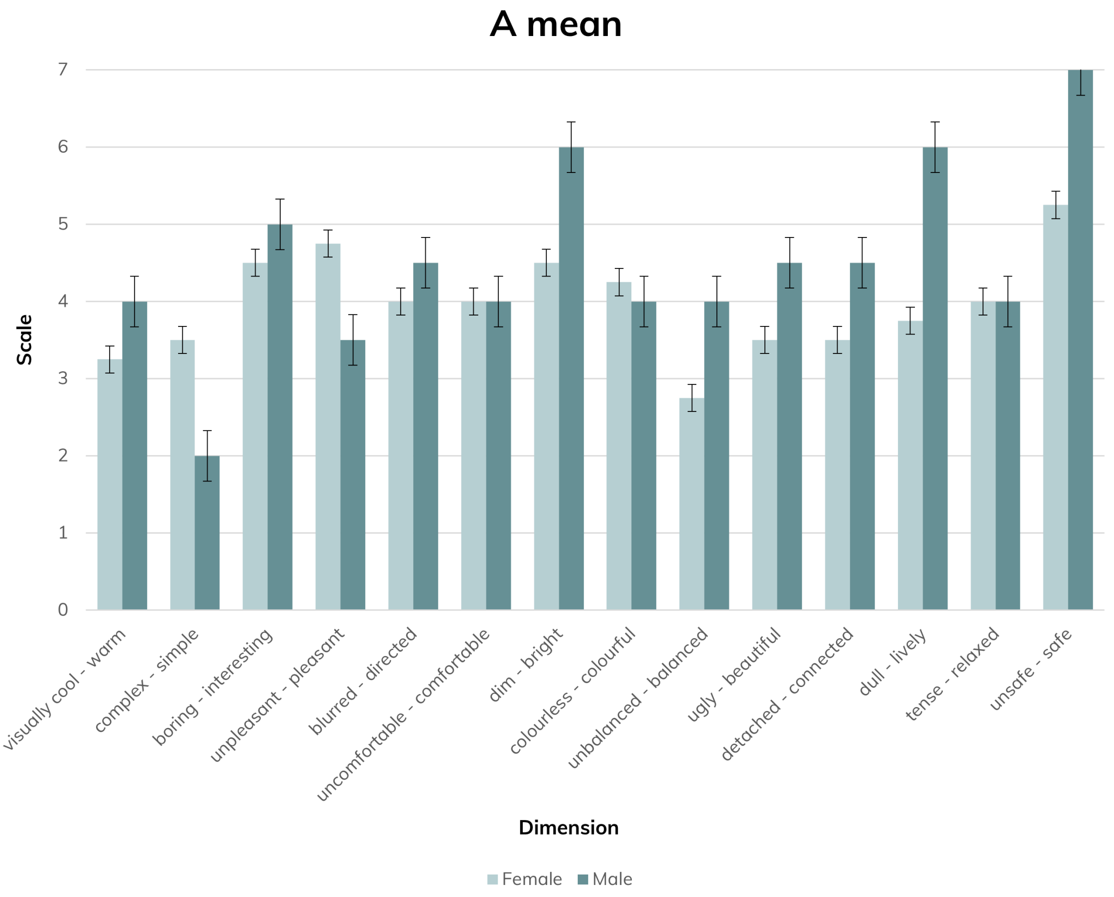
In summary, location D is seen by respondents as more simple, dim, and unsafe compared to A. These results raise the question on how to make the dark a safe place.

Looking at the gender regarding the mean results (see Figure 46), shows some differences. However, from a t-test comparing the gender responses within a location, only for the dimension unsafe-safe there is a significant difference ($p = 0{,}00598$) in location A. Here the female respondents rate lower on unsafe-safe than males.

Open comments

Most people that rated spot A mentioned one specific lantern near where they were standing. It was very bright, in your face, and distracting, they mention it influences a lot of the answers or mention that they tried to look around it and ignore the one lantern.

In spot D people mention that if you look to one side it is calming and easy on the eyes, such as the lights around the water, but if you look to the other side, it becomes bright and uncomfortable, mostly coming from the building of civil engineering. Next to that someone mentions that in spot D you have a good overview of roads and walkways because of the lighting there, which enhanced the safety perspective for this person.



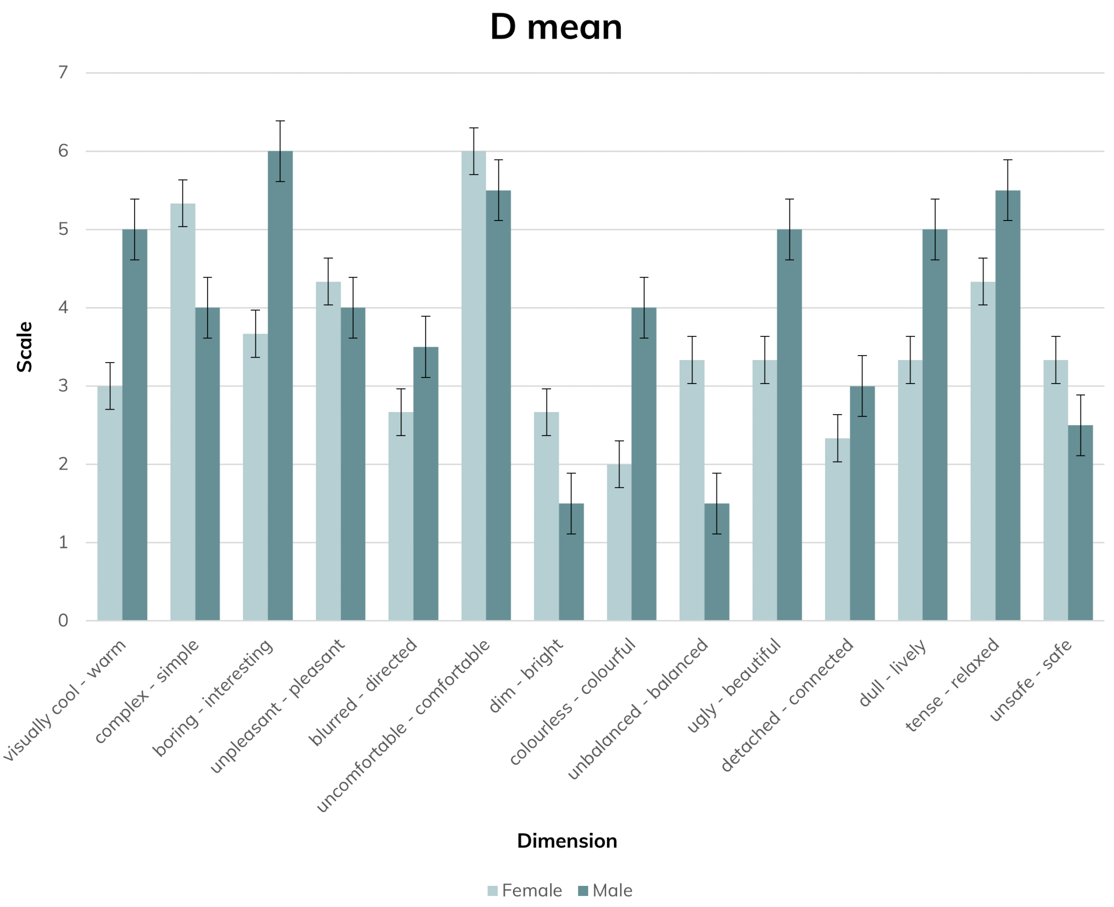


Figure 46. Comparison of the responses regarding gender.

3.8 Conclusion of the research study

After examining the responses and the results that fit the corresponding scale, it was determined that location A holds the most potential to achieve the desired impact. The determination of the location considered not just the survey results, but also how they are represented in the current environment and how bioluminescence could potentially add value. It was found that location A presented the best opportunities for promoting the values deemed desirable through the design for darkness approach. To maximize the impact, it was concluded that location A should be the focus for implementing the design.

It is important for location A to think about how to balance safety and darkness through a design. This entails creating a simple and dim environment, making the location darker while preserving safety.

Values

From the results it can be seen that the three dimensions, simple, dim, and safe are important factors. These are the handles to design for and integrate. These dimensions can be therefore seen as values and have a specific requirement or action to keep in mind, see Figure 47.

Values from significance test

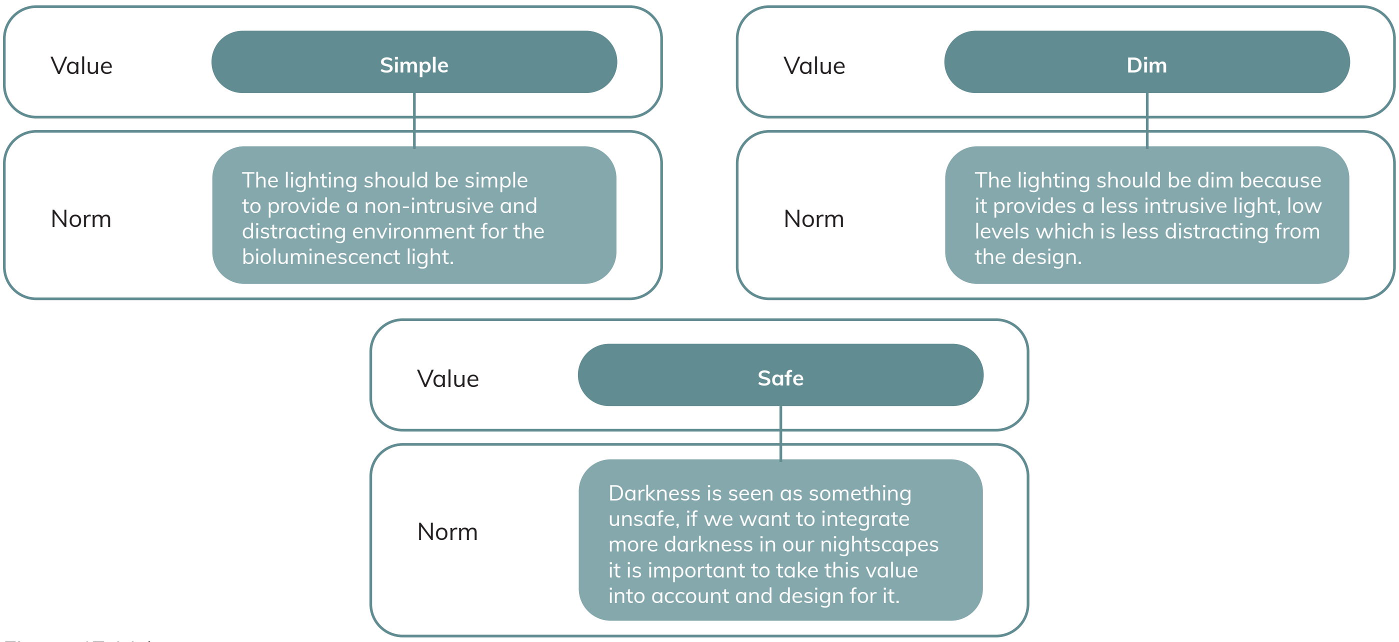


Figure 47. Values

4

Design

4.1 Direction

Design vision

I want to design a product that contributes to improving light pollution by integrating more darkness into our nightscapes by using the unique inherent qualities of bioluminescent algae. I want to spark people's curiosity and interest in bioluminescence, encouraging people to explore, experience and discover the material after dark. My goal is for people to be captivated by the material and connect to and appreciate nature's phenomena.

The final material application will change people's view or approach to darkness and outdoor lighting through the material's qualities as an organism to provide light.

By creating a dim and simple lighting environment that contains no visual clutter and glare, the user's attention would go to the design. Through the design elements such as material choice, form giving and interaction design, the users can be attracted towards the design. The design elements should support the user in their feeling of safety. The attraction and a safe feeling can create curiosity towards the design and allowing for them to really engage and interact.

Interaction vision

Interacting with my design should feel like you are blowing bubbles, you see something fun and surprising, and it pulls you towards it and instinctively you want to play with it like following and poking the bubbles. Then after the interaction it should feel like seeing and appreciating a rainbow, you are captivated, it is engaging, surprising and pleasant. The whole experience makes you slow down and have a break from a busy place, interact to distract.

Envisioned user journey

The envisioned user journey is derived from the interaction vision within the context of Mekelpark, see Figure 48.

From the vision and the user journey, it is clear that safety is not emphasized. I want safety to come forward through the design elements. For instance, form giving can play a role in how an object is perceived, but also the use of materials and creating intuitive interactions. It is important to take into account the surroundings' visibility and placement of the design without compromising the intended interaction. The balance between darkness and safety is something to keep in mind and address since the light will only appear after the interaction.

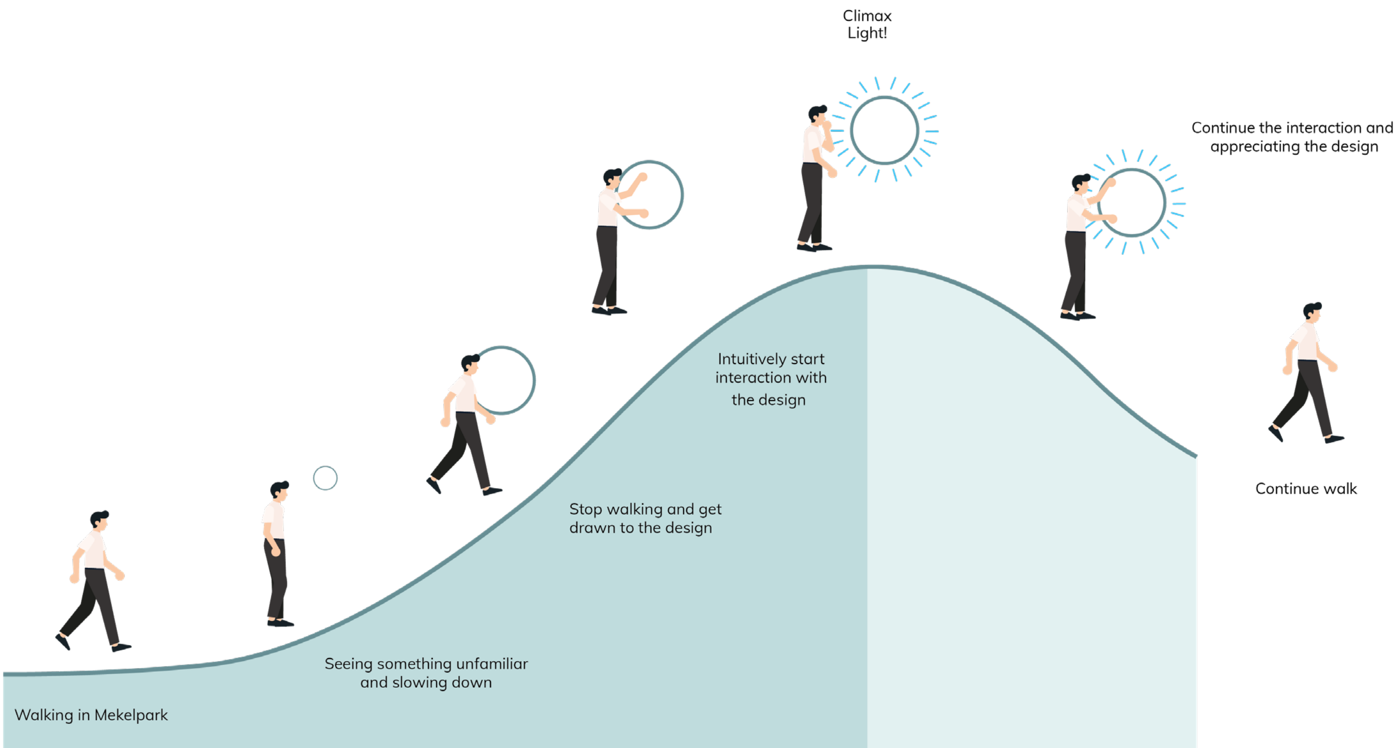


Figure 48. Envisioned user journey

Considering that the location around the Aula (location A) is a busy area with various types of traffic, such as bikers, people walking, jogging or people waiting for the bus, it would be interesting to create a design that encourages this target group slow down. This can be achieved by creating a design that attracts and seduces users to approach it and encourages instinctive interactions, which should be low threshold to make it easier and more attractive to approach. After interacting with the design seeing the light, users will experience a sense of awe and appreciation, causing them to slow down and be present in the moment. They will continue to explore and then proceed on their path.

From the interaction vision and user journey, we can derive that the design will not be constantly 'on', as it is also not possible for the algae to continuously product light due to energy constraints.

Therefore, the design should remain in the dark, attracting people to approach it and interact with it. The design should have an inviting and organic shape to make it feel comfortable and friendly to approach in the dark, as the survey indicated that people perceive darkness as an unsafe space.

The interaction required for the algae to light up should be instinctively, so a basic interaction such as squeezing, poking, compressing, pinching, grabbing, and moving. However, the interaction should be low-intensity to enable the algae to respond to low-intensity stimulations over time.

The size of the design will also influence how people perceive it. If it is too small, people will not notice it in the dark when passing by, which could result in them not slowing down or stopping. Therefore, the size should be noticeable but not too big that it could hinder the visibility and make people feel unsafe.

To encourage people to slow down and be in the moment, the design should allow users to immerse themselves in it by walking around or through it. Sitting down and facing away from the light would not be ideal unless the user could view it while laying down.

4.2 Design drivers

The design drivers are the important values mentioned above: dim, simple and safe. These values create certain requirements for the design among other requirements generated through the literature research and research study.

Form of the design

- The design should have transparent containers for the liquid culture so that it can do photosynthesis and the bioluminescent light is visible.
- The liquid culture should not get out of the container if it is not on purpose, such as adding new culture or nutrition, therefore there should be an opening to be able to maintain the culture.
- The design should facilitate for gas exchange.
- The product should provide for activation of the algae.
- The design should be suitable for outdoor environment. This would include the considerations for sunlight and temperature.
- The design should have an inviting and organic shape to make it feel comfortable and friendly to create the feeling of safety.
- The size of the design should not be too small, then it will not be noticeable, but not too big that it could hinder the visibility for people to feel safe.
- The materials used in the design should not hurt/harm the user during interaction.
- During daytime the design should also evoke curiosity.

Use of the design

- The design should allow people to touch/hold it without touching the algae or breaking it.
- The interaction with the design should have a low intensity to not drain out the energy of the algae to produce light too fast.
- The interaction that is needed for the light to turn on should be instinctively, so a basic interaction such as squeezing, poking, compressing, pinching, grabbing, and moving.
- The design should be able to withstand repeated user interactions.

Impact of the design

- The design should make an impact by decreasing the amount of light used in the environment in the designated location. The design should facilitate for lower light levels, illuminance (dim), lower contrast (1.7) and overall uniformity of the light (simple).
- The design should support the feeling of safety through the design elements, such as material choice, form giving, interaction design and visibility of surroundings.
- The design should meet as many values of darkness defined by Stone (2019) as possible.
- The design should not need any other light sources other than bioluminescence.

4.3 Ideation

Design approach

As the design direction is formulated, the next step is to ideate and conceptualize. This chapter introduces the design activities that were conducted in the ideation phase and the conceptualization towards the final design

Design activities

The design activities that resulted in the final design are described in Figure 49.

