MASTER THESIS

ILLUMINATE & ELEVATE.

DESIGNING A LIGHT INSTALLATION FOR HOFBOGENPARK, ROTTERDAM

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Delft University of Technology
Faculty Industrial Design Engineering
Master Integrated Product Design

TUDelft

ATELIER LEK
ONAFHANKELIJK LICHTONTWERP

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Delft, March 2025

Preface

This master thesis is the result of a graduation project for the master Integrated Product Design. The project was completed under the supervision of Atelier LEK and the TU Delft, during which I worked one day a week as a graduate intern at the studio.

This project began with a simple question: How can we make cities feel more human? Living in an urban environment, I often feel the tension between the fast pace of city life and the calming pull of nature. Parks have always been a place where that tension seems to ease, a feeling of getting back to our roots.

Through this project, I wanted to explore how design could amplify that feeling. Using light as a medium, I sought to create something that not only draws people into these spaces but also gives them a reason to hang around, to reflect, and to reconnect.

This report captures my journey—from inspiration to challenges, and ultimately to a design I hope can make urban life just a little bit more brighter and connected.

Summary

This thesis explores the design and development of a light installation for Hofbogenpark in Rotterdam. The main goal was to create a biophilic light(ing) environment within this context, taking into account the desired interaction/experience: reconnecting visitors of the Hofbogenpark with eachother and with (the surrounding) nature.

Before starting the design process, extensive research was done on the qualities of light, the psychology of light and the perception of light (Appendices A,D,E). This research provided a strong foundation for understanding how light influences us and can shape experiences. By exploring how light interacts with different materials and forms and how it affects spatial perception, the project was able to integrate these insights into the design choices. In addition, research on the biophilia theory and forming my own opinion about biophilic design has been an important aspect of the design (Chapter 4).

After an analysis of the meaning and influence of public space over time, a qualitative study on values/needs and motivations for Hofbogenpark visitors was conducted (Chapter 5). From this research, the most important key drivers were extracted to subsequently form a design vision:

*I want to **support** urbanites **reconnecting** with both the **natural world** and **each other**, by creating a **relaxing, nature-inspired break** from the city that **enhances** social connections.*

Experimenting and prototyping was essential to the design process because it helped to refine the concept. Every iteration, from preliminary drawings to tangible prototypes, advanced my knowledge of how forms and materials respond to light and motion (caustics/dichroic foils). These practical experiments influenced important design decisions, guaranteeing that the final installation takes into account the desired interaction and experience (Chapter 6).

Chapter 7 presents the final design: Illuminate and Elevate features dichroic plexiglass canopies that respond to the movement of the sun and reflect natural forms and light, and turnable chairs that provide a place to sit down and reconnect with other visitors. The design reinforces the natural phenomenon of the changing colours of the sun/moon due to its position in relation to the earth. In the mean time it gives more colour to the Hofbogenpark and city life. This thesis ends with recommendations and a personal reflection (Chapter 8).

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Acknowledgements

Sylvia

Thank you for your support, contribution but above all, knowledge during my project. You often showed me the light (pun intended). Thank you for your trust and enthusiasm. Our meetings gave me peace of mind and a recharged feeling.

Wim

Thank you for your support and assistance. You know exactly where to provoke me and bring out the best in me. Our shared critical opinions and conversations about design, life and much more have been a great source of inspiration.

Iris

Thank you for your mentorship and the time you have given to embark on this adventure with me. Your boundless passion for lighting design has managed to enthuse me time and again. Thank you for your candour, taking me along in many projects. I have learned an immense amount about designing with light.

Atelier LEK

Thank you all for your contribution and the fun time with you at the studio. Gerrit-Jan, thanks for your crash courses in DiaLux, and your technical advice. Ennio, thanks for your technical insights and advice. Yvonne, thanks for the good conversations, brainstorm sessions and your experiences about darkness and light.

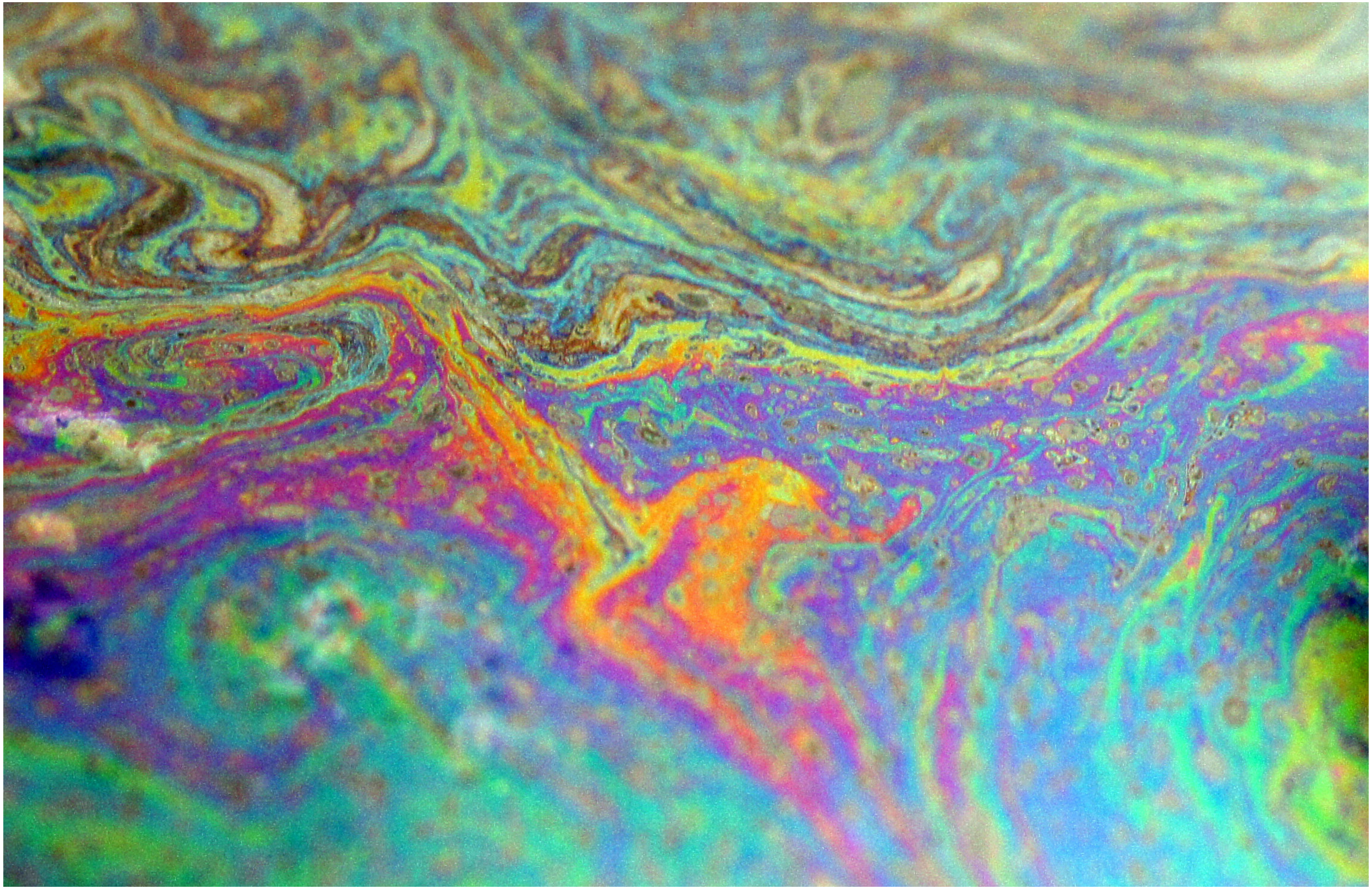
Project Partners

TU DELFT

This master thesis is the final project before graduating from the master Integrated Product Design. The TU Delft have had the assessing role within the project. Next to this, the TU Delft provided me with valuable support through the guidance of my chair Sylvia Pont and mentor Wim Schermer, with whom I had regular meetings.