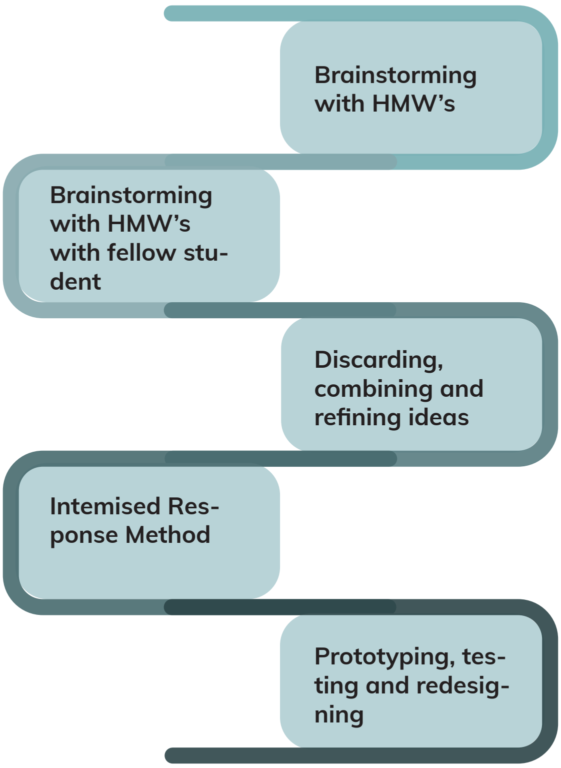


Figure 49. Design activities.

The first step of the ideation phase was a brainstorm session. The brainstorm session consisted of multiple How Might We's on different topics. Several ideas arise through this session. Next a brainstorm session with a fellow IPD student was conducted, to get a different perspective. New ideas were generated, and other ideas discussed and sometimes combined.

To help the process of discarding, combining and refining ideas, firstly similar ideas were clustered and then the process started by using the method SCAMPER (Van Boeijen et al., 2014). The ideas coming from the clustering and scamper were evaluated using the Itemised Response Method (Van Boeijen et al., 2014).

To determine which of the ideas are feasible regarding the bioluminescent light, the ideas were discussed with an expert from the biolab (Richard Groen). The remaining ideas that were feasible were then further developed to create concepts, and a choice was made. The main principle of the concepts were prototyped and tested in the biolab. A final evaluation with users was done, with improved prototypes. From the insights a final design was made.

Design explorations

The idea generation started with a list of multiple How Might We's in various categories such as: interaction, experience, meaning, darkness, and others. A full list of the questions can be found in Appendix C. The results of all the ideation steps are shown in Figure 50.

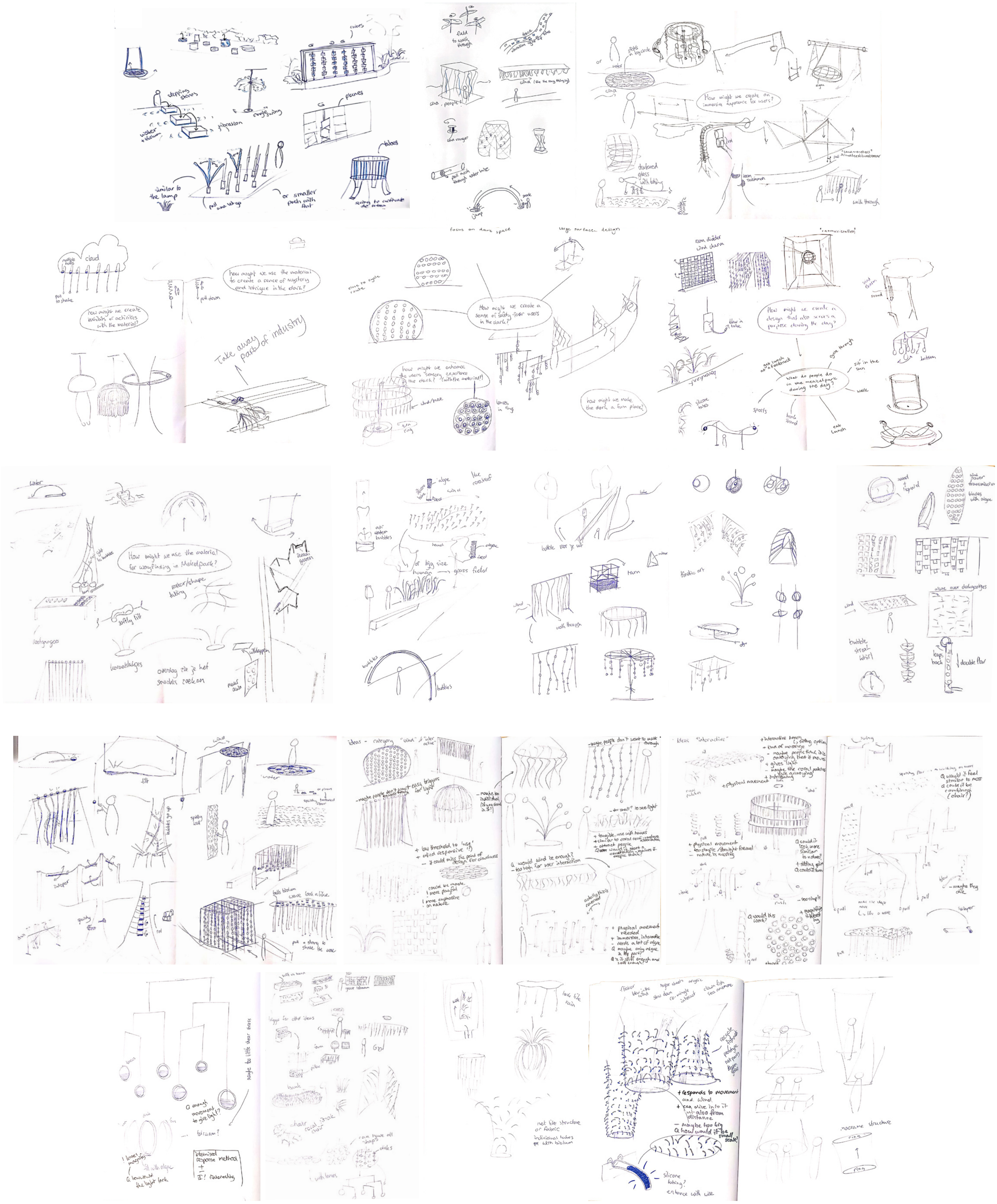
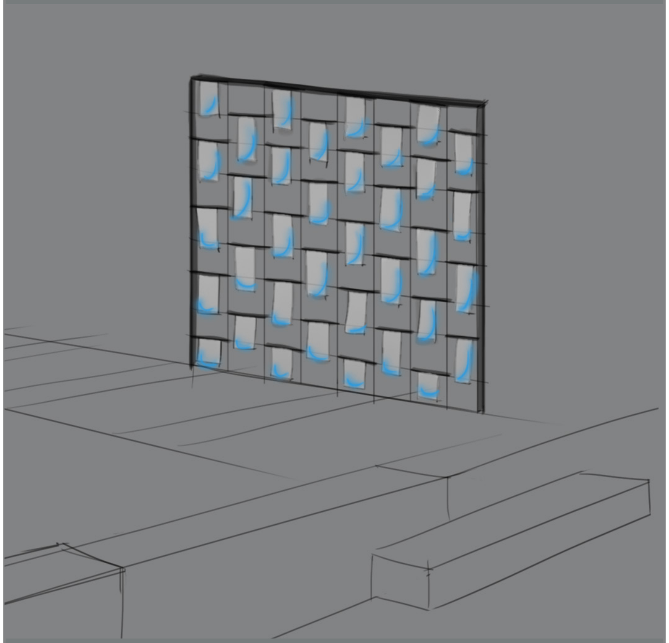


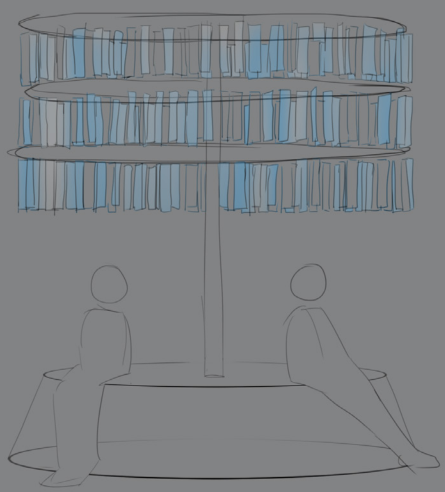
Figure 50. Ideas.

4.4 Conceptualization

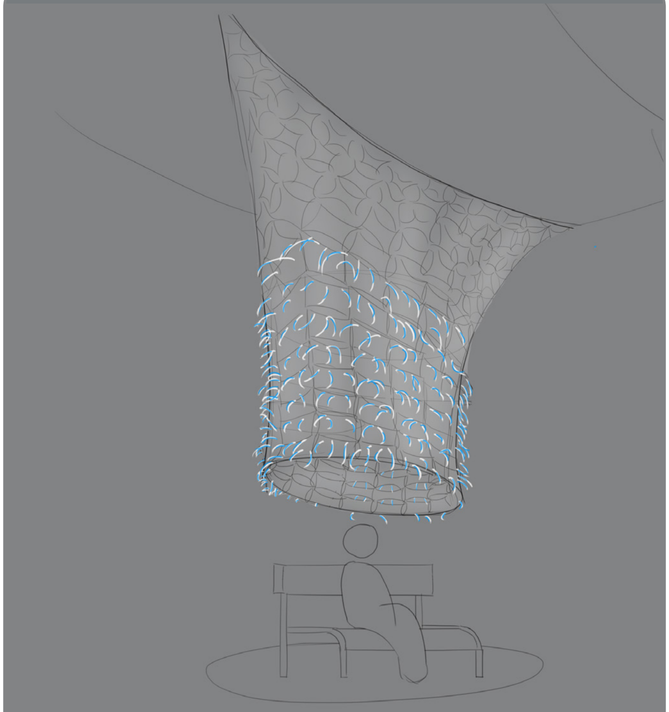
Subsequent to the idea development phase, the prospective ideas were refined into conceptual designs. During the development some questions arose which caused the ideas to develop as well. These are evaluated with the Itemised Response Method (see Apppendix D for the full evaluation). After the evaluation the concepts were converted into four designs. The concepts shown in the next page were discussed with the expert from the biolab.



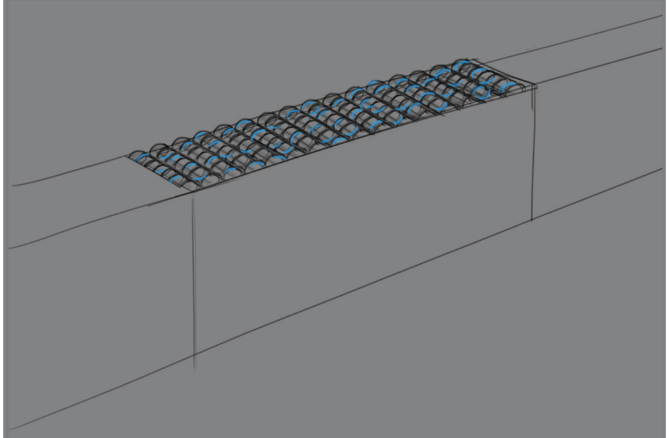
Idea
An installation that consists of multiple panels with bioluminescent algae. The panels are attached on a rod so it is able to rotate. The panels swing back and forth because of the wind. Users can also make the panels swing.



Idea
A round bench with in the middle a pole on which several rings are attached that are hanging above the bench. On the sides of the rings there are (test)tubes hanging down, which are filled with bioluminescent algae. The wind or people can make the tubes sway in which the light will appear. If the tubes are from glass/hard plastic it can also serve as a wind chime.



Idea
A net attached to create funnel shapes, on the outside there are silicone tubes attached to the net which are filled with a liquid culture. The user can activate the light by playing with the tubes. If the net is lightweight the wind can also cause it to move.



Idea
A bench where the seating area consists of multiple disks that roll when you move over the bench. The disks are integrated with bioluminescent algae. The light is activated when the user sits down on the bench and moves sideways.

Since some of the concepts contain similar key features, such as concepts 4 and 5 (which already are two ideas), the key features are combined into a more prospective idea. The key features of the concepts were discussed with an expert (Richard Groen) to determine what would be feasible to test with the algae. Some features were further developed to create an optimal movement for the algae to produce light. The concept changes, see Figure 51, and expectations of the algae behaviour that came out of the discussion:

- Concept 1: the rod is moved to the middle axis, so the liquid is divided over two bags instead of one, this might improve the duration of the movement.

- Concept 2: Here accumulation of the liquid culture can occur. I received two sizes of plastic test tubes with twist-off caps to create prototypes.

- Concept 3: Because the disk is rotating around the horizontal axis the liquid will stay at the bottom of the disk. Therefore, edges or walls can be created on the inside of the disk to guide the liquid upwards with the movement. This way they will receive more shear force.

- Concept 4: the liquid might accumulate which should be tested. I received two sizes of silicone tubing. The silicone tube increases in thickness if the diameter increases, which makes the tube stiffer and the interaction with algae harder. This is something to keep in mind.

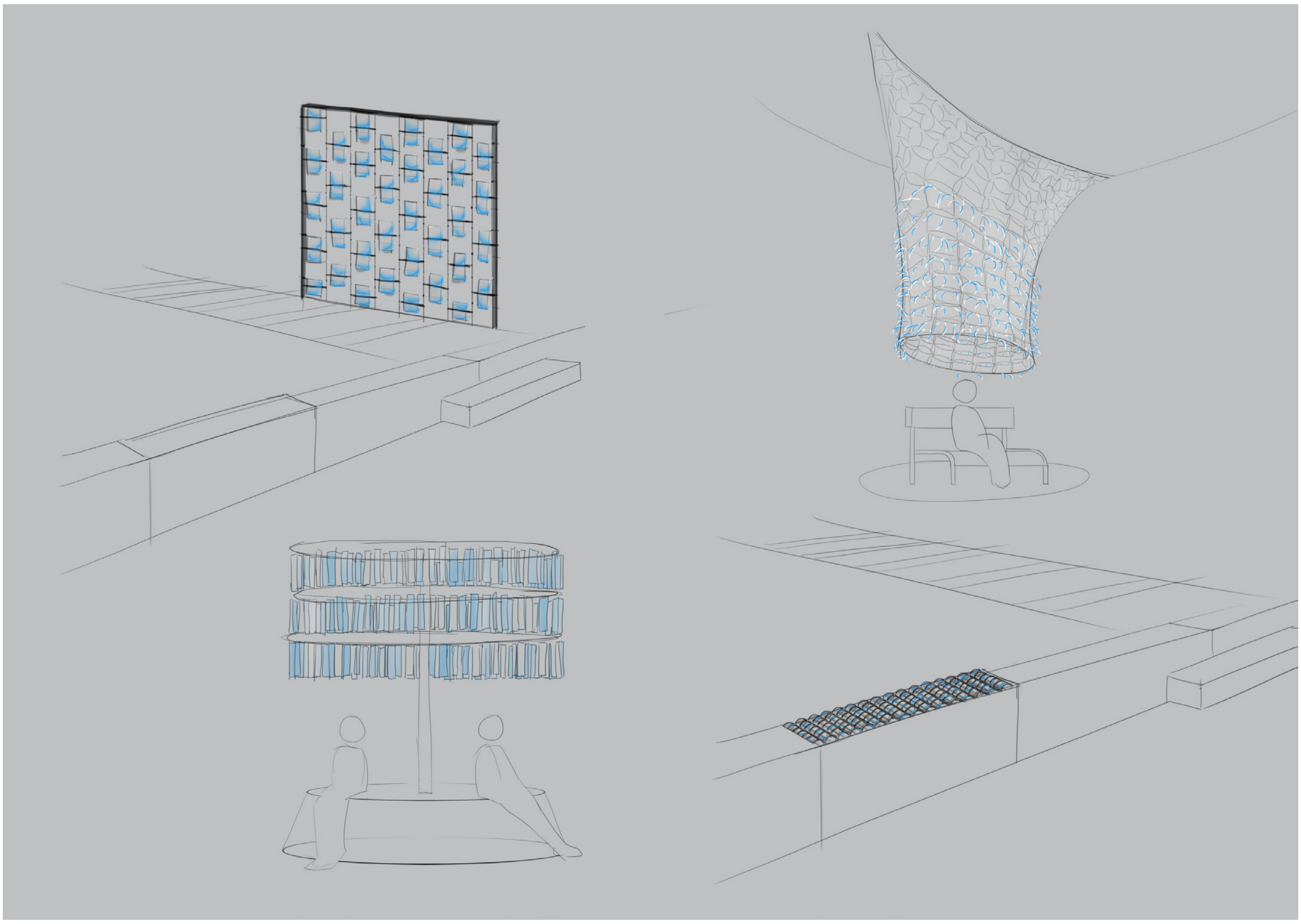


Figure 51. Concepts from discussion.

Due to the interaction vision and the added design driver safety, the ideas were re-evaluated and looked at what would be needed and the right fit for spot A.

For people to slow down and be in the moment, the design should be active: be immersed, walk through or past it. Next to that it is important that you can see the light, for example the bench with rolling disks, this way you are not directly looking at the disks and might not see the light since it is quite dim. Therefore, this idea is changed into a wall in which you can turn the disks while walking past, much like a wave in the ocean (see Figure 52).

The integrated bench with tubes (bottom left) could be a lying down bench that way you can directly look at the light but is not that active. Or without a bench at all, this way you can walk past it or through it, this is more a playful interaction.

Concept choice

Looking at the interaction vision the design drivers and the requirements two design will be prototyped and tested. Each concept was evaluated to determine which designs are the most promising. Since the key principles were already similar it was during the process already downsized to four concepts. I think that concepts 2 and 4 meet the requirements and achieve the interaction vision, but also create a safe environment. The behaviour of the light within these concepts would somewhat be unexpected when subjected to various sorts of agitations, such as pulses or vibrations, compared to the other two concepts which could only be rotated. Next that looking I think that both designs have a natural feel due to their shape and have a lot of options for material choices to become friendly and approachable. I think they also provide a lot of space for further iterations and refinements if tested with the algae and users.