ATELIER LEK

The project is commissioned by Atelier LEK. Atelier LEK is an independent design studio founded by Iris Dijkstra in 2003, that specializes in lighting: lighting in public spaces, lighting for the exterior and lighting for the interior of buildings. Iris had an important guiding role throughout the project.



Introduction

This master thesis is the documentation of a 28 week project that focuses on creating a public lighting installation for the Hofbogenpark in Rotterdam. The process involved exploring how elements like light, reflection, and form could come together to create an experience that feels both natural and welcoming. The design is intended to fit into the park's environment while encouraging visitors to pause and spend time there.

I hope you will enjoy reading this thesis report.

> "In the right light, everything is extraordinary
>
> AARON ROSE

1. Project outline

In this chapter, a brief introducion will be given of the Hofbogenpark and important keyfactors will be discussed.

1.1 A monumental city icon

For almost 100 years, the “Hofpleinlijn” was a direct rail link between Rotterdam and The Hague-Scheveningen. Opened 1st of October 1908, it was the first electric railway line in the Netherlands. Mainly because of the comfort and novelty of the modern train, huge queues of passengers arose. Final destination: the beach. Partly due to the arrival of the renovated Den Haag central station, the Hofpleinlijn was permanently closed in 2010. However, in 2002, the Hofplein viaduct was designated a national monument, and has become part of the Rotterdam city identity.

Figure 1: The Hofpleinlijn in action

1.2 Innovative engineering

The building is designed with reinforced concrete. Compared to common structures made of metal, this would be cheaper. Due to the use of a viaduct structure, there was no need to build through/under the (expanding) city centre. In addition, about half of the line ran through undeveloped polder land. The viaduct over which the Hofpleinlijn ran was designed as an open structure. It soon became apparent that the spaces under the arches were attractive to rent out. Right from the construction of the first part of the viaduct, the arches were gabled and given an additional function.
However, on some stretches, the viaduct was closed. As a result, the Hofpleinlijn was for a long time a barrier in the various neighbourhoods that the aerial railway crossed, both spatially and functionally.

In recent years, the barrier that the Hofbogen formed in Rotterdam Noord has increasingly been transformed into a connecting structure, think of new shops, restaurants and places where residents can come together. ‘The Hofbogen connects’ is the motto, with which new owner Dudok summarises the ambitions for the Hofbogen.

Figure 2: Impression of Hofbogen vision

1.3 Transformation into an urban park

At two kilometres long, the Hofbogenpark will be the longest rooftop park in the Netherlands and is part of the municipality of Rotterdam's seven urban projects. The main principles are attractive public places where residents and visitors can meet, exercise and recreate. A new icon for the city that not only connects the various neighbourhoods, but also contributes to a solution for climate change (see figure 2 and 3).

The Hofbogenpark is to everyone a place that inspires, connects and invites encounters. The roof is open to everyone, both Rotterdammers, entrepreneurs and visitors/tourists to the city. When people feel connected to a city, a city lives. A connection with the history of the Hofpleinlijn is important in this as a starting point for a recognisable place.

The design of the park creates the space for a biodiverse community of people, plants and animals and keeps a well-balanced balance in the sometimes conflicting spatial needs. Plant and animal diversity is under pressure worldwide. Conservation and restoration of biodiversity worldwide are therefore essential and cities play an important role in this. All of the different needs/wants of the stakeholders (human and non-human) need to be integrated together in the context of this urban park. Therefore, this project lends itself perfectly to a biophilic design approach.

Figure 3: Impression of Hofbogen vision

"

De Hofbogen verbindt

DUDOK

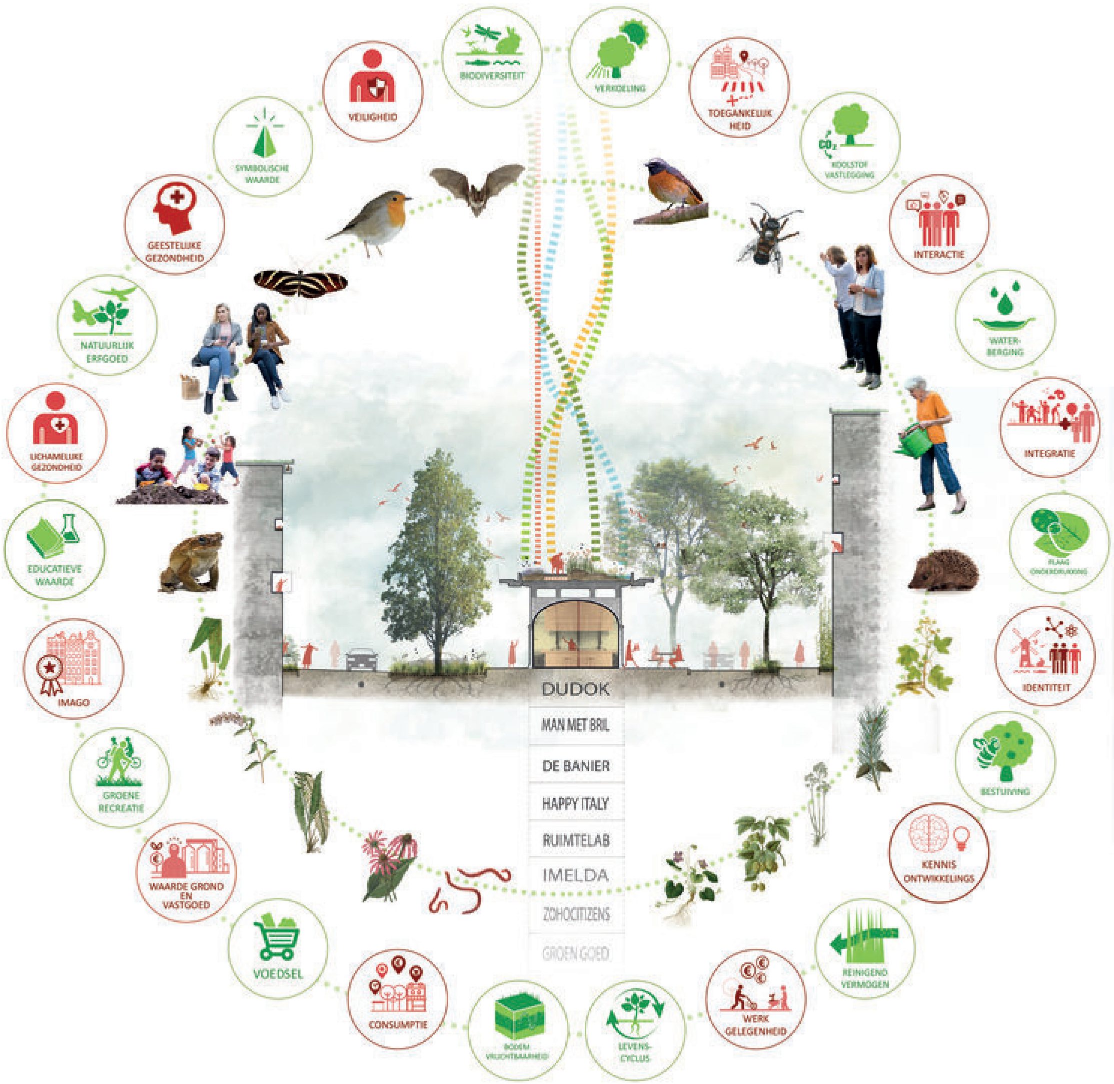


Figure 4: Overview of animals and plants at Hofbogenpark

1.4 Nature inclusiveness

Plant and animal diversity is under pressure worldwide. Conservation and restoration of biodiversity worldwide are therefore essential and cities play an important role in this. The design looks further into the space for a biodiverse community of people, plants and animals.