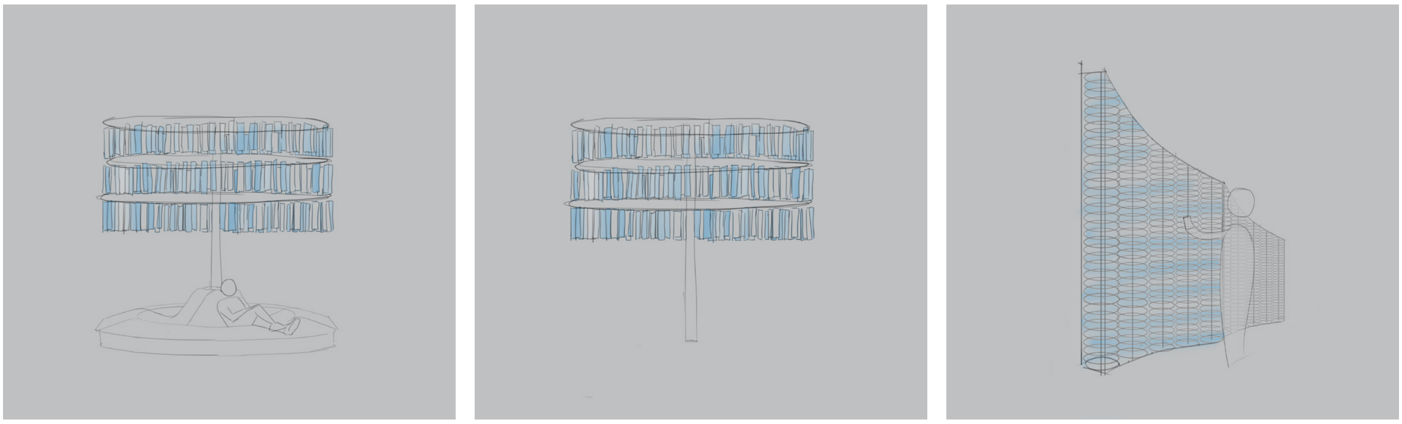
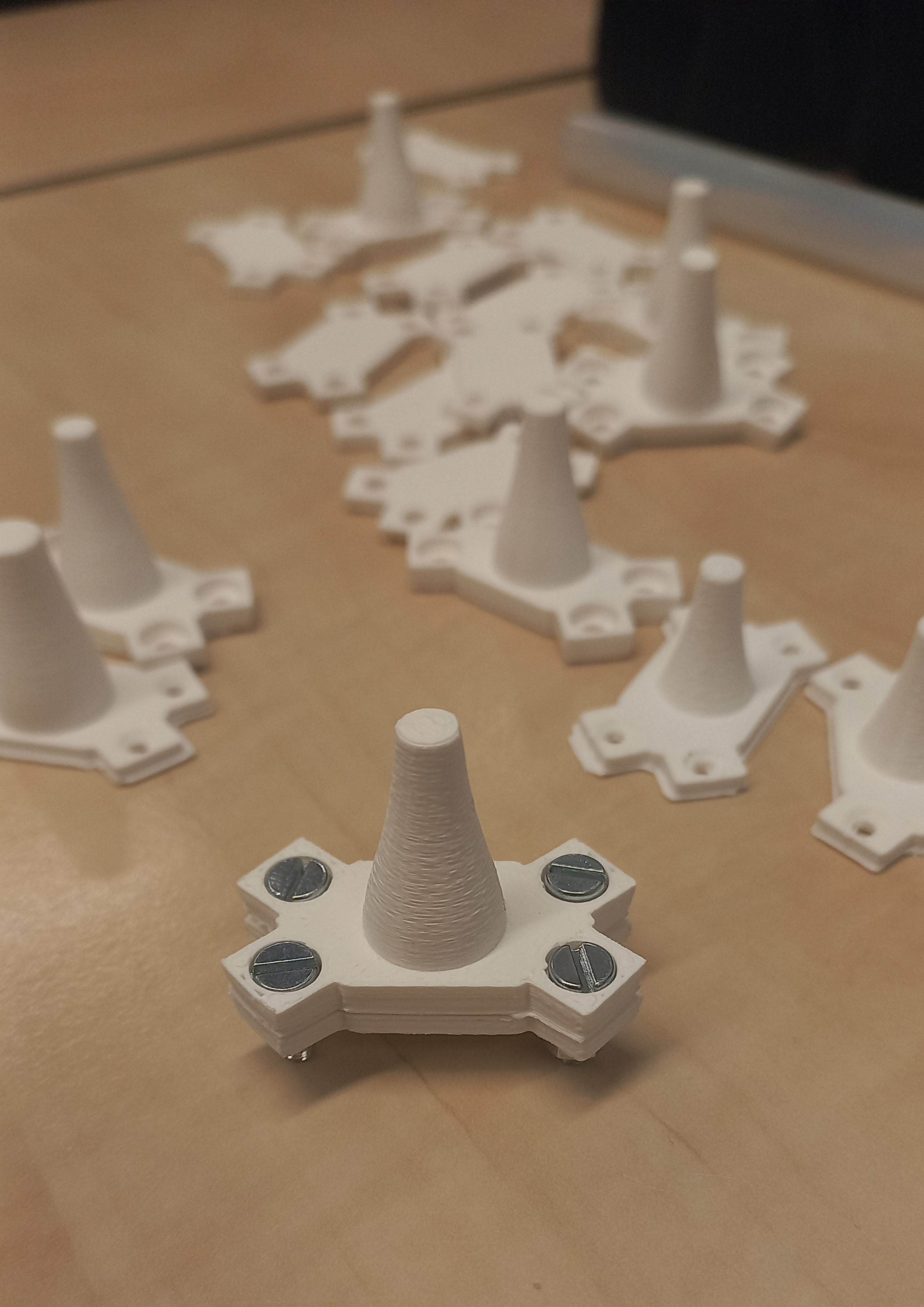


Figure 52. Redesign of previous concept 2 and 3.



4.5 Prototyping

The concepts detailed in the ideation phase are the starting point for prototyping, see Figure 53. Features from the concept were designed, prototyped, tested, and evaluated. See Appendix E for the complete prototyping process.

Simple and quick prototypes were created to determine the general idea and what needs improvement on, for example holding different parts together or keeping liquid from coming out a container. If the design is not sufficient after evaluation, they are redesigned.

For concept 2, a first simple prototype was made with metal wire and a keyring to hang on to the plastic bar. The movement that came out of this combination was a kind of a wiggle. Therefore, I changed the wire for a rope and the ring to a screw eye, which was screwed into the cap. This movement was much more flowing when you would move the tube.

For concept 4, the silicone tubes needed a part to fix it on and a stop to keep the liquid in the tube. The mounting system was prototyped by 3D printing and the stop by 3D printing a mould. The mounting system was designed by using the shape of the wire frame and creating a pin on top of it to hold the tube. The pin went to several iterations to hold the tube but also the base to be attached to the wire frame.

The pin was used as a base to create the mould. The mould was then used to pour in silicone to create the stop. For effortless demoulding Vaseline was used on the inside of the 3D print.

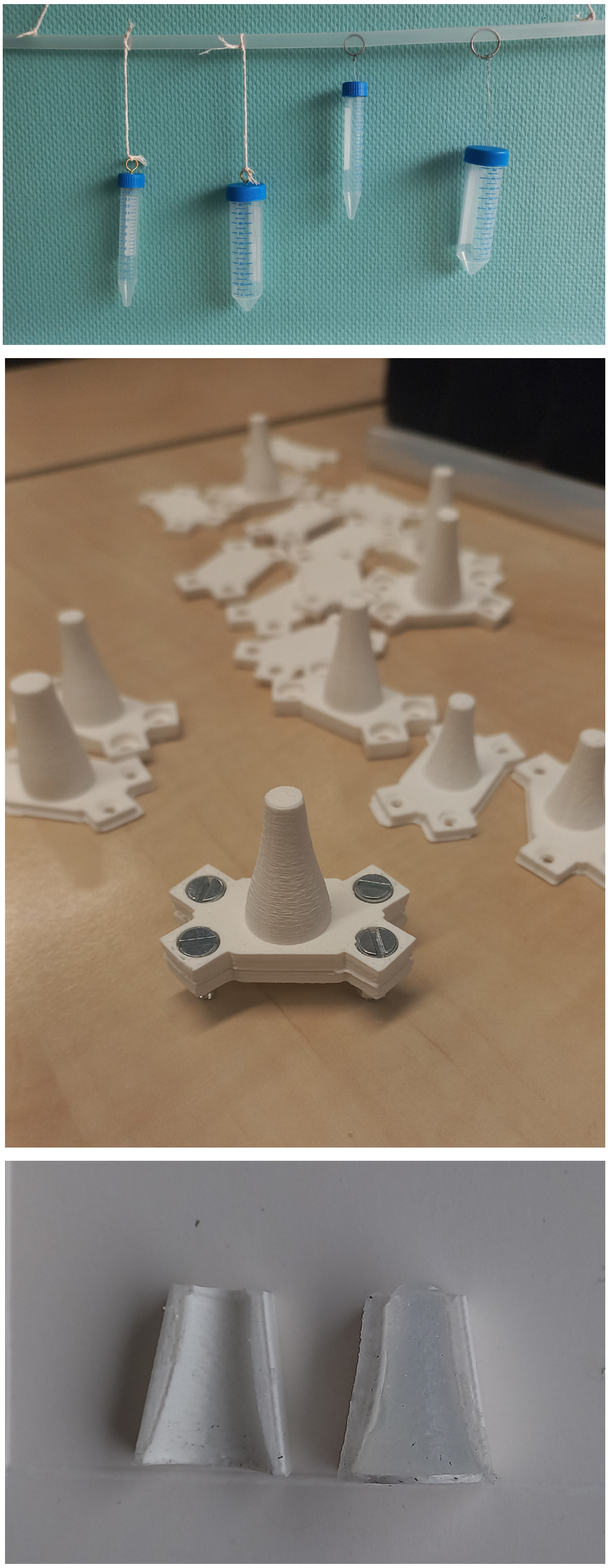


Figure 53. Part of the prototype process.

Prototype test in the biolab

The two prototypes created were tested in the biolab on the functionality. For the test it was important to see how the bioluminescent algae would respond to the type of interaction created through the prototype. The prototypes both had two different diameter types of tubes, so it was also tested which diameter works best for the interaction.

For concept 2, the hard plastic tubes were filled to 15 mL for the bigger tube and the smaller one to 9 mL. See Figure 54 for the setup. In that set up they were tested on multiple performative interactions:

- Compressing / Pressing
- Swaying, sideway movement
- Lift up and let go
- Poking
- Grabbing
- Rotating
- Shaking
- Tapping / Ticking
- Bumping, tubes against each other

On macro level

The tubes responded mostly to the shaking, tapping, and bumping, rotation, lift and let go. Especially the tubes bumping against each other caused the cells to light up the most. The bigger side tube provided more light than the smaller one, because more liquid and thus more cells were present that could respond. I also tested the length of the rope, and the longer the rope the more light appeared when bumped against each other. This is because the liquid has a bigger momentum. The rope helped to add to the playfulness of the prototype this way you could try different interactions.

On micro level

The overall light created when bumping was a bright flash and a longer glow. The textural qualities that appeared were similar to that of pulse agitation: many individual dots of light, lots of texture. Next to that some of the cells that got higher on the walls and then dripped down, were glowing longer than the ones in the liquid causing a beautiful effect.
The tubes bumping into each other also created a soft sound adding to the experience of the flash.
The material felt smooth but sturdy, the rope made it playful swinging in all directions.

The prototype was tested with a closed off cap but to allow for gas exchange with this kind of tube a special cap can be used, see Figure 55 for an example. On this cap a tube can be placed and it is possible to use this as the hanging system.

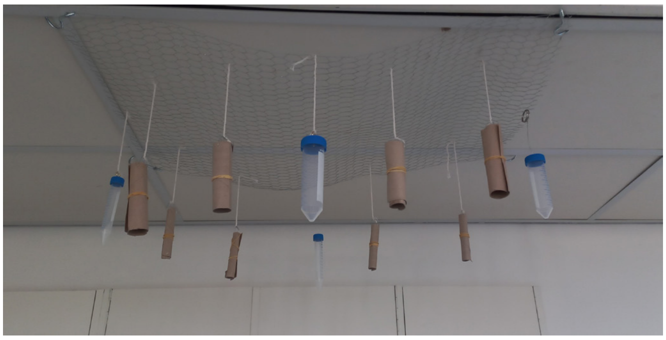


Figure 54. Test tubes prototype test in the biolab.

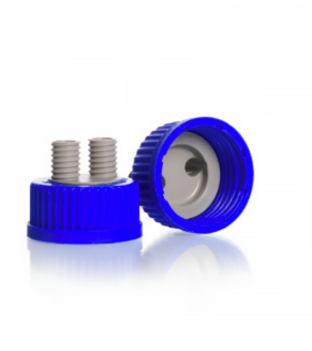


Figure 55. Cap for gas exchange for the algae.

For concept 4, the thin and thick silicone tubes were filled halfway. The silicone stop held the liquid in the tube and the 3D print kept the tube attached to the wire. See Figure 56 for the setup. In that set up they were tested on multiple performative interactions:

- Pinching
- Compressing / Pressing
- Stroking / Caressing
- Swaying, sideway movement, up, and down
- Lift up and let go
- Squeezing
- Poking
- Grabbing
- Rubbing
- Shaking
- Tapping / Ticking

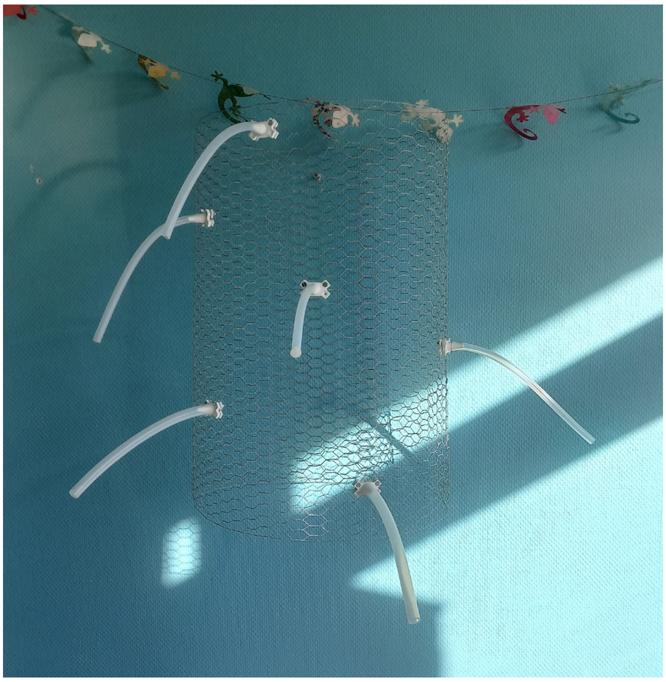


Figure 56. Silicone tubes prototype test in the biolab.

On macro level

The tubes responded mostly to the compressing and squeezing, tapping, shaking, and lifting up and letting go. The other interactions were too low intensity for the algae to respond. This is also because within a tube there are little amount of cells present so they also do not respond as much. With a larger scale, bigger tube the response would probably increase.

On micro level

The overall light was a soft glow. The textural qualities that appeared looked similar to pulse agitation. Mostly at the stop and the surface of the liquid the light would appear. If you squeezed or compressed the tube in that spot the light would appear and move away from your fingers, this was short and looked like glitter.

During the interactions the tubing made different sounds that added to the experience, especially when squeezing the tubing you heard the liquid move. I think this was also because the silicone stop was not completely closing the tube off, and thus letting air in. Which is probably what you heard, but it added to the experience of the glitter effect that was created.

The feeling of the soft material added to the playfulness of the prototype, it invited to keep interacting with it and try all sorts of interactions.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5

Evaluation of the prototypes and interaction

5.1 Evaluation approach

An evaluation session was conducted to obtain more insight on the interaction and performativity of the prototypes. The emphasis in performance is on how people interact with a particular set of physical and temporal factors that enhance the characteristics of the performance. The aim is to compare the prototypes on user interaction, performance of the algae and the engagement of the user. The two prototypes will be displayed in a dark room, where users can go in and interact with the algae.

Prototype

For the evaluation session the gained insights were used to create new prototypes, shown in Figure 57. The silicone tubes were increased in diameter meaning that the mounting system and stops were redeveloped. Ten tubes for each prototype were made, to compare the interaction. For the silicone tubes there were longer and shorter tubes and for the test tubes there were thin and thick tubes, to compare the interaction.

Figure 57. Prototypes in the darkroom.

Participants
The participants that were selected for this experiment were students from the TU Delft. For the session 11 participants took part in this evaluation. Each session took around 15 minutes, between each session there was an hour, as a break for the algae to rest. This is important because otherwise the light will be drained and will not give a proper representation. Due to the day and night cycle of the algae, testing was done at 14.00h and only 5 sessions on one day (also due to the representation of the light).

Procedure
In the morning the prototype is prepared and moved to a room. An hour before the testing starts, the room is made dark. The participants were instructed to investigate the prototypes freely while using the "think-aloud" technique to describe how and why they interacted with the prototypes. The prototype that each participant started with was alternated. At any given time, they can switch to the other prototype. Then they were taken into the darkroom, before starting the interaction a few minutes were given to adapt to the dark environment.

At the end, when coming out of the darkroom, the following questions were asked:

- How would you describe your overall experience?
- Which design did you prefer?
- What did you like the most?
- What did you like the least?
- What do you think is the application for such a design?
- Where can you imagine such a design?
- What do you think of the balance between dark and light?

Figure 58. Prototypes in the darkroom.

5.2 Results of the evaluation

The results will discuss the evaluation on user interaction, effects, performance of the algae and the engagement of the user. Below shows the results of 11 participants during the evaluation of the two prototypes, when looking at the interaction (macro and micro) and the engagement with the prototypes and performativity of the bioluminescence.

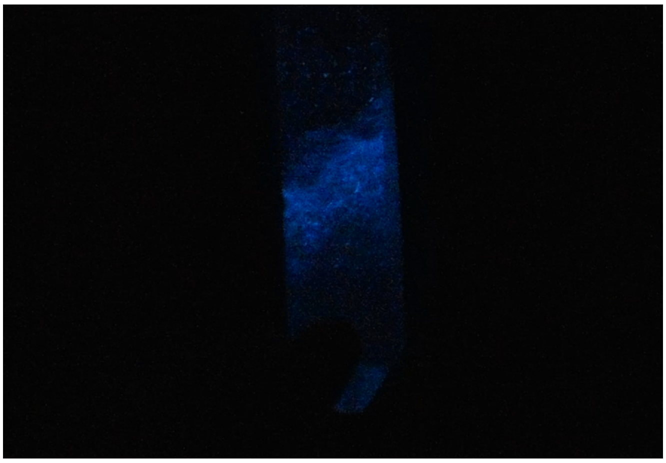

Figure 59. Test tube.

Overall experience

The following words were used to describe the overall experience of the participants.

Table 5. Overall experience

- Surprising
- Really nice / great fun
- Exciting interaction
- Extra terrestrial
- Satisfying
- Thought of special moments / associations
- Very interesting
- Calming / relaxing
- Positive
- Special / extraordinary
- Intimate
- Magical
- Playful
- Chemical and natural in one experience, what is happening

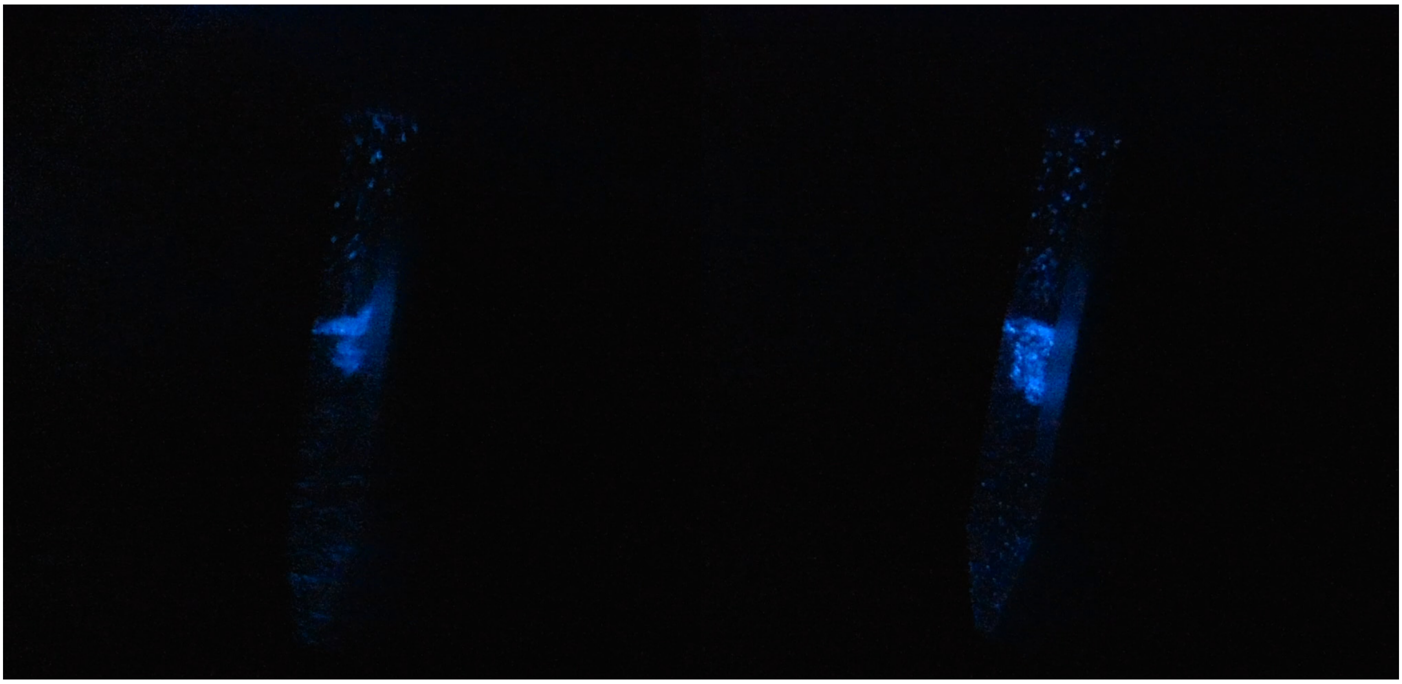

Figure 60. Test tubes.

Interactions

The following words were used during interaction with both prototypes to describe what the participants were doing.

Table 6. Interactions

Silicone tubes	Test tubes
• Tapping on the tube	• Tapping on the tube
• Shaking the tube	• Shaking the tube
• Shaking the mesh wire frame	• Pulsating the tube
• Pulsating the tube	• Bumping the tubes together (softly or hard)
• Lift up and let go of the tube	• Hand through all tubes like a wave (softly or hard)
• Lift up and lower down the tube	• Rotating the liquid in the tube
• Squeezing / pinching the tube	• Tilt the tube upside down
• Grasping the tube	• Squeezing / pinching the tube
• Feeling the tube	• Grasping the tube
• Hitting / clapping the tube	• Hold sideways and rock back and forth, creating waves
• Rotate the tube around fixed point	• Hitting / clapping the tube
• Connecting multiple tubes	
• Odd movements due to flexible tube	

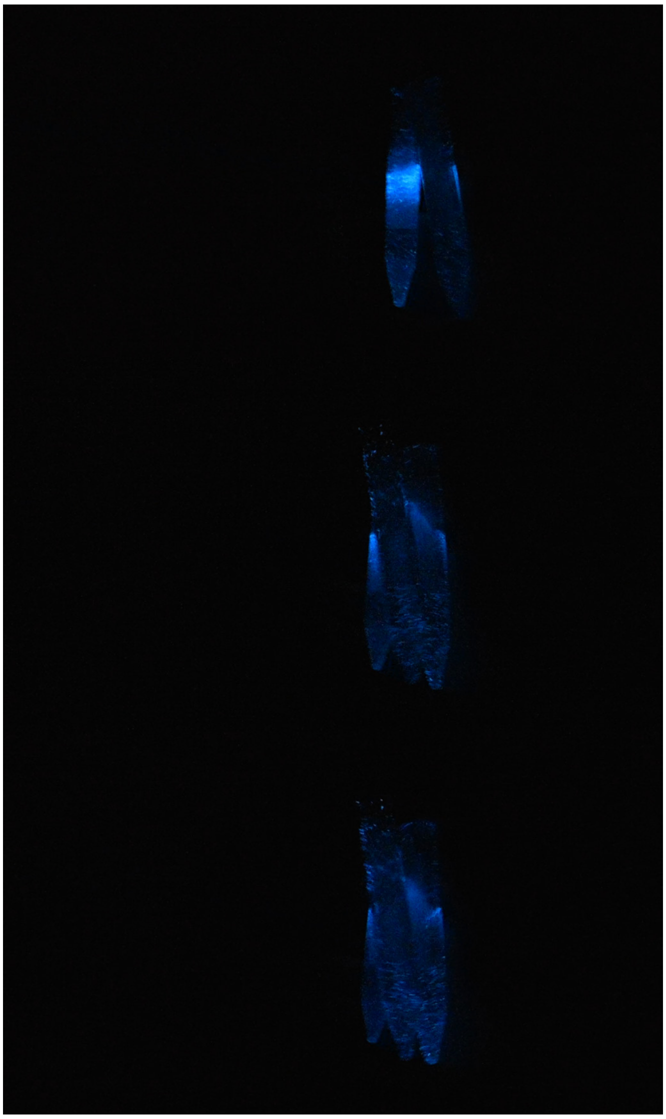

Figure 61. Bumping of test tubes.

Figure 62. Lifting of silicone tube.

It was interesting to notice that each participant had a different kind of approach while interacting. Some went in very gentle and only softly activate the algae where others would already start shaking. What people liked were mainly on certain interactions and the effect that it created, that something happened because of their actions, such as bumping, lifting, and lowering, waves and shaking. What people disliked differed, there was one person questioning if it had to be this dark and another mentioned that if you do not interact with it nothing will happen. Other people were afraid to break the prototypes or were not sure on the idea of the algae and if it would hurt them.

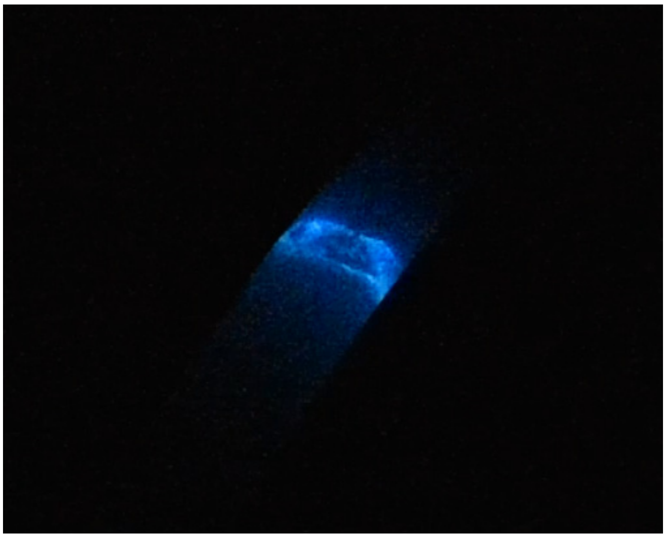

Figure 63. Silicone tube.

Effects

The following words were used during interaction with both prototypes to describe the effects of the interaction.

Table 7. Effects

Silicone tubes	Test tubes
• Silicone material feels nice to the touch	• Bigger tubes seem brighter than smaller
• See the algae travel / flow / spread	• See a wave
• Dots	• When tapping different layers light
• Glitter	• Dots
• Stars	• Glitter
• Afterglow	• Stars
• Similar to glowstick	• More light than the silicone tubes

There were two participants that mentioned something about the colour of the light. One did not expect the light to be this blue, since she knows algae as something that is green. And the other noticed that at first the light would be a bit white and then turns blue or greenish.

The output light was thoroughly examined, by for example shaking or rotating each tube and then looking close by. Especially the interaction lift up and lower down kept people engaged and really look at what would happen. Here people mentioned that they could really see the algae 'travel'.

The feeling of touch of the materials was also described, mainly that the silicone was nice to the touch and allowed for multiple interactions and freedom of movement.

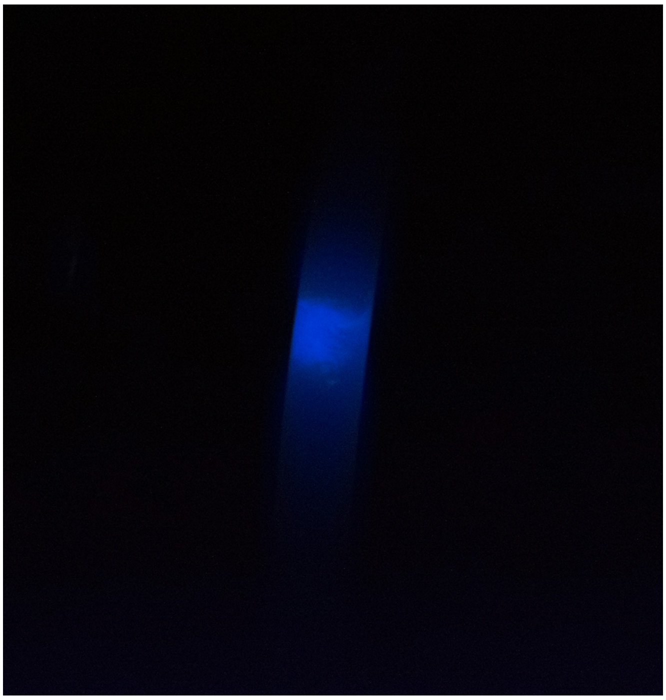

Figure 64. Silicone tube.

Engagement and preference

The following shows how many people had a longer engagement with one of the two prototypes and which prototype was preferred and why.

Table 8. Longest engagement

Silicone tubes	Test tubes
By **8** people	By **3** people

Preference

Silicone tubes	Test tubes
By **6** people: • Nice to the touch, and allows for a calming interaction and to be careful with it. • It gives more feeling through the use of the material, in sense of moving the tube but also touch. • The lifting and lowering of the silicone tubes and the effect that it creates (multiple times mentioned). • It gives the feeling that you can do more with it, and be careful with it. • It was more responsive, less feeling like it could break and instead could take hits, it was resilient. • It was flexible making it feel like there was more possible.	By **5** people: • With the test tubes I feel like you as a person can move underneath it and move freely around. • The bumping of the hard plastic tubes and the effect that it creates. • Has more of its own life, so you can watch it from a distance as well. • The different thickness provide for a different experience. • You receive more output and you see more light.

Applications

The participants were also asked what they thought the application could be or what other applications they could see besides this project. These applications provide a lot of inspiration for future steps.

Table 9. Different kind of applications

• Interactive wall of filled silicone patches • A bike path that shows wayfinding through vibrations • Interactive floor with silicone tubes • At home lamp that moves it self • In the forest to play with / play for children and adults • Education tool / object • In an attraction • Light pipes where it moves through • Like the neon light tubes • In circus equipment • Decorative in moving objects, such as a skateboard, bike, in vehicles • Recreational • As a light	• Museum • At home • Public space • Festivals • Science centre (for visitors) • In the city centre • Clubs

Balance of darkness and light

Being in such a dark room raised the question of how dark it needs to be. The participants were asked what they thought about the balance between darkness and light of the bioluminescence. It was found too dark, but as the organism's light appeared you could see more of the prototypes. They wondered how dark it should be to be able to see this, since it is not a functional light. Another question raised by someone was, if it was this pitch dark at night, how would you the design was there? People also felt the need to constantly activate the tubes to be able to see something because it was so dark.

Figure 65. Test tube.

Figure 66. Test tubes.

5.3 Conclusion of the evaluation

To decide which of the two container types will be used for the final design, there will be looked at the situation being designed for. From there, a decision will be made. This does not exclude one of the two container types as an example to design for darkness with bioluminescence.

In chapter 4. a design vision was drafted, the part focused on the user was drafted as:

“I want to spark people’s curiosity and interest in bioluminescence, encouraging people to explore, experience and discover the material after dark.”

With an interaction focus of:

“Interacting with my design should feel like you are blowing bubbles, you see something fun and surprising, and it pulls you towards it and instinctively you want to play with it like following and poking the bubbles. Then after the interaction it should feel like seeing and appreciating a rainbow, you are captivated, it is engaging, surprising and pleasant. The whole experience makes you slow down and have a break from a busy place, interact to distract.”

During the evaluation of the prototypes, you could clearly see people’s curiosity in the material, trying out different interactions to see how the algae would react. It encouraged people to really explore the possibilities and discover; ‘what is happening’ or ‘what am I holding’ which prolonged their engagement with the material. All participants had an immediate verbal reaction to the first time they saw the light and to the output with different types of interactions. It was interesting to see that due to the output to their interaction people were captivated and forgot to think out loud. The researcher would then prompt them to keep telling what they were thinking.

One person mentioned, when asked what they disliked, that they thought that after a while you would have enough of interacting, you are satisfied. I think that this is not a negative effect, since this is also inline with the algae losing sensitivity. When the user is satisfied they continue their walk, which means that the algae can have a rest.

From this we can conclude that the prototypes fit the visions. However, the project is focused on a specific location for which the concepts were created, the needs for this place are important to decide. The situation is the area in front of the aula where a lot of pedestrians and cycling traffic happens. A design to slow people down is the aim for this place, to distract them and be in the moment for a bit. What we want to achieve with the light is to create an impact by adding darkness and improving light pollution while using a natural light source.

First, the positive and negative aspects of the prototypes were analysed, see Table 10.

It is important to create a balance between light and darkness for people to enhance their feeling of safety. Since the aim is to bring more darkness to the location our dark adaption comes in to play, once you are dark adapted you will perceive a little amount of light as bright. To obtain the balance I think it is important for this location, since it would be a big change in light, to go for the container providing the most output and is perceived as brighter during the evaluation in the dark room. This is the test tube container, since the surface area within the tube is bigger and the material let all the light through.

I think the amount of light output counts more than the engagement time, which I also think was due to the material type and the amount of light it let through. This made people try more intense interactions to get more light, and thus be longer engaged. It is also important to take the algae's sensitivity into account, people trying harder and thus a higher intensity agitation will cause the algae to lose sensitivity. To support a longer energy span of the algae, the material of the test tubes will show their output more clearly and may stimulate the user better.

Another topic is that the design will be placed in a public environment, meaning that it is prone to people trying all sorts of things to interact with it. Even though people mentioned that the silicone material has a lot of freedom to move it was also mentioned that it felt like it could break easily. The hard plastic tubes would allow for multiple user interactions that are harder, since the material feels sturdier to for example really go through all the tubes harder (this was seen in the evaluation).

I think an added value/benefit would be that by using the idea of the test tubes, you can recreate waves as if you are recreating the natural habitat of the algae.

Table 10. Pro's and con's.

Silicone tubing

Pro	Con
• Material is flexible • Material feels nice to the touch • Multiple interactions possible • 1 tap and all tubes give light • Calming and Playful • Natural glowstick • See the algae travel / flow	• Material blocks a bit of light, for output and photosynthesis negative effect • Afraid to break it • Less surface area that shows light • User is constantly interacting for light • People try harder to reive light, tires out the algae

Test tubes

Pro	Con
• More light output • Material allows light to go through, for output and photosynthesis • Multiple interactions possible • You can try 1 interaction and watch from a distance • Calming and Playful • Sturdy for hard interactions • As a user lots of moving freedom around it • Bigger surface area that shows light • Creates waves similar to the sea they live in • Creates different layers of light when tapping	• Afraid to break it • Afraid to hurt the algae with harder interactions • Can get tied up if the wires are too long

Evening test

A small test was done at night to test if the algae are visible outdoors on location. For the purpose if the thesis the test was done in location A, at the aula, where a lot of light is present and in Location D, near the science centre where it is darker to compare the visibility of the light.
The results show, Figure 67, that in the darkest place on campus, location D, the light is showing more texture and appears bluer compared to location A. In the lightest location, the algae gave a slight blue haze and showing no textural qualities.

Figure 67. Evening test to compare the light in location D (left) and A (right).

6

Final Design

6.1 Description

The final design aims to showcase the potential of bioluminescence for design for darkness, specifically in front of the Aula in Mekelpark. The insights gained from the evaluation were incorporated into the final iteration. In this chapter the final design is presented.

The final design comprises of several organic shaped containers that are hanging on a main construction, see Figure 68 and 69. The containers follow a curve going around the construction, alternating in height, shown in Figure 69 at the top. The curve is implemented to creation motion in the design and to be an incentive to interact. The curvature can be associated with ocean wave, and by interacting with the containers, users can recreate the habitat of the algae by making waves.

The design responds to various interactions, resulting in bright flashes. The light creates a textural effect with many individual dots and layers, and the cells that get higher on the walls that drip down will have a more extended glow than the ones in the liquid, creating a beautiful effect. The containers produce a soft sound when bumped together, adding to the experience of the flash. The material feels smooth and sturdy, and the hanging system allows the users to swing the containers and move freely around it.

The design's liveliness stems from the algae's unpredictability of their response to stimuli, making every agitation produce a unique and distinct light, enhancing the idea that the content is alive, as this is one of the material's main strengths.

Figure 69. The wave curve (top) and the encapsulation design (bottom).

Figure 68. The final design.

Envisioned interaction

The envisioned interaction with the design involves placing it near the Aula in Mekelpark. During daytime people can watch the algae in the bulbs and from a distance it will reflect nature, see Figure 70.
At night, passersby will notice the design and approach it, intuitively try to interact with it, which will trigger the algae (Figure 71). By seeing the output, users will engage with the other containers and walk freely around the design. It allows for intermittent stimulation by different users.

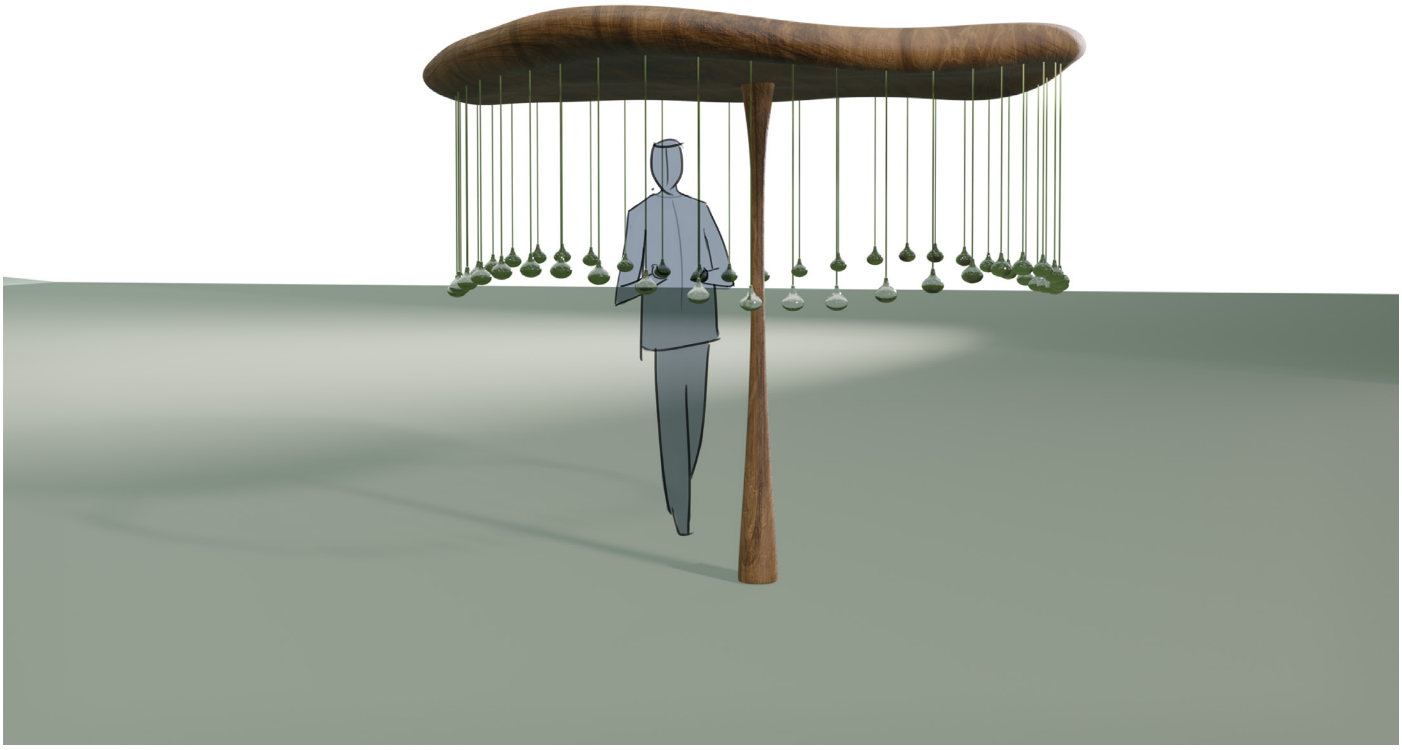

Figure 70. The design during daylight, where reflection of nature is in the bulbs.