A thought-through balance in the sometimes conflicting spatial needs is central.
Target species are: hedgehogs, various species of bats, house sparrows, amphibians, bees and butterflies. The roof provides habitat in the form of vegetation and food for the target species. This requires a biophilic approach, not only to the roof but also, among other things, to points of ascent and good connections to the surroundings. All the different species and plants that can be found at the Hofbogenpark are displayed in figure 4.

> Hofbogenpark welcomes both people and animals
>
> DE URBANISTEN

2. Project approach

In this chapter, my initial research and starting point for this project are presented.

2.1 State of the art

All the information given in the previous chapter, serves as a starting point for my design project. In the final design plan, the park section at Hofplein Station is a pilot area, where there is space for events in addition to the functionalities of a park. (see figure 5 and figure 7 on next page). Here it is possible to experiment with public lighting installations that are in line with the identity of the Hofbogenpark.

Public lighting has significantly changed how we view and utilize urban areas at night. Most of the times, public lighting is viewed as primarily a technological problem rather than a human one, relying on mostly visual properties and excluding non-visual human experience aspects (Goncalves, 2016). In the book: " The Comfort Crisis", Michael Easters states that happiness and mental wellness is found in experiencing wild nature. We evolved in nature and therefore have been programmed within our genes a need to be in and connect with nature and living things (Kellert & Wilson, 1993). Over the past few decades the time we spend outdoors has declined by 50% (OIA, 2023). The Biophilia hypothesis (Kellert & Wilson, 1993) suggests that nature and its processes are beneficial for humans and therefore, restorative. This includes attributes like natural light and natural materials. However, academic work for these specific attributes and their link to restoration is limited (Gillis & Gatersleben, 2015).

When looking at biophilic architectural projects, like the Hofbogenpark project, they are currently dominated by the use of natural forms/materials, lighting is often still very artificial.

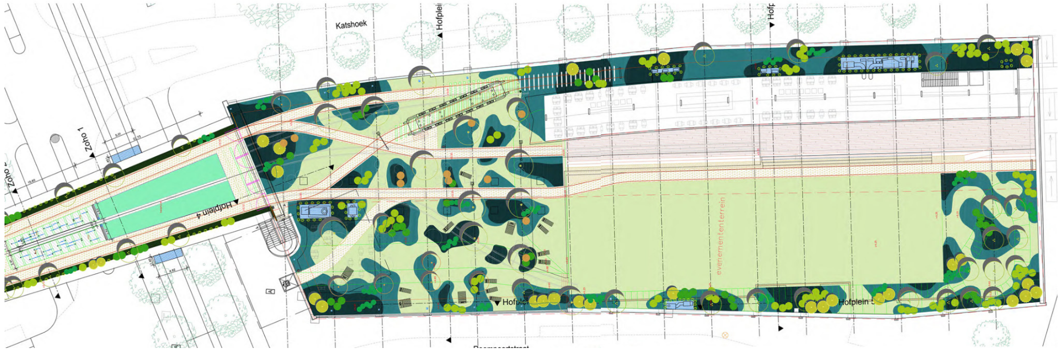


Figure 5: Redesign of station Hofplein

This situation presents an opportunity to create and research new lighting strategies and products that make (better) use of the biophilia principles to improve the relationship/interaction between users well-being and energy management in a restorative environment. Since we are visually dominant creatures (Spence, 2020), I think designing with light is the most logical step to realise this.

2.2 Project strategy

The current problem with light installations in parks/nature, is that they are mainly intended to illuminate the infrastructure for safety (Sloane & Choi, 2016), are static and do not promote interaction/playful elements (in contradiction with nature) and their design is human-centric, while plants and animals are sensitive to light in different manners. Moreover, they (and humans too) also need darkness / a regular day-night-rhythm to stay healthy.

Rahm et al. (2021) found that urban greenery and street lighting must be considered together, since their interaction influences perceived safety and impacts the walkability of mainly public parks.

Since biophilic design has been found to support cognitive function, physical health, and psychological well-being in humans (Kellert & Wilson, 1993), it will be a great starting point for a public light installation and see if it is possible to create a luminaire that contributes to a sense of safety. Therefore, this project will have the following 2 research questions:

- What function does public space, in this case Hofbogenpark, have for residents of a city?
- Is it possible to create a biophilic light(ing) environment within this context, taking into account the desired interaction/experience: reconnecting visitors of the Hofbogenpark with eachother and with (the surrounding) nature.

2.3 Stakeholders

This project has several stakeholders, who have knowledge and can make decisions in different areas. It is important that I include all these parties in my design process. The overview of stakeholders can be found in figure 6. This is done using a power-influence matrix.