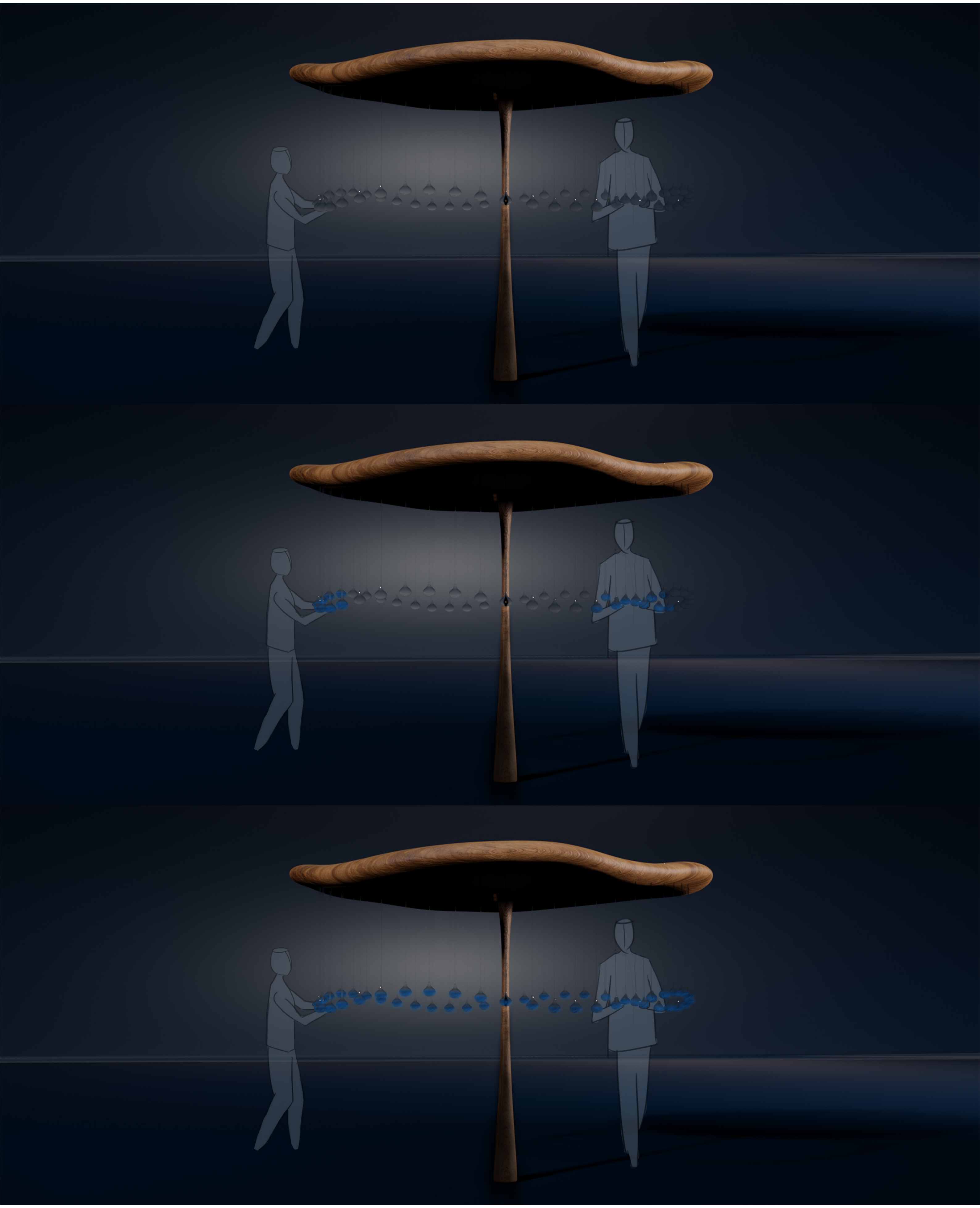

Figure 71. The design at night, during interaction.

6.2 Construction

The construction comprises a base, top, and the container fixed to the top that holds the algae, allowing them to move freely around the fixed point.

Base

The base serves as a stable structure to which the top is attached. It consists of a wooden structure that will be fixed to the ground. The structure is tapered shaped at the top and bottom, to recall a natural form.

Top

The top of the design is also made of wood, featuring a sculpted shape that aims to convey lightness, softness, and playfulness but also provides a protective feeling. The organic form is a flexible and eye-catching design element that enhances the intended playful experience.

Encapsulation design

The encapsulation design is composed of hard plastic with an organic natural shape to hold a liquid algae culture, see Figure 69. The container includes components that provide gas exchange, the introduction of viable cells, the removal of used medium and refilling. The organic shape has a recognisable volume that creates a good proportion which can be viewed from all sides.

The material used for the container is transparent, allowing the culture to be exposed to the appropriate lighting conditions for photosynthesis while also providing for the user to receive light. The surface area is optimised to increase the light output since most of the light is generated at the surface. Additionally, the round shape enables for a better rotational agitation.

Maintenance

The design considers the nurturing activities required to maintain the product's lifespan. As the organisms are unable to thrive on their own when they are removed from their natural environment. The design should include the necessary mechanisms to replace and remove the substances they need.

To maintain sterility and culture containment, there is an integrated opening to allow CO_2 to enter and O_2 to exit the encapsulation. It is essential to preserve the sterility because new organisms entering the culture run the risk of causing it to perish fast. Therefore, the opening is equipped with a filter that allows for gas exchange but block organisms from coming entering. To allow for proper gas exchange in the container used, it should be filled to ¼ or ½ of its maximum volume.

6.3 Validation of the final design

The final design was validated by 11 people using the vision as a basis for the questions and visuals of the design were shown in daytime, nighttime and during usage.

Figure 72 shows the mean of the scale ratings on different dimensions. In general, people think the design is beautiful, interesting, pleasant, comfortable, balanced, connected, lively, relaxed, and safe. Only on the dimension complex and simple is the mean neutral.

The design was described with the following words: pleasasnt, fluid, chic, interesting, playful, mindful, lively, movable, exciting, nature, miraculous, mushroom, rainy, very chill, vague, firm, woody, abstract and soft big friend.

People were curious towards the design because of the interesting look, unusual shape, and playfulness, they want to know what it is used for, such as the hanging bulbs or that it looks similar to a mushroom. These are also the reasons why they would want to explore and engage with the design.

However, someone mentioned that information signs would help since it is too abstract now to make them curious and explore the design.

It was also mentioned that the material (wood) initially takes all the attention.

After seeing the interaction visual where the light appears, people thought it was even more interesting, were curious and want to engage. For some, it was still a bit vague, but their opinion positively increased.

Regarding safety, their opinion increased after seeing the interaction visual. As it provides some light, people feel a bit safer but not fully safe since the light is not that strong. Also, the nature feeling helped, imagining it in a peaceful and quite surrounding.

When asked whether the design would make them think differently about darkness, individuals responded that when you stop interacting, it becomes dark making you think about the presence and absence of light. However, they think it also depends on the surroundings. The design could make it more comfortable since it will be interactive and looks fun.

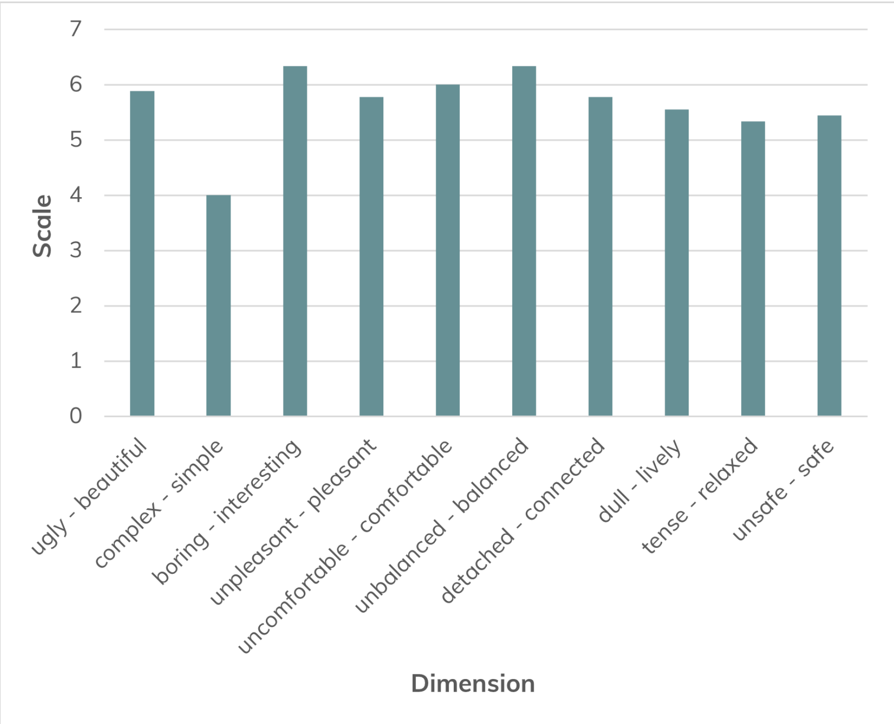

Figure 72. Ratings of the final design

7

Evaluation of the process and design

7.1 Dicussion and conclusion

The question of whether bioluminescent algae are a potential means for design for darkness is answered in this chapter. The feasibility, desirability, viability, and ethical side of the final design and the potential means of the material through the values of darkness are discussed.

At the beginning of the project, the following aim was formulated for the project:

"Explore if bioluminescence can be a means for the design for darkness approach, answering the question: "What design potentials would bioluminescent algae offer for our campus? "

To gain an understanding of the topic, the project started with literature research on light, darkness, and bioluminescent algae. The range of contrast is crucial in designing for darkness and our ability to adjust to the dark. Dimmer and layered lighting support people's perception of safety because the contrast is not distracting. After you become dark adapted, you can see more in the dark, and less light is required to make an environment appear bright.

The bioluminescent algae's capability to produce distinctive textures and patterns that could improve the nighttime environment was explored through literature and prototyping. The material's sensitivity to agitation, duration, and force makes it essential to maintain their energy with enough light during the day and using intervals in between agitations that go from low to high intensity. The textural qualities of the algae are also affected by the speed or intensity, creating a range from little visible texture to highly scattered texture. The encapsulation must be transparent to support their photosynthesis and for users to receive output.

Using Pont's framework, we could prove what the current lighting condition by conducting measurements. From the analysis it became clear that location A, near the Aula had a lot of light exposure. In location D, near the Science centre there was less light exposure, thus making it darker. A user study was conducted in these two locations, to compare users' perception of the light qualities. The analysis showed that the dimensions simple, dim, and safe were significant and were used as design values. Literature, study insights, brainstorming, expert opinion, and prototyping were used to define a design. Evaluation test with users provided insights focused on interaction and performativity, leading to the final design. A final test bringing the algae outdoors at night showed that the light is barely visible and showing no texture in the designated location near the Aula.

The final design received positive participant feedback regarding aesthetics, comfort, balance, and connectivity. The design was described using positive adjectives such as playful and interesting. Even so, the design was also perceived as somewhat abstract. To make it more informative and understandable, a participant recommended using a sign. The use of wood as the primary material was also noted, with some participants mentioning that it initially takes all the attention. Participants' interest and involvement increased because of the interactive design feature, particularly the appearing light. Overall, the design has the potential to make people think about darkness and light.

Feasibility

The use of Pyrocystis Fusiformis as a material can be implemented right away, since it is a natural source that can reproduce itself with nutrients and light. It is not dependent on recent or coming innovations, only on light to gain energy and new medium once every month. As shown in the previous chapter, there is potential to create a functional product. However, the product itself is not fully developed therefore construction, calculations and cost analysis still need to be taken into account. Next to that it is important that the lights at the Aula should be more dimmed to increase the visibility of the unique characteristics of the light from the algae as shown in the evening test.

Desirability

The design with bioluminescent algae created for the area in front of the Aula is desirable, because of the excessive use of light in that location. The design is a way to promote the re-introduction of darkness and other types of lighting. Because it is a busy location the designed shapes allow for a playful user interaction and support the feeling of safety through the organic shapes and freedom of movement. From the user evaluation it became clear that people had a positive experience with the material, however it should be proven that the final design will support the feeling of safety in a darker environment after the user is dark adapted.

Viability
Implementing bioluminescent algae in the proposed design could be used for outdoor and indoor areas, creating a level of versatility that increases its viability. One of the key benefits of the proposed design is its ability to contribute to the long-term acceptance of darkness and we can take steps towards bringing back darkness re-establishing a more natural balance.

In addition to its potential use for outdoor areas, bioluminescent algae could also be applied in indoor settings. This opens up many possibilities for unique and creative designs integrated with the material. Exploring different applications and designs will not only increase its viability, but also contribute to a more sustainable and environmentally conscious approach to urban design.

Ethics
Using bioluminescent algae for design purposes raises ethical questions that need to be considered, such as should we be doing this at all and do we need it? Looking at the effects of light pollution on humans and ecosystems, implementing darkness is needed. Additionally, the use of bioluminescent algae may still raise the question whether there are other, more sustainable solutions to the issue of light pollution. In the end, the choice to use bioluminescent algae for design purposes should be taken carefully considering the advantages and disadvantages, emphasising the long-term effects on the environment and society.

Overall, the project and final design have demonstrated the importance of considering darkness and how it can be supported through bio-lighting design. Bioluminescent algae highlight the need for further exploration and experimentation with integrating darkness into our nightscapes.

To assess the use of bioluminescent algae for design for darkness, the values of darkness mentioned in chapter X are considered.

Efficiency
The preservation and introduction of darkness becomes a symbol of economical use of lighting sources. In cities and urban settings this can be very useful, conserving resources and improve economic efficiency.

Sustainability
Bioluminescent algae is a natural source that can consume large amounts of carbon dioxide by converting it into oxygen. Next to that, we can grow it in a lab to multiply, and therefore it is preserving non-renewable resources. During this phase there is energy needed, since the algae need a certain amount of light, still once they are outside the lab, they provide a sustainable way of lighting which is energy saving. Since the amount of light produced by the algae is small, we can say that they provide a responsible use of lighting.

Ecology
Regular amount of daylight and darkness are necessary for species and habitats. As a result, the re-introduction of darkness is related to maintaining this, since bioluminescent algae also have a day and night rhythm this also accounts for them. The algae promote darkness for others but also need it themselves to thrive.

Healthiness
The ability to access and experience darker night can be considered as beneficial for personal health. By interacting with the material, people are active and outside experiencing darkness. This will result in us as humans getting more familiar with darkness and grow acceptance towards it.

Happiness
Most people have not seen or interacted with something like this before, and it generates a positive effect on people once they see it. The focus on the experiences, small moments of pleasure, the enjoyment of (natural) beauty and the calming and beneficial effect of interacting with the algae and being under the night sky are a few ways that can enhance happiness.

Connection to nature

By using bioluminescent algae as the light source we try to bring the user closer to nature. Because of its unpredictability and generally unpredictable response to stimuli of the light produced by the algae people really engage with it. They try to understand what is happening. As this is one of the key strengths of the material, this might emphasize that the content is alive. Next to the material being alive, it is also encouraging dark nights to be seen as a means of maintaining the natural nighttime circumstances.

Stellar visibility and Heritage and tradition

Preserving for stellar visibility is something that can only happen if we actively start to integrate more darkness in our cities. However, this may not be an easy feat as people tend to have negative associations with darkness at night, which may lead to resistance towards this change. Bioluminescence can promote the positive sides of darkness and help grow the acceptance towards darker night.

Wonder and beauty

By turning off the lights, one would be able to appreciate the wonder and beauty of the starry night sky to a far greater extent, enhancing the fundamental benefits of darkness. This can also be linked to the light coming from bioluminescence algae, the need for darkness to be able to witness the behaviour and texture created with the light.

The nine values of darkness show us that bioluminescent algae can be a means to design for darkness. However, there are still steps needed for it to have a greater impact. Therefore, in the near future it can serve to promote darkness, the positive effects, and positive experiences. In the distant future, more significant measures can be taken implemented, such as the implementation of policies that require the turning off lights. Also, different applications and designs can contribute to the long-term of bringing back darkness in the urban nightscape. Per situation it should be carefully considered if bioluminescent algae are the fitted material choice and what form this should take.

In conclusion, this chapter has addressed whether bioluminescent algae can be used as a potential means for design for darkness. The project aimed to explore the design potentials of bioluminescent algae for our campus, and the final design presented shows that they are indeed a feasible and desirable option for creating unique lighting effects in low light conditions.

Furthermore, the chapter addresses the viability and ethical considerations of the final design, demonstrating that it is not only a visually appealing and interactive option but also a sustainable one. By nurturing the algae and providing the necessary conditions for them to thrive, the design allows for an extended lifespan. However, it is important to ensure that the implementation of bioluminescent algae is done in a responsible and sustainable way, considering the potential risks associated with the use of living organisms.

Overall, the project has successfully demonstrated that bioluminescent algae can be used as a means for design for darkness, offering unique and dynamic lighting effects that can create a sense of liveliness and interaction in low light conditions. The material's potential via the values of darkness has been fully explored, and the final design showcases its possibilities. Bioluminescent algae offer a promising potential for the design for darkness approach to promote darkness and could have significant positive impacts on both the environment and human society.

7.2 Recommendations

Firstly, it is important that the lights at the Aula should be more dimmed to increase the visibility of the unique characteristics of the light as shown in the evening test. Further tests in the outdoor lighting environment will show in what conditions the bioluminescent algae perform well.

The bioluminescent characteristics of the culture appear to be influenced by the size and shape of the encapsulation. It would be interesting to understand how the algae would react to the shape of the encapsulation. Performing trials with various encapsulations could reveal added information on the relationship between the bioluminescent properties and the shape.

The algae culture is highly depended on receiving enough light during the day. From the evaluation tests it became clear that the silicone material did not let enough light through for the algae to gain new energy for the next day of testing. Therefore, it would be interesting to research if the encapsulation design would receive enough light for the algae to conduct photosynthesis and how this could be optimized. This would also count for temperature, since the algae are affected by it, how would this work during summer and winter periods if it is standing outside.
Looking at the final design, it is interesting to know if the construction would obstruct sunlight from reaching the encapsulations by casting shadows.

Having the final design tested in a real environment will provide new insights and increase the acceptance, however it should be proven that the final design will support the feeling of safety in a darker environment after the user is dark adapted.

In addition to its potential use for outdoor areas, bioluminescent algae could also be applied in indoor settings. This creates opportunities for unique and creative designs such as the examples shown in the evaluation results, for instance an interactive wall or floor in musea or at the science centre to create an education tool. But mainly in a more energy-friendly form and in brightly lit spaces, it also provides the opportunity to improve the balance between light and dark, such as in a railway station.

To get the bioluminescent algae into the urban nightscape, increased awareness of the need for darker nights is necessary. Only then it is possible to take steps towards re-introduction of darkness, policy, and protections measures.

7.3 Reflection

Upon completing this project, I want to reflect on the period working on the project. Firstly, I feel fortunate to have had the opportunity to work with my supervisors Elvin and Sylvia, who were supportive, engaged, and enthusiastic throughout the project. I therefore look back on this project with happiness and gratitude. From both a design and personal point of view, this project has been enlightening for me.

I wanted to broaden my knowledge on lighting design, since I followed the Lighting Design course I got more interested in the topic and after some hesitation decided I wanted to do my graduation within the field. Within the project the focus was on design for darkness, but this also needs an understanding of light and lighting design. By diving into this topic and learning as much as I could to understand my results and interpreting them, I learned a lot, however, this was and still is sometimes confusing. Conducting the lighting research and calculations was not something I expected beforehand, especially the calculations, but I did enjoy doing it since this created a good base for the project because I could prove it with my results.

The second personal ambition I had was to gain experience with biobased materials and how to bring this into practice. This was also related to another learning ambition of learning and applying the Material Driven Design method. But as I learned the different steps of the method, the knowledge available on the bioluminescent material already showed that for example, material tinkering to understand the material, was at hand. Also due to other steps in the process I was not in the lab trying out different interactions with the algae, which did not help me during the ideation phase since I was not sure on how the algae would react to some of my ideas. I should have started earlier on prototyping small tests to conduct with algae in the lab to show if certain ideas would work. Since this was also the part that I most enjoyed when I got to it. I certainly gained new experiences here since I joined workshops in the lab about how to work sterile and with different organisms, and also by trying out my own prototypes and seeing how the algae reacted was something I really liked.