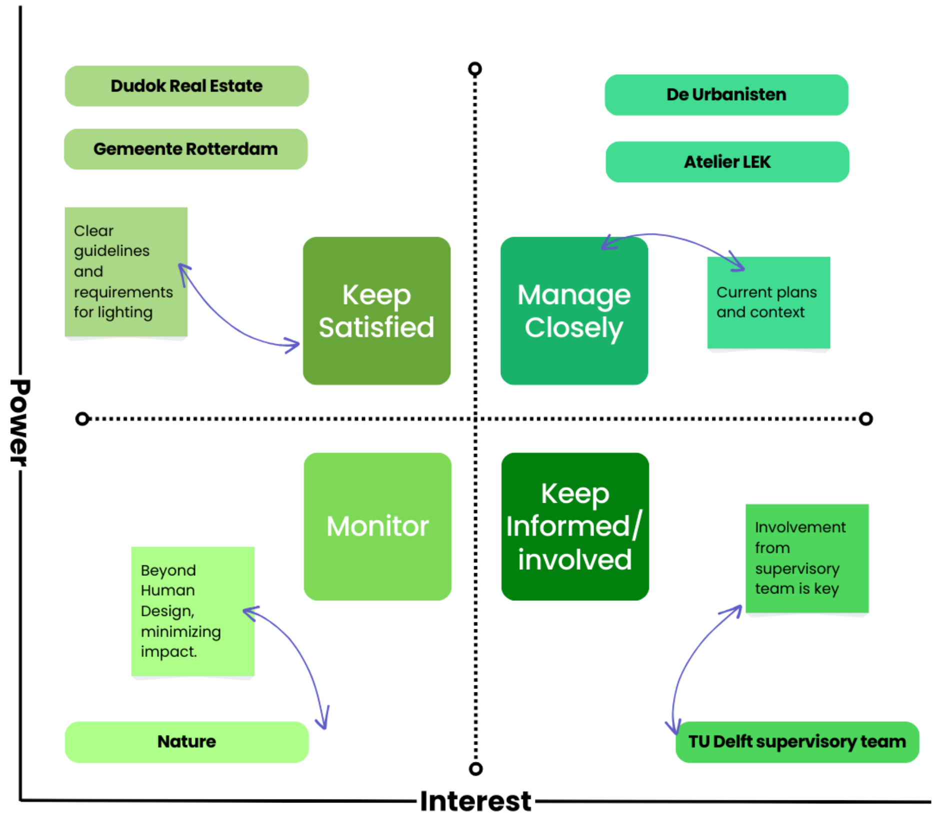


Figure 6: Stakeholder diagram

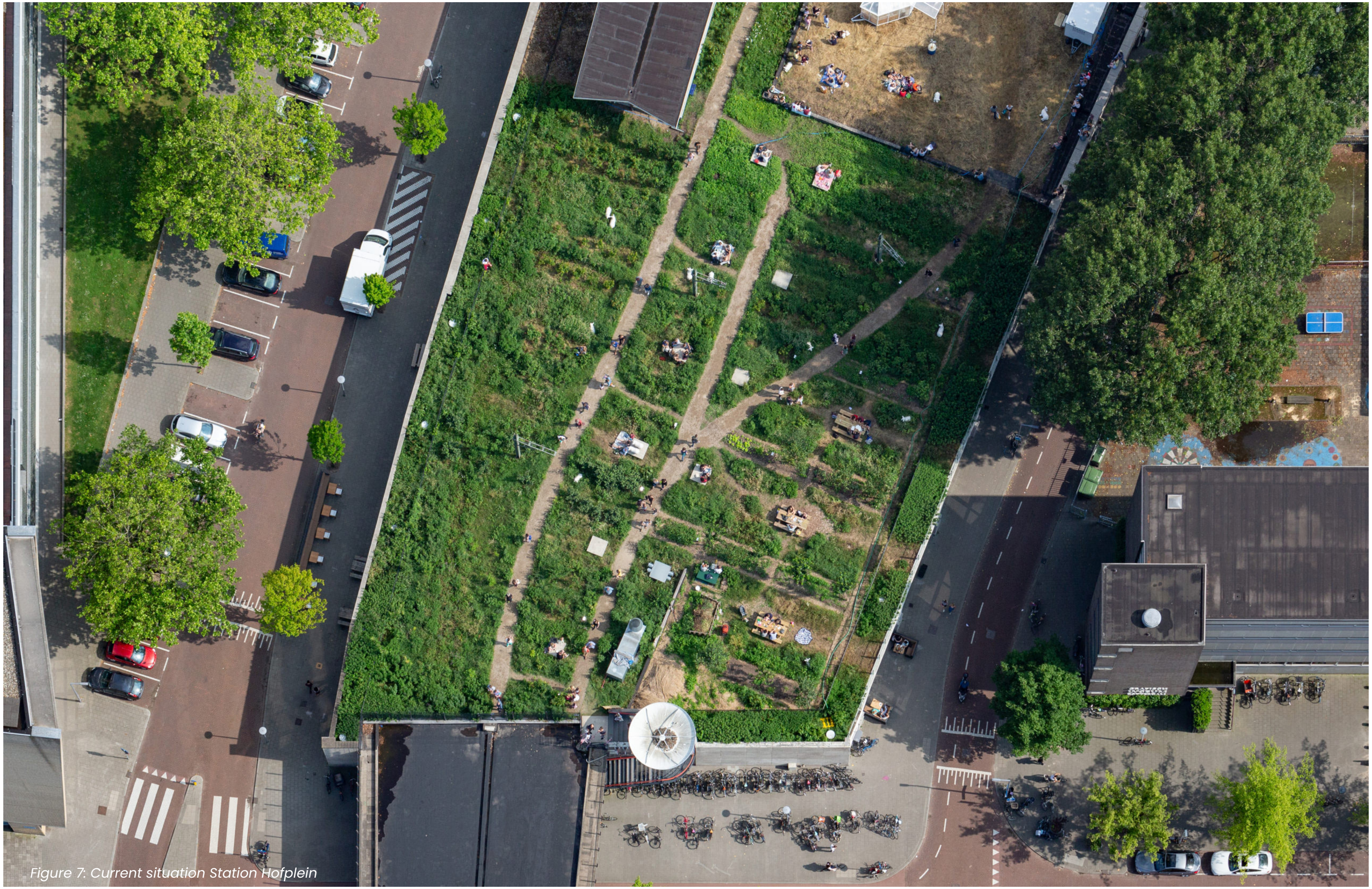


Figure 7: Current situation Station Hofplein

3. Public lighting

This chapter dives deeper into the evolution of public lighting and the main functions of public lighting. In the second part of this chapter, relevant trends for the future of public lighting will be discussed.

3.1 The evolution of public lighting

Simple torches and oil lamps, which were primarily used to light the streets and public areas in larger or smaller settlements, were the first types of public lighting in Europe. These early lighting technologies produced very little illumination and were comparatively rudimentary and inefficient. The Spanish city of Cordoba installed oil lamps along its streets to provide nighttime illumination in the ninth century, marking the establishment of the continent's first public street lighting system. They provided a limited amount of light, primarily serving as markers to guide pedestrians and vehicles along the streets during the night.

One significant new development in public lighting technology at the beginning of the 1800s was gas lighting. In 1807, London became the first city in Europe to install gas streetlamps, and other cities quickly followed. Because gas lighting was much brighter and more efficient than previous types, it gained popularity as a representation of modernity and advancement.

In most urban areas, electric lighting had become the norm for public lighting by the early 1900s. Compared to gas lighting, electric lighting was again far brighter, more dependable, and allowed for more adaptable and effective lighting schemes.

Numerous European cities have taken the lead in conducting research on the application of lighting to improve public safety and well-being, switch to energy-efficient lighting in public areas (e.g. LED).

3.2 Main functions of public lighting

Public lighting is part of the public space. The public space is a physical space that is accessible to everyone. The government is the owner of this public space and therefore largely takes responsibility. The main functions of public lighting are:

- Increasing road safety
- Increasing objective and subjective safety
- Increasing quality of space

Increasing road safety
Road safety is the measure of how safely people can move about in public areas. Every road user has different requirements/wishes for proper lighting and routing. Visibility is often the most important criterion.

Increasing objective and subjective safety
Objective safety can be described as the actual number of risk of road accidents/robberies/ injuries, while subjective safety is the feeling of perception of safety, i.e. how people experience accident risk in traffic (Sørensen & Mosslemi, 2009). Public Lighting is very important when it comes to improving both objective and subjective safety. Good public lighting reduces vandalism, burglaries, theft and violence and can positively influence subjective safety by improving the atmospheric perception of an area (Mitre-Becerril et al., 2022).

Increasing quality of space

Public lighting shapes people's perceptions of and interactions with their surroundings, which can greatly improve spatial quality. Especially at night, well-designed lighting enhances safety and visibility while promoting social interaction and enhancing the appeal of public areas. In addition, it can draw attention to architectural details, improve the visual appeal of cities, and establish a feeling of place through ambiance and mood. More on this and the psychology of light can be found in Appendix A.

3.3 Public lighting trends

The market for public lighting is undergoing numerous changes due to the development of LED technology, telematic monitoring, the increasing need for safety in urban areas, intelligent controls, and the fusion of monitoring and lighting.

- **Smart lighting systems:** networked streetlights with sensors and Internet of Things (IoT) capabilities that change light levels in response to real-time information about things like ambient light, traffic volume, and pedestrian activity. These devices can increase security while using less energy.

- **Interactive and adaptive lighting:** Certain cities are experimenting with lighting that adjusts to the needs of users, for example, dimming in places with little traffic or turning on when someone approaches. This improves user experience and energy efficiency.

- **Beyond human lighting:** an emerging trend in public lighting that emphasizes the balance between illumination and darkness to create healthier, more sustainable environments for humans and nature (eco-friendly lighting) This approach aims to minimize light pollution, reduce energy consumption, and preserve the natural night sky/nocturnal life while still ensuring safety and functionality in public spaces.

- **Aesthetic and artistic integration:** Colour-changing lights, projection mapping, and artistic installations that strengthen a city's cultural identity are just a few of the ways that public lighting is being used to create dynamic urban environments in addition to its intended use.

- **Light as a social tool:** Public lighting is being utilized more and more to promote engagement with the community and social interaction. Urban areas can be transformed with flexible lighting schemes for festivals, art installations, or cultural events. These environments can be made to be more welcoming to people and encourage interaction.

- **Biophilic lighting:** This design approach enhances the relationship between people and nature in urban environments by incorporating natural light patterns and materials that resemble the outdoors. It encourages wellbeing and lowers stress by using lighting that synchronizes with natural circadian rhythms, particularly in public spaces like parks or plazas.

4. Biophilic (lighting) design

The design of the Hofbogenpark creates a space for a biodiverse community of people, plants and animals and keeps a well-balanced balance in the sometimes conflicting spatial needs. Over the past few decades the time we spend outdoors has declined by 50% (OIA, 2023). However, in the book: "The Comfort Crisis", Michael Easters states that happiness and mental wellness is found in experiencing wild nature. This chapter will explain why this is, dive deeper into the biophilia theory, provide examples and will end with a personal opinion.

4.1 The biophilia theory

Biophilia is ‘the innate desire to be connected to our environment and other living things’ (Wilson, 1984). We evolved in nature and therefore have been programmed within our genes a need to be in and connect with nature and living things (Kellert & Wilson, 1993). We are visually dominant creatures (Spence, 2020), so (natural) light plays a significant role.

The goal of biophilic lighting design is to mimic the properties and advantages of natural (sun)light. More on sunlight (and moonlight) can be found in Appendix B. Biophilic lighting design supports our circadian rhythms naturally and a sense of health and well-being by imitating the dynamics and colour temperature of daylight (Alimoglu & Donmez, 2005 ; Beute & De Kort, 2014). Research by Aristizabal et al. (2021) has shown that immersive biophilic (lighting) environments can improve “users” satisfaction and cognitive performance, while reducing stress. Not only is this the case for immersive environments, but also pictures/images of nature (Ulrich & Lunden, 1990).

It is obvious that taking in natural scenery (such as figure 8) is good for your health. It’s interesting to note that even natural patterns of observation can be beneficial. Research indicates that looking at statistical fractals (patterns like beach waves, fireplace flames and dappled sunlight beneath trees) also reduces stress (Hägerhäll et al., 2015).

In addition, natural light can take on visually pleasing shapes and forms through creative interactions between light and shadow, diffuse and variable light, and the incorporation of light with spatial properties, going beyond simple exposure (Kellert et al, 2015). However, biophilic design should never be implemented in a fragmented or disconnected way; rather, it should create an integrated ecological whole (Kellert et al, 2015).

Despite the importance of each of these advantages, there has been worry that the biophilic reactions may wane with repeated exposures. However, Biederman (2006) found that viewing a biophilic image, such as a Japanese garden, sustains approximately the same level of interest over time. According to more recent studies; recurring exposures actually improve positive physiological and psychological responses (Determan et al. 2019).

The basics of the biophilic design framework consist of three kinds/ways of experiencing nature. An overview can be seen in table 1.

Direct Experience of Nature	Indirect Experience of Nature	Experience of Space and Place
• Light • Air • Water • Plants • Animals • Weather • Natural landscapes and ecosystems • Fire	• Images of nature • Natural materials • Natural colours • Simulating natural light and air • Naturalistic shapes and forms • Evoking nature • Information richness • Age, change, and the patina of time • Natural geometries	• Prospect and refuge • Organized complexity • Integration of parts to wholes • Transitional spaces • Mobility and wayfinding • Cultural and ecological attachment to place

Table 1: Basics of the biophilic framework

Figure 8: Natural scenary

4.2 Biophilia applied

In this sub chapter, some examples of biophilic (lighting)design projects are shown. In the next chapter, I will give my opinion about these projects and on the biophilic design approach as a whole.

Park Pavilion De Hoge Veluwe: light chandeliers by Beersnielsen
The requirement that the entire building be an essential component of the park's landscape and experience was a major consideration in the project's design. The incorporation of natural light and shadows from the forest into the building has been a key component of the chandelier design. Thus, savouring the calming effects of nature for a little longer. It simulates the shadow play of a light wind passing through tree leaves. This is a great example of biophilic design, which integrates natural elements into the intrerior built environment.

Sunne: Marjan van Aubel Studio
The sun is shaped like the edge of space. Sunne Rise, Sunne Set, and Sunne Light are the three settings on the lamp that replicate every natural sun moment. With photovoltaic cells installed, the light collects solar energy during the day and turns on at night, particularly when it is positioned in front of a window or in direct sunlight. Its brightness and battery level are correlated to provide the longest possible glow. How long the light glows depends on how much sun the day before. In this way, the lamp reconnects us to the sun directly.

Figure 9: Biophilic light chandeliers by Beersnielsen

Figure 10: The Weather Project by Olafur Eliasson

Figure 11: Sunne by Marjan van Aubel Studio

The Weather Project: Olafur Eliasson

This site-specific installation was made for Turbine Hall of Tate Modern in London. It used a ceiling of mirrors, a semi-circular screen, and fake mist to create an artificial sun. Eliasson's choice of mono-frequency lamps produces this warm, synthetic sunlight. You get the impression that you've entered a different world because of the dreamy atmosphere created by the lights and mist combined. It's an immersive experience and conversation starter rather than just a piece of art. Eliasson claims that we frequently forget about nature in the rush and bustle of city life, and he hopes that this installation will help us rediscover it.

4.3 Personal view on biophilic design

Current definitions of biophilic design often feel limited and too theoretical, missing the core of what it can really mean for people in everyday environments. I want to avoid being influenced during my design process by existing concepts and terms by sharing a my opinion that leaves more room for creativity and a deeper, more meaningful connection between people and not people and nature. With this, I hope to start a discussion on how we can continue to renew this design principle and make it more relevant to the challenges of today and in the future.

My definition of biophilic design is: Design and architecture that brings humans (and animals) closer to nature and environmental roots. Our entire evolution is based on day and night rhythms/cycles. We as humans have disrupted this rhythm. Not only for ourselves, but also for nature itself. Designing light, especially in the evening, comes with a great responsibility that I think is rarely reflected. Biophilic design has to carry social sustainability with it and for that, collaborating with site-specific communities is so hugely important. Biophilic design should always be integrated into the whole, just like nature. There, too, are few if any separate links.

Biophilic design should inspire and feel natural. The natural stimulates us in many ways. We face unpleasantness, such as bad weather and darkness. In my opinion, darkness is a subject that deserves more attention and should also be preserved.

The challenge within biophilic design lies in the fact that you are trying to create something that is not everyone's reality. As a lighting designer, you have a responsibility to give confidence to people not to get intimidated by the elements of nature. I also think too little thought is still given to the impact of biophilic design on the environment. You create an artificial nature that is bound to affect the environment. This can be done in a positive way, by stimulating, inspiring or teaching people about our roots with nature, but also in a negative way, through overexposure etc.

In Chapter 7, where I present my final design, I reflect and describe how I included biophilic design in my design process, and how this is reflected in my final design.

5. Influence of public space

In this chapter, the influence of public space, specifically the Station Hofplein, will be researched. In addition to a literature review about how the meaning of public space changed over time, a qualitative research is conducted. This chapter will end with a strategic design vision that will be the starting point for the next phase.