The different topics in this project made it sometimes complicated for me. Because I was so close to it, I would lose the overview a bit, and I needed to really zoom out and try to connect the topics. I also learned that within an explorative study, there is no optimal decision. Each unexplored path will generate useful results when chosen. In the future I should be more pragmatic and direct. For instance, in the user study results I wanted to add more dimensions to generate more values to design with, but these did not show significance. I was afraid that only 3 values would not be sufficient to move forward. I learned that sometimes I want to cover too much to make sure it is the right way to go. It can be time consuming and they are often not the deciding factors.

Altogether, I have completed a great project and enjoyed it through its ups and downs. However, I have learned a lot about my abilities and qualities as a designer by doing this project. I will be more confident in myself and what I produce in the future. I can look back on a successful project that allowed me to delve into this interesting and diverse topic.

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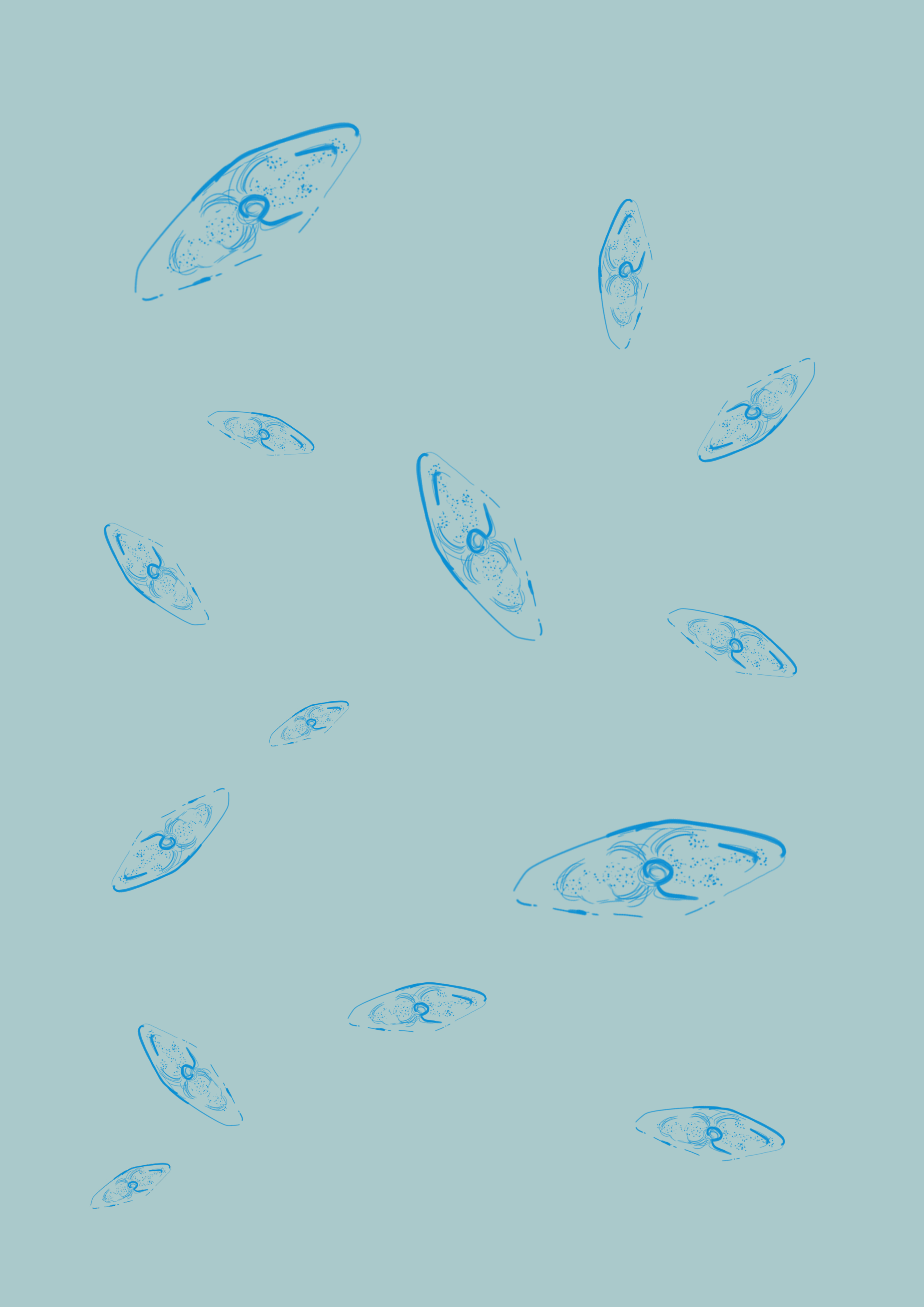

Appendices

Appendix A. Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Smolders
initials: V given name: Vera
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): [x] IPD [ ] DfI [ ] SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: [ ] Honours Programme Master
specialisation / annotation: [ ] Medisign
[ ] Tech. in Sustainable Design
[ ] Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Elvin Karana dept. / section: EM
** mentor: Sylvia Pont dept. / section: HICD
2nd mentor:
organisation:
city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

Biodesign for darkness: the potentials of bioluminescence for TU campus

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 31 - 10 - 2022

31 - 03 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The climate crisis and the increasing attention to this issue brought forward an interest in integrating living organisms into design. Exploring this potential would allow for alternative and more sustainable ways of living with less impact on the environment. Light pollution is a fairly recent phenomenon and is defined as the increased brightness of the nighttime environment due to the use of artificial light. The excessive use of lighting can disrupt nature, but also human health and well-being, and affects the overal experience of the night sky. The current debates arround light pollution provides an unique opportunity to re-introduce darkness into urban nightscapes. This is where design for darkness can add value, by looking at the positive aspects of darkness at night and how this can be corporated into the design of night time lighting (Stone, 2019). In the dutch randstad, levels of light pollutions are high, therefore the reduction of light could be of great benefit for the biodiversity in the cities, and improve human health. The created urban nightscape would foster a connection with nature through the lighting design focused on enhancing urban life after dark.

Lighting plays a vital role in the quality of our day to day lives, lighting design brings performance, comfort and safety. Lighting design aims to create perceptual conditions that enable us to work efficiently and safely orient ourselves in an environment. Next to that it is promoting a sense of well-being as well as enhancing that same environment in an aesthetic sense. The lighting design approach is based on the three 'layers of light'. Richard Kelly differentiated three basic functions: ambient light, focal glow and play of brilliance. These categories provide a simple and structured range of possibilities to address buildings and objects, but also the perceptual needs of the users of the space (Gansland & Hofmann, 1992).

An interesting quality some living organisms possess is the ability to produce and emit light, known as bioluminescence. Through a chemical reaction light is produced in the presence of oxygen, a substrate luciferin and an enzyme luciferase. This is seen in living organisms such as fireflies or glowworms, but also in marine organisms. The most common type is generated by a marine plankton, dinoflagellates, known as pyrocystis fusiformis. Due to its size the light emission is relatively high compared to other species from the dinoflagellate. During its day cycle, it uses light to create their own energy (via photosynthesis) and emit light when agitated during its night cycle (Valiadi & Iglesias-Rodriguez, 2013). Bioluminescence, offers a novel approach to design with light. How to use nature as a source of energy, exploring the potential for alternative and more sustainable ways.

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introduction (continued): space for images

image / figure 1: Glowing Nature by Studio Roosegaarde

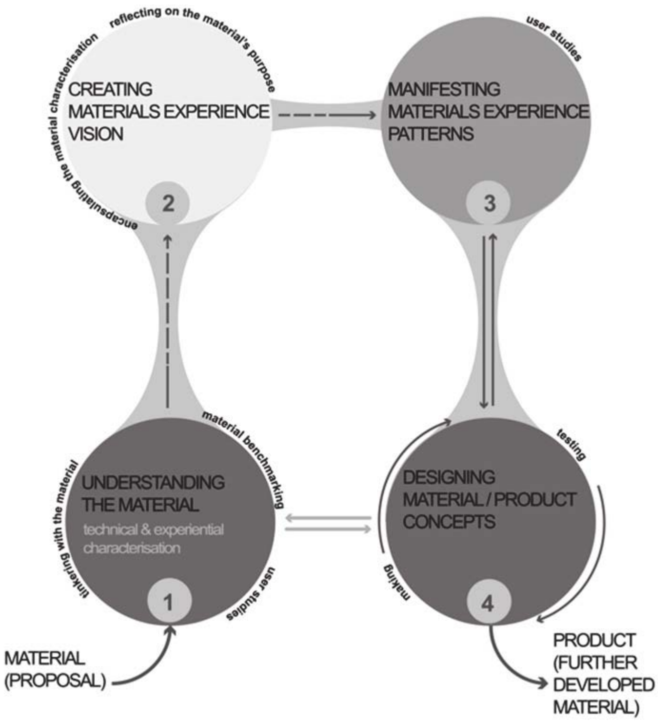


image / figure 2: The Material Driven Design Method

Initials & Name V Smolders Student number 4684346

Title of Project Biodesign for darkness: the potentials of bioluminescence for TU campus

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

This graduation project explores the possibilities of creating a meaningful application that brings the unique qualities of the bioluminescent organism combined with lighting design forward with a focus on design for darkness. The product stimulates people to actively discover bioluminescent material's unique experiential and performative qualities through interaction. The context is focused on public space at the TU Delft Campus with a flow of passerbyers that can seek this interaction with the material. After initial research on living organisms the choice is made to continue with the bioluminescent algae. The main challenge of this project will be to create a sustainable environment where the organisms cannot be contaminated. Their ecosystem has to be carefully recreated and maintained. Another challenge within the project is that the algae have a specific day and night cycle in which they do and do not emit light when agitated. Next to that, the light intensity decreases when the fusiformis are agitated for a while. So when designing, it is important to remember that these organisms are living creatures and have certain limits. As the liveliness of the material is one of its core strengths, it is important to try and emphasise that the material is alive.

The Material Driven Design method will be used. The method has four main steps:
1. Understanding the Material: Technical and Experiential Characterization, 2. Creating Material Experience Vision, 3. Manifesting Materials Experience Patterns, 4. Designing Material/Product Concepts.

The research questions for this project are:
- What design possibilities do bioluminescent algae provide for our campus?
  Design potentials with regards to the user experience, sustainability (e.g. light pollution), etc.
- How do people currently experience the lighting on campus? In regards to light pollution, do they realize that it is too much?
- How can bioluminescent algae be used as a means to design for darkness?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The graduation project is focused on how bioluminescent organisms can be integrated within lighting design to foster urban nightscapes within the scope of the TU Delft campus. Answering the question 'What design potentials would bioluminescent algae offer for our campus '.

The aim is to explore and integrate the potentials of bioluminescent organisms in lighting design that could work as a means for design for darkness. It creates opportunities to design interventions that enhance urban life after dark on the TU Delft campus and foster a connection with nature and other people.
The behaviour of the integrated organisms should stimulate people to actively discover the material through interaction. The wish is to show the outcomes in the form of a demonstrator that takes us a step closer to showing the application of the bioluminescent lighting design.

- What is the user experience of campus currently regarding lighting design.
- How do people experience bioluminescent algae.
- Explore the potentials of bioluminescent algae regarding the campus and as means for design for darkness.

Since the focus of this thesis is on designing a product for lighting design with bioluminescence I will use the guidelines, insights and research results from previous studies that explored bioluminescence organism behaviour. The result of this thesis is a designed concept/product for lighting design.

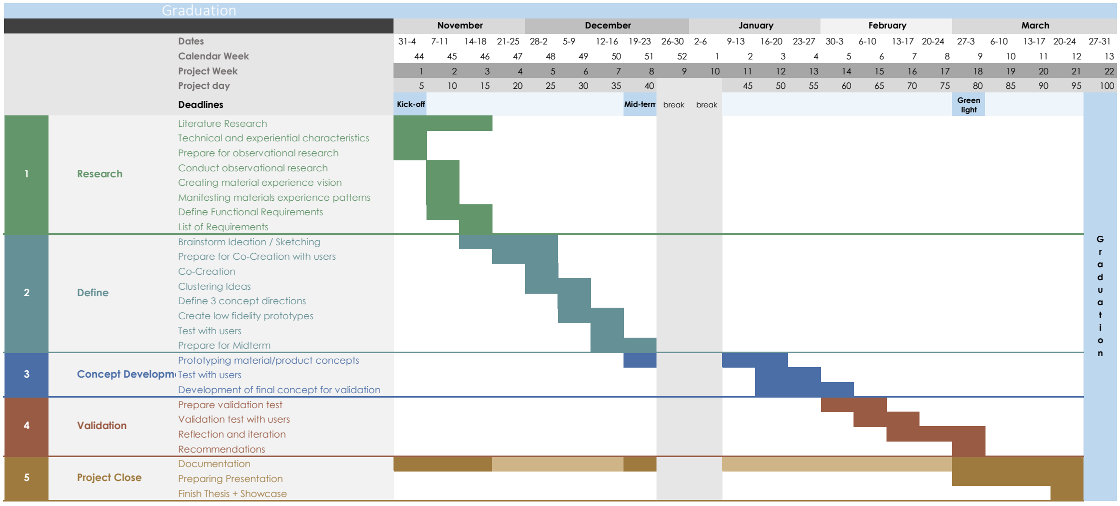
Initials & Name V Smolders Student number 4684346

Title of Project Biodesign for darkness: the potentials of bioluminescence for TU campus

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 31 - 10 - 2022   31 - 3 - 2023 end date



The Material Driven Design method will be used, where the four steps will be executed in order to understand the material and its technical, experiential characteristics, create the material experience vision, indicate the material experience patterns and create material product concepts. More detailed activities are written down to support the steps of the method. The material product concepts will be prototyped and evaluated. After this the final demonstrator/product will be developed and validated. Based on the validation, I will make some improvements and write recommendations for future steps.

Initials & Name V Smolders   Student number 4684346

Title of Project Biodesign for darkness: the potentials of bioluminescence for TU campus

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My motivation and passion lies in the design of physical products. Within the design process you will have to choose a certain material which can greatly impact the environment. This is where my interest in biobased materials comes in. This is my first time designing with living organisms, but am very eager and excited to learn more about this. For this project I plan to use the Material Driven Design method in order to systematically create a design derived from the bioluminescent organism and light setting combination. As this approach is new for me I expect to learn a lot from applying this method.

Next to this, I have an interest and experience in the field of lighting design. I followed the elective course lighting design and the past 6 months I did an internship with a company that was working on products with interactive lighting that are inspired by nature and also take light pollution into account. I am looking forward to exploring and learning about the implementation of living organisms into lighting design.

Learning ambitions:
- Learn about designing with biobased materials and bring it into practice.
- Learn and apply the Material Driven Design method.
- Broaden my knowledge on lighting design, design for darkness and combining this with living materials.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Appendix B. HREC

Date 20-Jan-2023
Contact person Dr. Cath Cotton, Policy Advisor Academic Integrity
E-mail

Human Research Ethics Committee
TU Delft
(http://hrec.tudelft.nl/)

Visiting address
Jaffalaan 5 (building 31)
2628 BX Delft

Postal address
P.O. Box 5015 2600 GA Delft
The Netherlands

Ethics Approval Application: Biodesign for darkness: the potentials of bioluminescence for TU campus
Applicant: Smolders, Vera

Dear Vera Smolders,

It is a pleasure to inform you that your application mentioned above has been approved.

In addition to any specific conditions or notes, the HREC provides the following standard advice to all applicants:

- In light of recent tax changes, we advise that you confirm any proposed remuneration of research subjects with your faculty contract manager before going ahead.
- Please make sure when you carry out your research that you confirm contemporary covid protocols with your faculty HSE advisor.
- Our default advice is not to publish transcripts or transcript summaries, but to retain these privately for specific purposes/checking; and if they are to be made public then only if fully anonymised and the transcript/summary itself approved by participants for specific purpose.
- Where there are collaborating (including funding) partners, appropriate formal agreements including clarity on responsibilities, including data ownership, responsibilities and access, should be in place and that relevant aspects of such agreements (such as access to raw or other data) are clear in the Informed Consent.

Good luck with your research!

Sincerely,

Dr. Ir. U. Pesch
Chair HREC
Faculty of Technology, Policy and Management

Data management plan

DELFT UNIVERSITY OF TECHNOLOGY: TU DELFT DATA MANAGEMENT PLAN TEMPLATE (2021)

0. ADMINISTRATIVE QUESTIONS

1. Name of data management support staff consulted during the preparation of this plan.
Not applicable

2. Date of consultation with support staff.
Not applicable

I. DATA DESCRIPTION AND COLLECTION OR RE-USE OF EXISTING DATA

3. Provide a general description of the type of data you will be working with, including any re-used data:

Types of data
Describe very briefly what type of data are you planning to collect/work with. For example:

- *Measurements of light parameters*
- *Images: namely panoramic photographs of the context, without recognizable people*
- *Quantitative interview data*
- *Qualitative interview data*
- *Gender, age*

How will the data be collected?
E.g. with a survey, datasets received from someone else (specify the source and terms of use), observations, recordings etc.
Survey on location, light meter and images(camera).

Purpose of processing
Briefly explain the purpose for data processing i.e. why do you need to collect the data.
I need to collect the data to find out the preferences and experiences of people related to lighting quality to be able to create and test an interaction product/light design.

Storage location
Explain the storage solutions which will be used to store research data for the duration of the research project.
The data will be stored on the password-protected researchers laptop and an external hard drive.

Who will have access to the data?
Please explain who will have access to the data. Note that access to personal or other types of confidential data should be restricted as much as possible, based on 'need to have' principle.
Access includes using third party service providers such as cloud storage providers or survey platforms. If parties outside of your research team will have access to the confidential data, explain if you already have appropriate data processing agreements in place. If you don't yet have processing agreements in place, get in touch with the privacy team: privacy-tud@tudelft.nl.

Example Answer:

Type of data	File format(s)	How will data be collected (for re-used data: source and terms of use)?	Purpose of processing	Storage location	Who will have access to the data
Gender, age	*.xlsx*	*Online survey*	*To collect the age of the respondents and their gender to make appropriate correlations*	*Computer and external hard drive*	*The project team (Chair, mentor and master student)*

Scale ratings	*.xlsx*	*Online survey*	*To understand the preferences of lighting qualities between different people*	*Computer and external hard drive*	*The project team (Chair, mentor and master student)*
Images: panoramic photographs of the context, without recognizable people	*.jpg and .NEF*	*Nikon D3400 camera*	*To visualize the lighting in an environment*	*Computer and external hard drive*	*The project team (Chair, mentor and master student)*
Light measurements: illuminance, ambient, focus, luminance, pixel value	*.xlsx, .m*	*Lightmeter and a photo reflective sphere*	*To collect light measurements, calculations and make appropriate correlations with the Linkert scale ratings*	*Computer and external hard drive*	*The project team (Chair, mentor and master student)*

4. How much data storage will you require during the project lifetime?

- > 5 TB
- **< 250 GB**
- 250 GB - 5 TB

II. DOCUMENTATION AND DATA QUALITY

5. What documentation will accompany data?

- Methodology of data collection
- Documentation in master thesis and presentations
- I will adhere to disciplinary metadata standards - please explain which standards in the box below
  Embedded metadata: TIFF files

III. STORAGE AND BACKUP DURING RESEARCH PROCESS

6. Where will the data (and code, if applicable) be stored and backed-up during the project lifetime?

- *Researchers computer hard drive*
- *External Hard drive*

IV. LEGAL AND ETHICAL REQUIREMENTS, CODES OF CONDUCT

7. Does your research involve human subjects or 3rd party datasets collected from human participants?

- **Yes**
- No
- Not sure

8A. Will you work with personal data? (information about an identified or identifiable natural person)
If you are not sure which option to select, ask your Faculty Data Steward *for advice. You can also check with the* privacy website *or contact the privacy team: privacy-tud@tudelft.nl*

- Yes
- **No**

8B. Will you work with any other types of confidential or classified data or code as listed below? (tick all that apply)
If you are not sure which option to select, ask your Faculty Data Steward *for advice.*

- Yes, data falling under export control regulations
- Yes, national security data (e.g. nuclear research)
- **No, I will not work with any confidential or classified data/code**
- Yes, I work with other types of confidential or classified data (or code) - please explain below
- Yes, politically-sensitive data (e.g. research commissioned by public authorities, research in social issues)
- Yes, confidential data received from commercial, or other external partners
- Yes, data which could lead to reputation/brand damage (e.g. animal research, climate change, personal data)
- Yes, data related to competitive advantage (e.g. patent, IP)

9. How will ownership of the data and intellectual property rights to the data be managed?
The datasets underlying the published papers will be publicly released following the TU Delft Research Data Framework Policy. During the active phase of research, the researcher is the owner of the data. The data is only accessible with the computer of the researcher which is restricted with a password and the drive which is also password protected.