5.1 Research approach

To structure this chapter, one main objective was drawn up beforehand:

Understanding the current urbanite park go'er lifestyle, their key values and mindset, in order to get useful information on the cultural meaning of the Station Hofplein.

To answer this main goal, two sub-research questions were devised. The two sub-research questions are:

- How did the meaning of public space and its influence on urbanites change over time?
- What are the overlapping values/motivations and needs for urban living park go'ers, and how does this come back in their everyday behaviour and other parts in their life?

Desk research was conducted as a first step to come up with an answer to the first sub-research question. This gave a lot of insight into the meaning and influence of public space and how it changed overtime. In addition, interviews were conducted with urbanite park go'ers. All the findings were compared with the literature research and based on this a conclusion was drawn.

5.2 Meaning and influence of public space over time

Historical public spaces
Public spaces such as the Roman forum or the Greek agora functioned as the hub of civic life in ancient cities. They served as multipurpose platforms for social interaction, business dealings, and political discussions, representing the democratic ideals of the era. These areas were crucial for community cohesion, governance, and public participation.

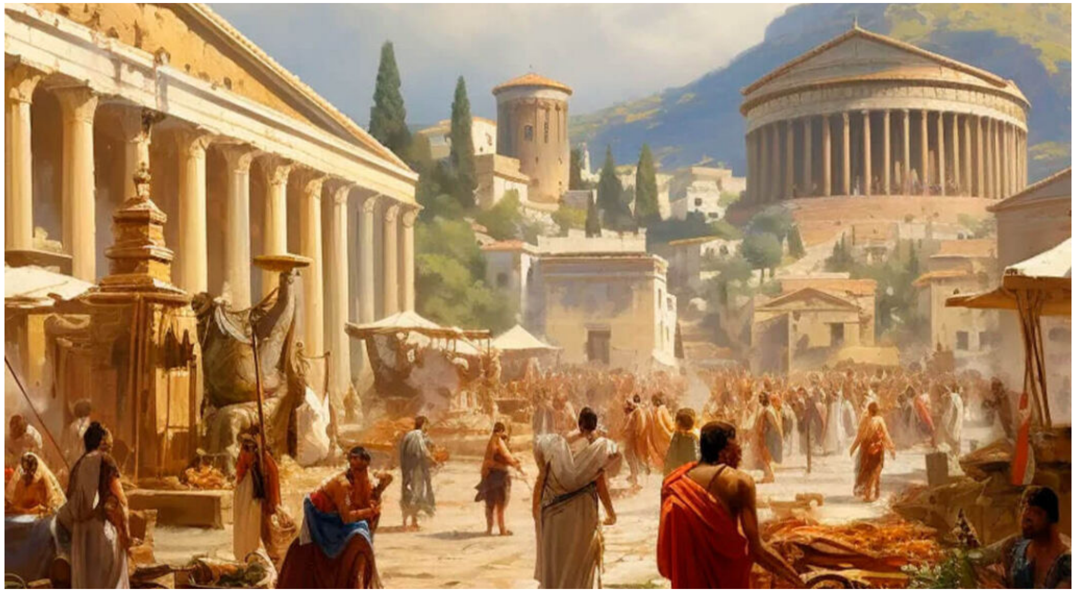


Figure 12: A Greek agora, the hub of civic life in ancient cities

Urbanization and industrialization
Land became privatized and cities became denser as a result of the 19th-century industrial revolution. Public areas lost importance and were frequently ignored or reduced to serving utilitarian purposes like marketplaces or transportation hubs. However, the need to relieve urban stress and enhance public health led to the introduction of parks (such as Central Park in New York) in response to the congested and dirty conditions of industrial cities.

Urban planning: 20th century
Modernist architects like Le Corbusier prioritized zoning that divided residential, commercial, and industrial areas viewing public space more functionally. Skyscrapers were usually accompanied by expansive, open plazas that, because of their size and lack of human-centred design, were often underutilized. Public spaces lost their historical significance as thriving hubs of social life and became more utilitarian.

Figure 13: Central Park in the 19th century

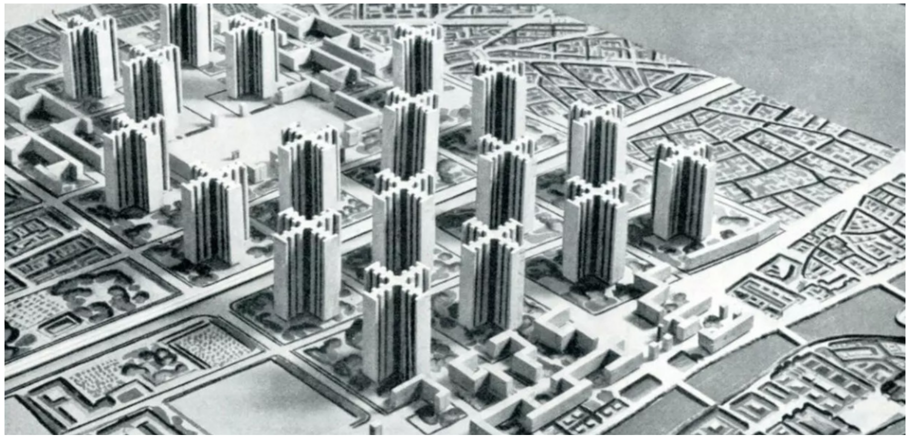


Figure 14: 20th century urban planning, “Towers in the park” by Le Corbusier

Taking back public space

Urban planners such as Jane Jacobs renewed the focus on human scale of cities by the late 20th century. She promoted mixed-use areas that promoted social interaction within the community and emphasized the importance of public spaces in developing thriving, liveable cities (Jacobs, 1961). According to Jacobs: “Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody.”
Public spaces were becoming more and more important for social well-being, leisure, and cultural life, as evidenced by the growth of pedestrianization projects (growing importance of side-walks), green space revitalization initiatives, and city square revitalization.

Modern public areas

Public spaces are now viewed as venues for expression, diversity, and civic engagement in addition to being places for leisure and socializing. Public spaces are being designed to accommodate diverse groups, promote accessibility, and foster community building in response to the growing emphasis on inclusivity and quality of life (Ellis and Roberts, 2016; Hagerty et al., 2001). In this era, research has shown that nature in the city can also enhance the physical, psychological, and social well-being of urbanites (IUCN, 2018; Calvo, 2010; Shanahan et al., 2015; Forest Service, 2018).

Figure 15: Jane Jacobs promoting liveable cities

Figure 16: One Green Mile by MVRDV in Mumbai

Public space of the future
Future-focused design of public areas will prioritize adaptability and sustainability. With the help of green infrastructure (such as rain gardens and urban forests), they are now helping to combat climate change (Peinhardt, 2021; Orsetti et al., 2022). Additionally, adaptable designs will make it possible to host a variety of events, such as markets and cultural gatherings.

Although most research focuses on creating parks and public areas that are more aesthetically pleasing and physically useful, the effects of these attributes on users' psychological sense and general well-being have not received enough attention in literature. Understanding the process of creating an affective bond between individuals and particular locations, including emotion, meaning, and behaviour, has received less attention (Manzo and Devine-Wright, 2014; Manzo and Perkins, 2006; McCunn and Gifford, 2014). Essentially, as urban populations' needs and values change over time, public spaces have evolved from purely functional areas to dynamic, inclusive settings that promote social interaction, urban liveability, and sustainability.

Figure 17: Public space of the future

5.3 Values and needs for urbanite park go'ers

The reasons for visiting a certain place can be divided into push and pull factors (Dann, 1981). Push factors include family or relaxation, sports and novelty (Cha et al., 1995). Pull factors are described as factors (motivations) that attract you to a certain place (Dann, 1981).

The motivations for visiting parks naturally vary among visitor. For many visitors, the benefits of being in contact with nature are the main draws. People want to be in environments with clean air (Gashu et al., 2020; Irvine et al., 2013); they want to enjoy the weather (Kruger and Saayman, 2010); they want to see the beauty of the land, plants, and animals (Chiesura, 2004; Shariff et al., 2020; Tsantopoulos et al., 2013); and they want to be in environments where it is quiet (Irvine et al., 2013).

Individuals' social needs are also satisfied by parks. Research indicates that people who visit parks tend to spend time with their friends and family (Kruger and Saayman, 2010; Chiesura, 2004; Gashu et al., 2020; Terkenli et al., 2017); they also look for locations that offer kid-friendly activities (Gashu et al., 2020). Additionally, it has been observed that park visitors look for chances to relax (Chiesura, 2004; Gashu et al., 2020; Sheriff et al., 2020); and enjoy themselves (Tsantopoulos et al., 2013; Sheriff et al., 2020).

Numerous additional studies revealed that the primary motivation for visiting urban parks was relaxation (Chiesura, 2004). According to Andriotis (2011) and Chiesura (2004), some park visitors went there to escape their daily life routines, while others went there to take a break or engage in individual activities like reading (Irvine et al., 2013).

As can be seen, many studies have looked into the motivations behind park visits. Kruger and Saayman (2010) found, however, that even when the product (e.g. park) is the same, visitor motivations may vary. For that reason, a qualitative study was done with visitors of the Hofbogenpark (near Hofplein).

The most important results can be found in figure 18. The research approach for this qualitative study can be found in Appendix C.

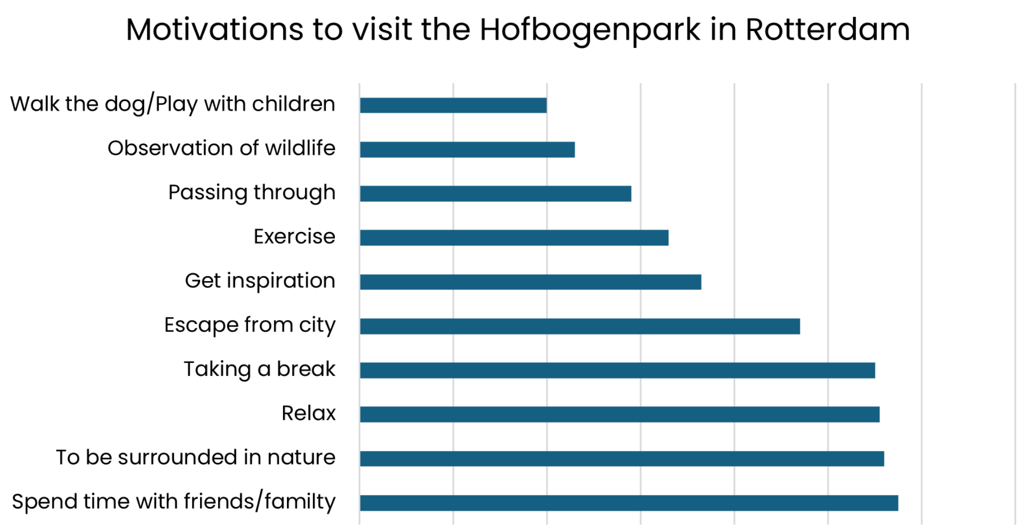


Figure 18: Results qualitative research

Some interesting answers from the interviews afterwards are stated below:

"The Hofbogenpark is a beautiful spot in the middle of the city, great contrast to the rest of the city. Very nice, because the city is busy, and this is an oasis of calm."

"The park gives the feeling of being away from the city for a while."

"I often look for places to retreat, I am easily overstimulated, especially in the city."

"It is very inspiring to see nature growing, I have noticed that people lose connection with nature because of technology, I would like to stay in touch with where I came from."

"I don't have a garden, so use the park as a collective garden. I often cook at home and then eat together in the park, like an extended room."

"I find that I work/perform better when I have been in nature for a while, which is why I think taking a break is so important."

"Being with family and friends recharges me, we live for the people we know. Sharing things: experiences, food, music, knowledge."

5.4 Creating a vision

From this research, I extracted the most important key drivers to subsequently form a design vision/ frame using Kees Dorst's frame innovation method.

The key drivers that served as starting point for my vision are: Nature, Escape from the City, Community and Connectivity. These values were found during the qualitative interview with the participants. The biggest challenge for urbanite park-goers is that the current Hofbogenpark does not meet the needs of visitors who seek a healthy balance between nature, tranquillity, social connections and their urban work. The urbanite park-goers are looking for an escape/break from the city/want to refresh, and know from experience that seeking nature helps.

After multiple iterations I came up with the following design vision:

*I want to **support** urbanites **reconnecting** with both the **natural world** and **each other**, by creating a **relaxing, nature-inspired break** from the city that **enhances** social connections.*

Why do urbanites feel that they need a break from the city? Cities can be both inspiring and overwhelming for people. On the positive side, they offer endless opportunities to connect with others, pursue careers, and experience culture, which can enhance creativity and personal growth. Having everything at your fingertips—from restaurants to healthcare—makes life convenient and full of possibility. However, the constant rush, noise, and crowds can take a toll, leading to stress and anxiety. Many people find themselves feeling overstimulated or isolated despite being surrounded by others. Additionally, environmental factors like air pollution and higher temperatures in cities can also affect physical well-being, making urban life both a source of excitement and challenge (Schmidt, 2022; Murayama & Estoque, 2019).

With this vision, as a central thread, I enter the development phase of my design process.

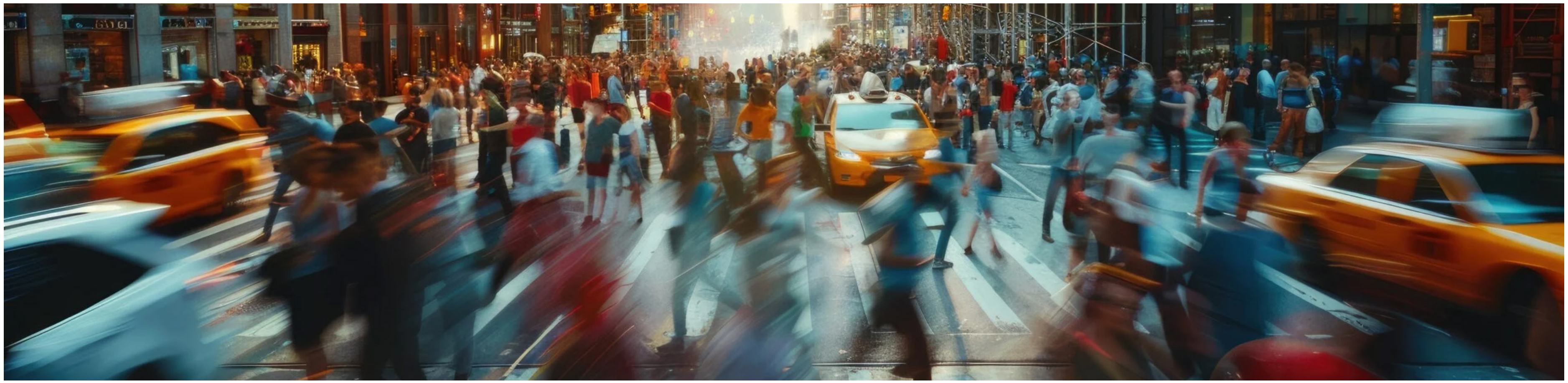


Figure 19: Overstimulated city life

6. Playing with light

Before starting my ideation phase, I first experimented with light, eventually ending up with different aspects/requirements that I can use to come up with different concepts. What light exactly is, how we percieve light and how we can control light can be found in Appendices D,E,F. Research into this provided a solid foundation for my experiments.