10. Which personal data will you process? Tick all that apply

- Financial information, such as bank account numbers
- Citizen Service Number (BSN)
- Copies of passports or other identity documents
- X Gender, date of birth and/or age
- Telephone numbers
- X Photographs, video materials, performance appraisals or student results
- X Signed consent forms
- X Data collected in Informed Consent form (names and email addresses)
- Special categories of personal data (specify which): nationality, race, ethnicity, criminal offence data, political beliefs, union membership, religion, sex life, health data, biometric or genetic data
- Names and addresses
- Other types of personal data - please explain below

- IP addresses
- Email addresses and/or other addresses for digital communication
- Access or identification details, such as personnel number, student number

11. Please list the categories of data subjects

Students, residents, general public in a certain area.

12. Will you be sharing personal data with individuals/organisations outside of the EEA (European Economic Area)?

- **No**
- Yes

13. To which countries will you be transferring personal data:

- *No countries*

14. Please contact the privacy team (privacy-tud@tudelft.nl) for advice on data transfer.
Not applicable

15. What is the legal ground for personal data processing?

- **Informed consent**
- Other - please explain and contact the privacy team (privacy-tud@tudelft.nl). If you have already contacted the privacy team and received their advice, please record their advice below.

16. Please describe the informed consent procedure you will follow:
All study participants will be asked for their consent for taking part in the study and for data processing before the start of the survey.

17. Where will you store the signed consent forms?

- **Same storage solutions as explained in question 6 but separately from the research data**
- Other - please explain below

18. Does the processing of the personal data result in a high risk to the data subjects?
If the processing of the personal data results in a high risk to the data subjects, it is required to perform a Data Protection Impact Assessment (DPIA). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data during your research (check all that apply).
If two or more of the options listed below apply, you will have to complete the DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to receive support with DPIA.
If you have any additional comments, please add them in the box below.

- Matching or combining datasets
- Data processed on a large scale

- **X Evaluation or scoring**
- Automated-decision making with legal or similar significant effect
- Systematic monitoring
- Sensitive personal data
- Data concerning vulnerable data subjects
- Innovative use or applying new technological or organisational solutions for data processing
- The processing prevents data subjects from exercising a right or using a service or a contract
- None of the above applies

Guidance:
Evaluation or scoring
Processing that includes profiling and predicting, especially from aspects concerning the data subject's performance at work, economic situation, health, personal preferences or interests, reliability or behaviour, location or movements.
Examples of these types of processing are research on the movement of students and employees through the campus areas or research on migrants movements in cities/countries with the aim to have a predicting function.
Automated-decision making with legal or similar significant effect
Processing that aims at making decisions on data subjects, without human intervention, producing legal, or similarly significant, effects concerning the natural person which may lead to the exclusion or discrimination against individuals.

Systematic monitoring
Processing that is used to observe, monitor or control data subjects, including data collected through networks or systematic monitoring of a publicly accessible area.

Sensitive personal data
Processing of special categories of personal data, personal data relating to criminal convictions or other types of sensitive data such as financial data and location data. Please note that photo and video materials of research participants are also considered as sensitive personal data. Please see TU Delft GDPR terminology for more information.

19. Did the privacy team advise you to perform a DPIA?

- Yes
- **No**

20. Please include below the outcome of the DPIA, what measures did you take?

Not applicable

21. Where will you store the DPIA documents (document on data processing features and document on risk assessment)?

- **Same storage solutions as explained in question 6**
- Other - please explain below

22. What will happen with personal research data after the end of the research project?

- Personal data will be shared with others **-** please explain which personal data will be shared, with whom, how and whether you have specified this in the informed consent form
- Other - please explain below
- **Personal research data will be destroyed after the end of the research project**
- Anonymised or aggregated data will be shared with others

23. How long will (pseudonymised) personal data be stored for?

- **10 years or more, in accordance with the TU Delft Research Data Framework Policy**
- Other - please state the duration and explain the rationale below

24. What is the purpose of sharing personal data?

- **For research purposes, which are in-line with the original research purpose for which data have been collected**
- Other - please explain below

25. Will your study participants be asked for their consent for data sharing?

- No - please explain below
- **Yes, in consent form** - please explain below what you will do with data from participants who did not consent to data sharing

V. DATA SHARING AND LONG-TERM PRESERVATION

26. What data will be publicly shared?

- All data (and code) underlying published articles / reports / theses
- No data can be publicly shared - please explain below why data cannot be publicly shared
- Not all data can be publicly shared - please explain below which data and why cannot be publicly shared
- All validated non-positive results
- **All data (and code) produced in the project**

27. Apart from personal data mentioned in question 22, will any other data be publicly shared?

- No other data can be publicly shared - please explain below why data cannot be publicly shared
- **All other non-personal data (and code) produced in the project**
- I do not work with any data other than personal data
- Not all non-personal data can be publicly shared - please explain below which data and why cannot be publicly shared
- All validated non-positive results which do not contain personal data

- All other non-personal data (and code) underlying published articles / reports / theses

28. How will you share your research data (and code)?

- I will upload the data to another data repository (please provide details below)
- I will share my data and code via git(lab)/subversion and also create a snapshot in a repository
- My data can't be shared in a repository, but the metadata will be registered in 4TU.ResearchData and all research publications resulting from the project have a statement explaining what additional datasets/materials exists; why access is restricted; who can use the data and under what circumstances.
- My data will be shared in a different way - please explain below
- **All data will be uploaded to 4TU.ResearchData**

29. How will you share research data (and code), including the one mentioned in question 22?

- No data can be publicly shared - please explain below
- My data can't be shared in a repository, but the metadata will be registered in 4TU.ResearchData and all research publications resulting from the project have a statement explaining what additional datasets/materials exists; why access is restricted; who can use the data and under what circumstances.
- All pseudonymised data will be uploaded to 4TU.ResearchData with restricted access
- I will upload the data to another data repository (please provide details below)
- **All anonymised or aggregated data, and/or all other non-personal data will be uploaded to 4TU.ResearchData with public access**
- I will share my data and code via git(lab)/subversion and also create a snapshot in a repository
- My data will be shared in a different way - please explain below

30. How much of your data will be shared in a research data repository?

- **< 100 GB**
- 100 GB - 1 TB
- > 1 TB

31. When will the data (or code) be shared?

- Other - please explain
- **As soon as corresponding results (papers, theses, reports) are published**
- At the end of the research project

32. Under what licence will be the data/code released?

- EUPL-1.2
- Apache
- GPL-2.0
- CC0
- **CC BY**
- CC BY-SA
- CC BY-ND
- CC BY-NC
- CC BY-NC-SA
- CC BY-NC-ND
- MIT License
- BSD
- GPL 3.0+
- LGPL-3.0
- AGPL-3.0
- Other - Please explain

VI. DATA MANAGEMENT RESPONSIBILITIES AND RESOURCES

33. Is TU Delft the lead institution for this project?

- No - please provide details of the lead institution below and TU Delft's role in the project
- Yes, leading the collaboration - please provide details of the type of collaboration and the involved parties below
- **Yes, the only institution involved**

34. If you leave TU Delft (or are unavailable), who is going to be responsible for the data resulting from this project?
The data stored on the laptop, external hard drive and google drive will not be accessible, but on the 4TU.ResearchData where the thesis is published.

35. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?
4TU.ResearchData is able to archive 1TB of data per researcher per year free of charge for all TU Delft researchers. We do not expect to exceed this and therefore there are no additional costs of long term preservation.

HRX Checklist

I. Applicant Information

PROJECT TITLE:	**Biodesign for darkness: the potentials of bioluminescence for TU campus**
Research period: *Over what period of time will this specific part of the research take place*	**January to April**
Faculty:	**IDE**
Department:	**SDE and HCD**
Type of the research project: *(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)*	**Master's thesis**
Funder of research: *(EU, NWO, TUD, other – in which case please elaborate)*	**-**
Name of Corresponding Researcher: *(If different from the Responsible Researcher)*	**Vera Smolders**
E-mail Corresponding Researcher: *(If different from the Responsible Researcher)*	
Position of Corresponding Researcher: *(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)*	**Masters**
Name of Responsible Researcher: ***Note:*** *all student work must have a named Responsible Researcher to approve, sign and submit this application*	**Sylvia Pont**
E-mail of Responsible Researcher: *Please ensure that an institutional email address (**no Gmail, Yahoo, etc.**) is used for all project documentation/ communications including Informed Consent materials*	
Position of Responsible Researcher : *(PhD, PostDoc, Associate/ Assistant/ Full Professor)*	**Full professor**

II. Research Overview

NOTE: *You can find more guidance on completing this checklist **here***

a) Please summarise your research very briefly (100-200 words)

What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbrevations)
The purpose of the study is to learn how people perceive the lighting on the TU Delft campus in relation to the qualities they believe to be important for comfort, safety, preference and interest. For the study 12 to 20 participants will rate around 14 scales and provide an open comment if they want. The participants are recruited through personal network, online communities and personal communication.

b) **If your application is an additional project** related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbrevations)

c) -**If your application is a simple extension of, or amendment to,** an existing approved HREC submission, you can simply submit an HREC Amendment Form as a submission through LabServant.

III. Risk Assessment and Mitigation Plan

NOTE: *You can find more guidance on completing this checklist* *here*

Please complete the following table in full for all points to which your answer is “yes”. Bear in mind that the vast majority of projects involving human participants as Research Subjects also involve the collection of **Personally Identifiable Information (PII)** and/or **Personally Identifiable Research Data (PIRD)** which may pose potential risks to participants as detailed in Section G: Data Processing and Privacy below.

To ensure alignment between your risk assessment, data management and what you agree with your Research Subjects you can use the last two columns in the table below to refer to specific points in your Data Management Plan (DMP) and Informed Consent Form (ICF) – **but this is not compulsory**.

It’s worth noting that **you’re much more likely to need to resubmit your application if you neglect to identify potential risks**, than if you identify a potential risk and demonstrate how you will mitigate it. If necessary, the HREC will always work with you and colleagues in the Privacy Team and Data Management Services to see how, if at all possible, your research can be conducted.

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
A: Partners and collaboration						
1. Will the research be carried out in collaboration with additional organisational partners such as: • One or more collaborating research and/or commercial organisations • Either a research, or a work experience internship provider[1] *[1] If yes, please include the graduation agreement in this application*		X				
2. Is this research dependent on a Data Transfer or Processing Agreement with a collaborating partner or third party supplier? *If yes please provide a copy of the signed DTA/DPA*		X				
3. Has this research been approved by another (external) research ethics committee (e.g.: HREC and/or MREC/METC)? *If yes, please provide a copy of the approval (if possible) and summarise any key points in your Risk Management section below*		X				
B: Location						
4. Will the research take place in a country or countries, other than the Netherlands, within the EU?		X				
5. Will the research take place in a country or countries outside the EU?		X				
6. Will the research take place in a place/region or of higher risk – including known dangerous locations (in any country) or locations with non-democratic regimes?		X				
C: Participants						
7. Will the study involve participants who **may** be vulnerable and possibly (legally) unable to give informed consent? (e.g., children below the legal age for giving consent, people with learning difficulties, people living in care or nursing homes,).		X				
8. Will the study involve participants who **may** be vulnerable under specific circumstances and in specific contexts, such as victims and witnesses of violence, including domestic violence; sex workers; members of minority groups, refugees, irregular migrants or dissidents?		X				
9. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children, own students or employees of either TU Delft and/or a collaborating partner organisation)? *It is essential that you safeguard against possible adverse consequences of this situation (such as allowing a student’s failure to participate to your satisfaction to affect your evaluation of their coursework).*		X				
10. Is there a high possibility of re-identification for your participants? (e.g., do they have a very specialist job of which there are only a small number in a given country, are they members of a small community, or employees from a partner company collaborating in the research? Or are they one of only a handful of (expert) participants in the study?		X				
D: Recruiting Participants						
11. Will your participants be recruited through your own, professional, channels such as conference attendance lists, or through specific network/s such as self-help groups	X		**Their information can be found and connected to the data collected.**	Only the gender, age will be asked during the data collection. The data will be stored on a different devices than where the participants are recruited from.		
12. Will the participants be recruited or accessed in the longer term by a (legal or customary) gatekeeper? (e.g., an adult professional working with children; a community leader or family member who has this customary role – within or outside the EU; the data producer of a long-term cohort study)		X				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
13. Will you be recruiting your participants through a crowd-sourcing service and/or involve a third party data-gathering service, such as a survey platform?		**X**				
14. Will you be offering any financial, or other, remuneration to participants, and might this induce or bias participation?		**X**				
E: Subject Matter *Research related to medical questions/health may require special attention. See also the website of the CCMO before contacting the HREC.*						
15. Will your research involve any of the following: • Medical research and/or clinical trials • Invasive sampling and/or medical imaging • Medical and *In Vitro Diagnostic Medical* Devices Research		**X**				
16. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants? *If yes see here to determine whether medical ethical approval is required*		**X**				
17. Will blood or tissue samples be obtained from participants? *If yes see here to determine whether medical ethical approval is required*		**X**				
18. Does the study risk causing psychological stress or anxiety beyond that normally encountered by the participants in their life outside research?		**X**				
19. Will the study involve discussion of personal sensitive data which could put participants at increased legal, financial, reputational, security or other risk? (e.g., financial data, location data, data relating to children or other vulnerable groups) *Definitions of sensitive personal data, and special cases are provided on the TUD Privacy Team website.*		**X**				
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)		**X**				
21. Has your study been identified by the TU Delft Privacy Team as requiring a Data Processing Impact Assessment (DPIA)? *If yes please attach the advice/ approval from the Privacy Team to this application*		**X**				
22. Does your research investigate causes or areas of conflict? *If yes please confirm that your fieldwork has been discussed with the appropriate safety/security advisors and approved by your Department/Faculty.*		**X**				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
23. Does your research involve observing illegal activities or data processed or provided by authorities responsible for preventing, investigating, detecting or prosecuting criminal offences *If so please confirm that your work has been discussed with the appropriate legal advisors and approved by your Department/Faculty.*		**X**				
F: Research Methods						
24. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places).		**X**				
25. Will the study involve actively deceiving the participants? (For example, will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study).		**X**				
26. Is pain or more than mild discomfort likely to result from the study? And/or could your research activity cause an accident involving (non-) participants?		**X**				
27. Will the experiment involve the use of devices that are not 'CE' certified? *Only, if 'yes': continue with the following questions:*		**X**				
• Was the device built in-house?						
• Was it inspected by a safety expert at TU Delft? *If yes, please provide a signed device report*						
• If it was not built in-house and not CE-certified, was it inspected by some other, qualified authority in safety and approved? *If yes, please provide records of the inspection*						
28. Will your research involve face-to-face encounters with your participants and if so how will you assess and address Covid considerations?	**X**		Covid	Keep distance from the participant and clean the device used for the survey after each use.		
29. Will your research involve **either:** a) "big data", combined datasets, new data-gathering or new data-merging techniques which might lead to re-identification of your participants **and/or** b) artificial intelligence or algorithm training where, for example biased datasets could lead to biased outcomes?		**X**				
G: Data Processing and Privacy						
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (eg: obtaining Informed Consent or disbursing remuneration)	**X**		**The informed consent could be linked to the data collection.**	The informed consent should be stored separately from the research data.		

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and **what other Personal Research Data** (including personal or professional views) will you be collecting?	X		The data collection could be linked to the consent form.	The informed consent should be stored separately from the research data.		
32. Will this research involve collecting data from the internet, social media and/or publicly available datasets which have been originally contributed by human participants		X				
33. Will your research findings be published in one or more forms in the public domain, as e.g., Masters thesis, journal publication, conference presentation or wider public dissemination?	X		**Re-identification of participants.**	The thesis will not contain personal data. The personal data that is collected will be destroyed at the end of the research project.		
34. Will your research data be archived for re-use and/or teaching in an open, private or semi-open archive?		X				

H: More on Informed Consent and Data Management

__NOTE:__ You can find guidance and templates for preparing your Informed Consent materials) here

Your research involves human participants as Research Subjects if you are recruiting them or actively involving or influencing, manipulating or directing them in any way in your research activities. This means you must seek informed consent and agree/ implement appropriate safeguards regardless of whether you are collecting any PIRD.

Where you are also collecting PIRD, and using Informed Consent as the legal basis for your research, you need to also make sure that your IC materials are clear on any related risks and the mitigating measures you will take – including through responsible data management.

Got a comment on this checklist or the HREC process? You can leave your comments here

IV. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

Name of Corresponding Researcher (if different from the Responsible Researcher) (print)
Vera Smolders

Signature of Corresponding Researcher:

Date: 09/01/2023

Name of Responsible Researcher (print)

Signature (or upload consent by mail) Responsible Researcher:

Date: 16/01/2023

V. Completing your HREC application

Please use the following list to check that you have provided all relevant documentation

Required:

- **Always:** This completed HREC checklist
- **Always:** A data management plan (reviewed, where necessary, by a data-steward)
- **Usually:** A complete Informed Consent form (including Participant Information) and/or Opening Statement (for online consent)

Consent form

BioDesign for Darkness: the potentials of bioluminescence for the TU Delft Campus

The goal of this project is to find out how bioluminescent algae can be integrated within lighting design to foster urban nightscapes on the TU Delft Campus.
This study is part of a graduation project from the Faculty of Industrial Design Engineering at the TU Delft. The graduation team from the TU Delft consists of Vera Smolders (Graduating student), Prof. Dr. E. Karana (Chair), and Prof. Dr. S.C. Pont (Mentor).
You are being invited to participate in this research study, which is an online survey on location (Mekelpark). The purpose of this study is to learn how people perceive the lighting on campus in four different places in relation to the qualities they believe to be important for comfort, safety, preference and interest.
The data that is collected during the study consists of rating of different scales, open comments if you think of something, and pictures of the study conducted. The data will be used for analysis of the lighting qualities. Later on the research findings resulting from the analysis will be published as a thesis.
We will be asking you to rate different Linkert scales on 4 different locations in Mekelpark and you can provide open comments.
As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. The data that is collected from the survey will be stored on a hard drive, the consent form will be stored separate from the other data.
Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions at any time.

Best,
Vera

1. I have read and understood the study information dated […./..../……..], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: [rating scales, providing open comments, completing the survey when given consent]	☐	☐
4. I understand that the information I provide will be used for [Data analysis and stakeholder communication]. The following parties will be involved: The TU Delft and the graduation team. The data will be: Presentations, thesis report, visuals/images, plots/graphs.	☐	☐
5. I understand that personal information collected about me that can identify me, such as [gender, age, nationality], will not be shared beyond the study team.	☐	☐
6. I understand that the (identifiable) personal data I provide will be destroyed after the end of the project.	☐	☐
7. I give permission for the de-identified data that I provide to be archived in the TU Delft repository so it can be used for future research and learning.	☐	☐

Signature

I have read the information / the information has been read to me and I understand the content of the study. It is clear that I have the right to withdraw at any time from the study without it having consequences. This includes the right to request that my data be deleted.

______________________________ ______________________________ _________

Name of participant [printed] Signature Date

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

______________________________ ______________________ _________

Researcher name [printed] Signature Date

Study contact details for further information: Vera Smolders

Appendix C. Brainstorm

Interaction

- How might we create interactive exhibits or activities that incorporate the material?
- How might we create an immersive experience for users that incorporates the material?
- How might we use the material to create a unique and memorable experience for users on the TU Delft campus?
- How might we attract people to discover the material (design)?
- How might we spark an interest in people?
- How might we create desire to experience and discover the material?
- How might we use bioluminescent algae for wayfinding in Mekelpark?
- How might we emphasize the material's qualities?

Experience/ meaning

- How might we increase the awareness on light pollution with the material?
- How might we make the design represent naturalness?
- How might we create a connection between the users and nature in the dark?
- How might we emphasize the material's livingness?
- How might we communicate that the material is delicate?
- How might we create a design with the material that will make people appreciate nature/ darkness?

Darkness

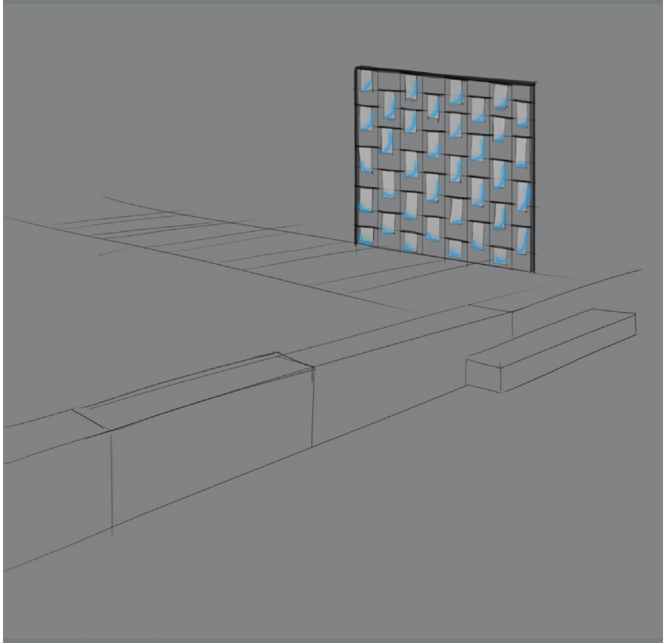
- How might we create a sense of safety for users / make people feel safe in the dark?
- How might we use the material to enhance the sensory experience of users in the dark?
- How might we make the design a place that people want to go to in the dark?
- How might we surprise people in the dark that will make them feel safe and comfortable?
- How might we use the material to create a sense of mystery and intrigue in the dark?
- How might we change people's view on darkness and outdoor lighting?
- How might we invite more people into the park / use the park?
- How might we make the dark a fun place?

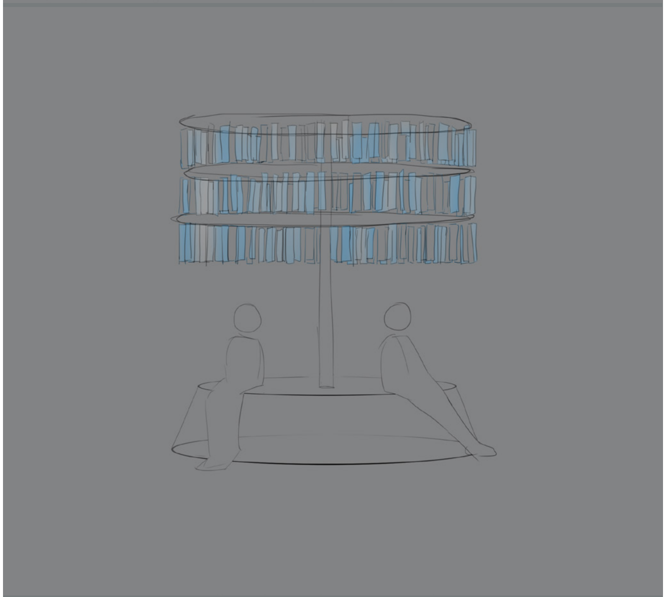
Others

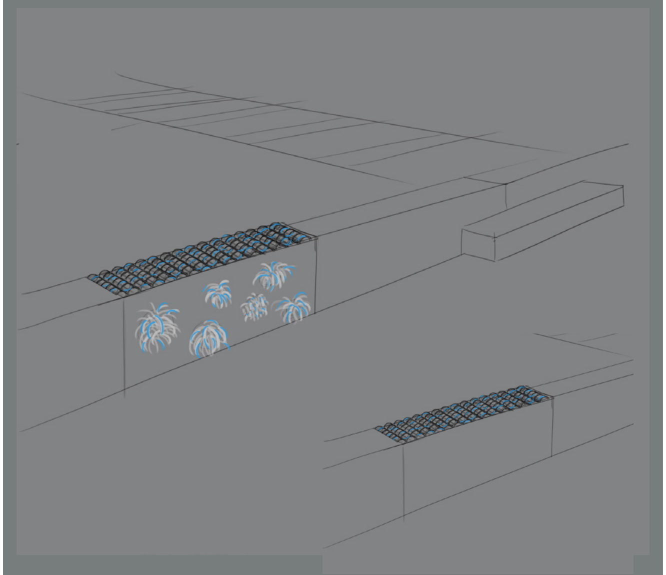
- How might we create a design that also serves a purpose during the day?
- How might we integrate bioluminescent algae into the existing architecture and infrastructure of the TU Delft campus?
- How might we create a design which can be replicated in other places and spaces?

Appendix D. Ideas

See the next page for the Intemised Response method on the ideas.







Concept 1
An installation that consists of multiple panels with bioluminescent algae, the panels are in rows and are alternating. The panels are attached on a rod so it is able to rotate.
Idea: The panels swing back and forth because of the wind. Users can also make the panels swing.

Iteration 1: The panel should be longer on the bottom side of the rod to increase the area to which the wind can blow to make it swing
Iteration 2: Instead of square shaped it could be the shape of the algae and on the inside disk could be used.

Evaluation
+ Responds to the wind and people that swing the panels.
+ It could be intriguing during day light.
– It does not have a connection to nature or organic shapes.
– It is not very playful.
– It might be unclear what people could do to trigger the algae.
– Maybe the panels would need a lot of algae.
! How could it look more organic and represent something natural?

Concept 2
A round bench with in the middle a pole on which several rings are attached that are hanging above the bench. On the sides of the rings there are silicone tubes hanging down, which are filled with bioluminescent algae.
Idea: The wind or people can make the tubes sway in which the light will appear.

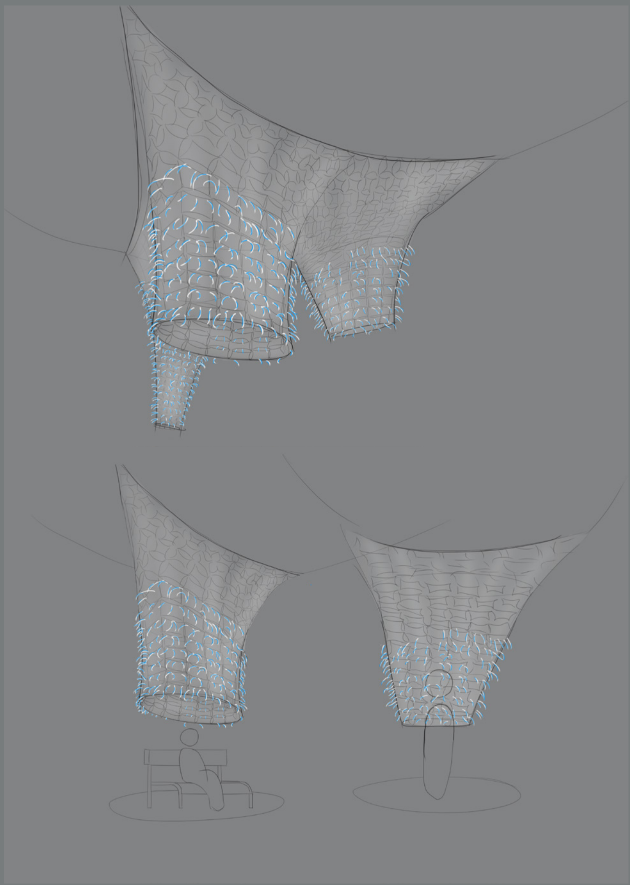
Iteration 1: To make the bench more interactive the rings can be turned. This way the tubes will receive more force and the light will be activated.
Iteration 2: To make the bench represent more natural/nature another ring is added, this way it resembles more a sea anemone.
Iteration 3: Instead of plates, tubes could be used since these are often used in the biolab and thus at hand.
Iteration 4: Instead of the silicone tubes, they could be a harder plastic, this way the artefact acts as a wind chime. During daylight it would then also have an interesting aspect to it.

Evaluation
+ Responds to physical movement of people that give the rings a swing or the tubes.
+ The bench could be intriguing even during day light.
+ Acts as a wind chime stimulating more senses than only sight and touch.
– It might be unclear what people could do to trigger the algae.
– Maybe the tubes would need a lot of algae.
! The tubes could be smaller, so it would need less algae.
! What if it was not a bench?

Concept 3
A bench where the seating area consists of multiple disks that roll when you move over the bench. The disks are integrated with bioluminescent algae. The light is thus activated when you move over the bench back and forth.
Idea: The user sits down on the bench and moves sideways to activate the light.

teration 1: At the bottom of the bench there could be silicone patches that look like coral which are also integrated with the algae. This way your legs also activate a part of the bench in a playful way.
Iteration 2: The bench could be made by only adding a top part to the current structure of Mekelpark. This way we make use of what is already there and only adding a part to enhance the experience.

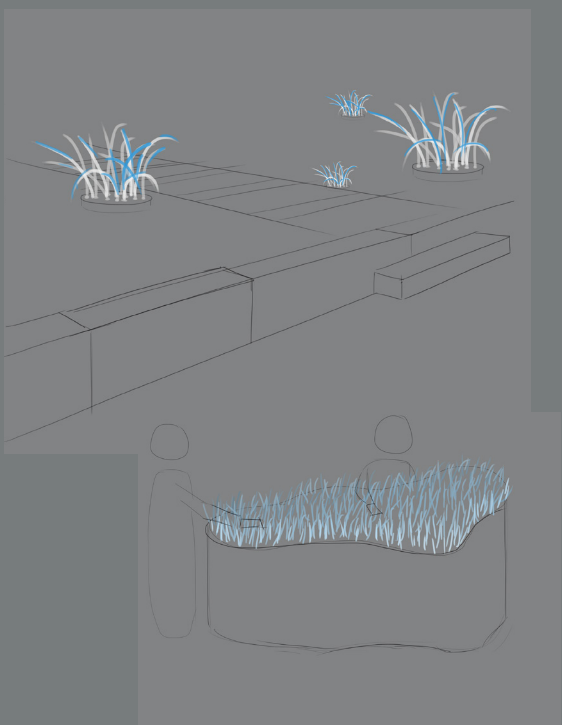
Evaluation
+ Responds to physical movement of people that are sitting down.
+ The bench could be intriguing even during day light.
+ It can be added on top of the current infrastructure of Mekelpark.
+ Feels like a massage.
– It might be unclear what people could do to trigger the algae or see it since they are sitting.
– Maybe the disks would need a lot of algae to work.



Concept 4
Plastic panels attached to create funnel shapes, on the outside there are silicone tubes attached to the panel which are filled with a liquid culture. The silicone tubes can be played with to activate the bioluminescent light.
Idea: the user can activate the light by playing with the tubes. Because the fishnet is lightweight the wind can also cause it to move.

Iteration 1: Underneath the funnel a bench could be placed, this way you can look up into the funnel as if you are looking at the night sky.
Iteration 2: The funnel could have the silicone tubing on the inside as well.
Iteration 3: You can step into the funnel and be surrounded by the bioluminescent light. This way the experience is immersive.
Iteration 4: The panels are changed to recycled fishnets. This way, the fishnets have a new purpose and they are strong and lightweight to withstand weather.

Evaluation
+ Responds to movement of people, easily triggered, could also be done by the wind.
+ Slowing people down, look at it as if you are looking at the night sky.
+ You can look at it from a distance but also submerge yourself into it.
+ Association with nature, formgiving is natural and organic.
+ It looks intriguing even during day light.
– It might be unclear what people could do to trigger the algae.
– Maybe the artefact is too big in size, it would use a lot of algae.
! How would it be on a smaller scale?
! How would it be if it was not a net but more a sturdy structure?



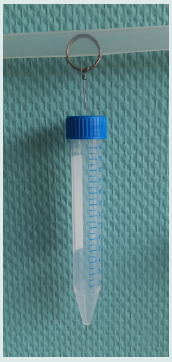
Concept 5
Several big patches of silicone tubing with bioluminescent algae integrated, resembling coral.
Idea: Users can walk through the patches, touch the tubes, play with it.

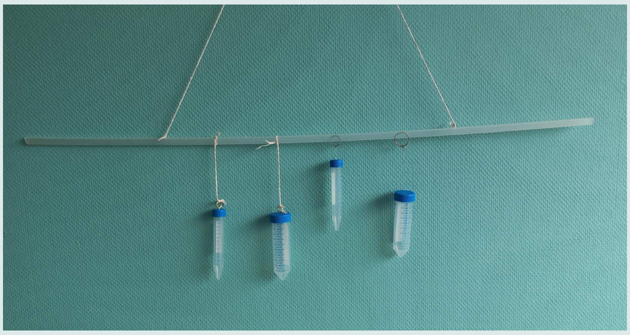
Iteration 1: Can make the top part out of silicone to show the light. The other part could be another type of material. This way it saves on using a lot of liquid culture.
Iteration 2: Instead of several small patches it could be a larger one, as if you are walking through a coral field (reef).
Iteration 3: Instead of it being big size it could be small sized, so you run your hands through the silicone tubes. This way it also saves liquid culture.

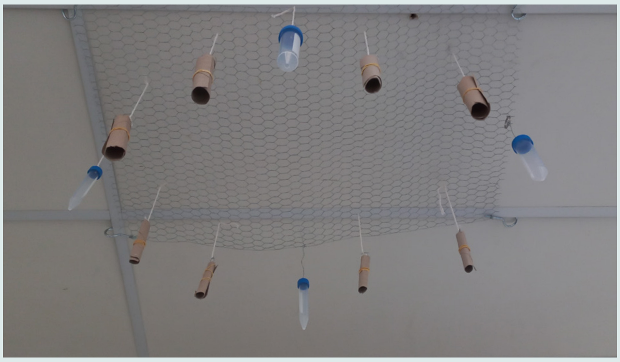
Evaluation
+ Responds to physical movement of people that go through on big scale and the smaller scale. It could also respond to wind.
+ It could be intriguing during day light.
– It might be unclear what people could do to trigger the algae.
– The big scale could be more easily destroyed.
! Would hand size be interesting to passerbyers?

Appendix E. Prototyping

For concept 2 a first simple prototype was made with metal wire and a keyring to hang on to the plastic bar. The movement that came out of this combination was a kind of a wiggle. Therefore, I changed the wire for a rope and the ring to a screw eye, which was screwed into the cap. This movement was much more flowing when you would move the tube. In figure X an overview of the different tubes hanging on a structure can be seen, this was to test the movement and see their differences.

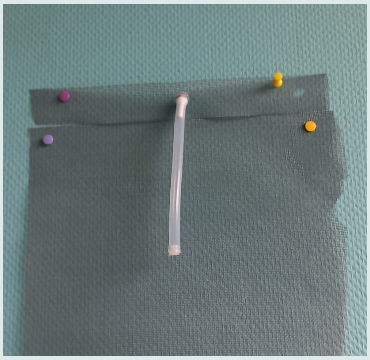
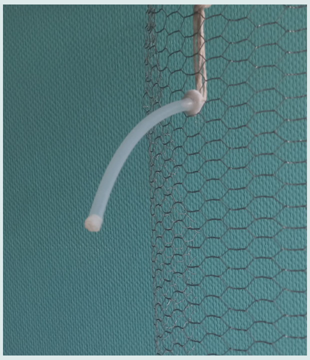


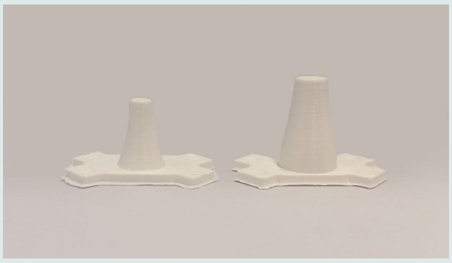


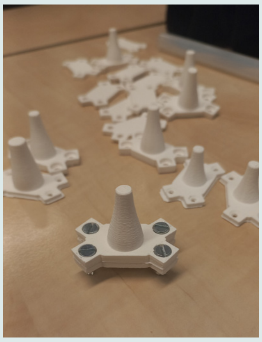


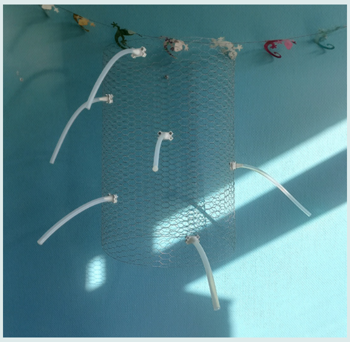
For concept 4 a first try out with the silicone tubes was done with the towel hangers in the bathroom, it was similar to what the tubes would need if they were hanging. This was also a good way to see if the tubes needed support pointing up, forward or pointing down, but also to see what kind of shape the support needs to be. Below are three different shapes, but quite similar, one 3D printed and 2 normal ones. The first one is a thicker round support, here the thicker tube (11 mm) fitted best around it. The second is smaller on the top and runs out thicker towards the bottom. Here the smaller tube (... mm) also fitted well, but the shorter tube would stand up instead of hang, even when water was added to the tube. The last is the 3D printed one, both the tubes fitted but the longer smaller tube would hang too much.

After these first test, the question was how the tube can be attached to a net or wire frame. With a golf pen and a hole in the mesh screen a first try was done. The mesh started hanging forward and the pen was not fixated. The mesh is so small that it is difficult to create a structure that would be fixated without it hanging a lot or ripping the structure.
The wire frame is much sturdier and can be shaped easily in any shape you want, and it wiggles if you would hang it on ropes or wires.
A first setup was made to look what kind of structure would fit this wire frame and where the points should be for fixing it.

To create a more rigid structure that can hold the tube and attach it to the wire frame, a 3d part was created. Two 3d prints were created to hold the silicone tube to the wire frame. The front part contains a cone shaped part that holds the tube and a base plate with holes for screws/bolts to be attached to the wire frame. The back part contains of a base plate with holes for the nuts. From figure X it can be seen that the silicone tube (d11) just fits, but it slides off because there is not enough surface area to grip on. A redesign was made where the bottom and top circle diameters are made larger and the curve that the conical shape is made convex at the bottom for more grip.

However for the smaller tube the small cone works well. For creating a prototype both will be used to compare the interaction and how the bioluminescence reacts.
You can see that the bigger tube fits around the bigger cone, but it does not align with the back plate. A redesign was made to both fit the smaller and bigger tube, and increase the size of the holes so the 3d prints can be attached with nuts and bolts.

The redesign for the attachment of the tubes was used on a bigger scale wireframe so more tubes could be attached and mimic the idea better for user testing. To close off the other end of the silicone tube, from the 3D model here above a mould is made from the pin part by 3D printing. The mould is used to pour in silicone to create a silicone stop.

The mould is prepared by sanding it down, hairspray for a protection layer and then a layer of Vaseline for easy demoulding. Since the mould is quite small, I taped it to the table so it would not move or tip over. The clamp is used to keep the mould together when the silicone is injected.