6.1 Experimenting with light

Based on the results of the cultural study, I came up with several domains in which I want to experiment with light. How can I combine light with natural materials? How can I highlight nature? How can I mimic/enhance the dynamic changes during the day and night?

In my first experiments, I tried combining a simple LED light with various natural materials (see figure 20). This was not exciting enough. Nature never stands still, so I experimented further with moving light effects in nature. First, I researched what effects are out there, and soon decided to limit myself to caustics. Caustics are different envelopes of light rays which have been reflected or refracted by a curved surface or object, or the projection of that envelope of rays on another surface (e.g. water surface, see figure 21).

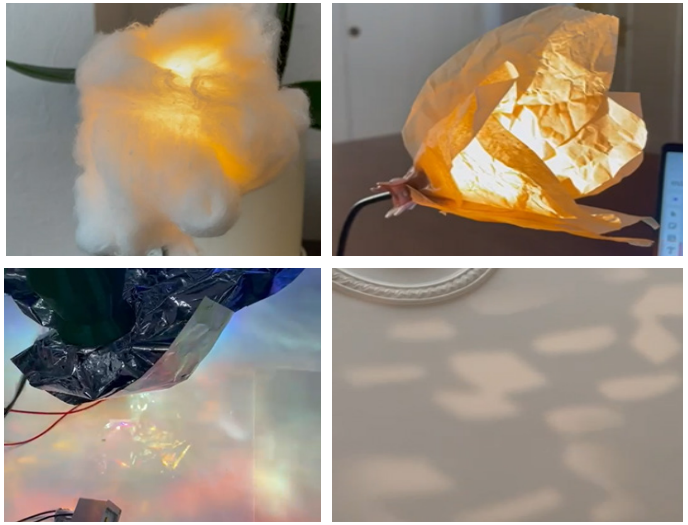


Figure 20: Light experiments

In my design scope, the two most applicable ways to create these caustics are with water or with reflective materials, such as foils/mirrors. The challenge lies in the fact that you need moving surfaces, to simulate water caustics. I have experimented with this in various ways (see figure 21).

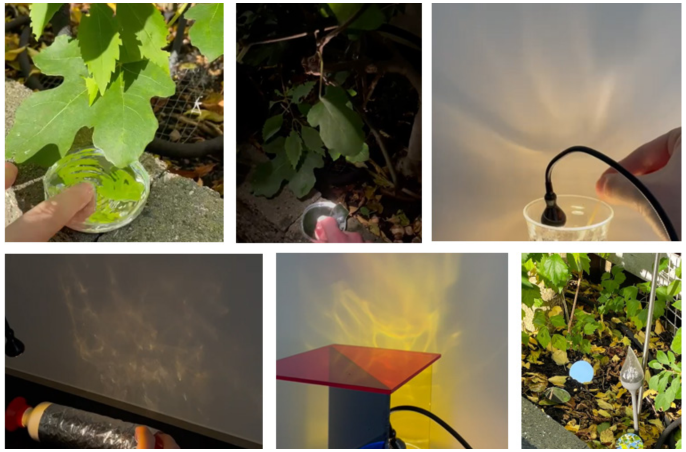


Figure 21: Light experiments

After these experiments with water, I came to the following conclusion: during the day, the caustics look interesting, it just adds an extra dimension to the environment. However, in the evening, when it is dark, the caustics are far too intense and take over, giving a very busy and chaotic effect. In the lighting lab at the faculty, I experimented with foils and prisms to get the same effects. This is where I came across dichroic films. The impressive thing about these foils is that at different angles/positions of light, there is yet another light output. This reminded me very much of light in nature, which is also never the same. By being able to use these foils, it is possible to add colour to light effects in a natural way (see figure 22 on next page).

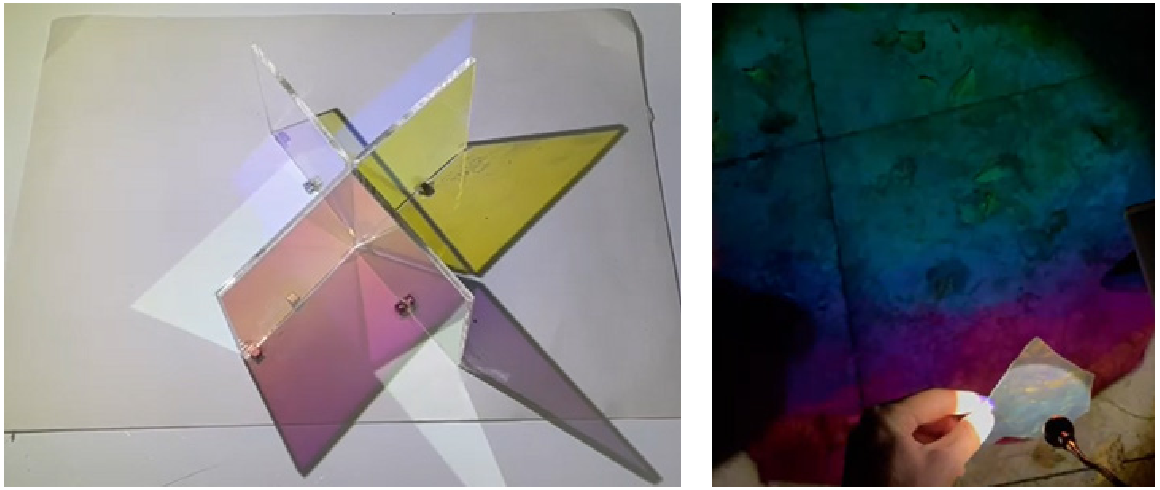


Figure 22: Experimenting with dichroic materials

In order to compare the results of my culture study, I did a small version of my research in another park in Rotterdam. This ended up being a small focus group of regular visitors to Euromast Park. Here are the main differences and conclusions: The Euromast park, is seen more as a day activity than as a (quick) break. Partly because of its location (not close to the city centre) and spaciousness, this is a place where people meet up with their children, dogs, and friends. BBQing is allowed in this park, so in summer many Rotterdammers use this as a garden. There are also several catering establishments present, so there are many people on walking dates in the park. Group exercise and runners are also present. This outcome reinforces my design vision drawn from my previous culture research, however, it made me question one very important aspect.

The Hofbogenpark, for which my design is going to be, is mostly used as a break during the day. The park is closed after 18:30, and few people are likely to be here in the evening, as dog walking is also not allowed. This made me realise that 90% of the time my design has to do with daylight. I therefore decided to mainly use natural light in my design.

In one of my first experiments after this insight, I looked at what happened when I combined dichroic mirrors with moving light (just as the sun moves from east to west). As can be seen in figure 22, this has a very interesting optical effect. So with the use of dichroic material, the sun can give different coloured shadows.

6.2 Desired interaction

It is very difficult to prototype interaction. As a starting point, I started with dark sketching light installations/interaction in the evening. I soon came to the conclusion that to reconnect the user with each other and to reconnect with nature, two types of interaction are needed. Interaction with each other (in order to reconnect), and interaction with nature (in order to reconnect).

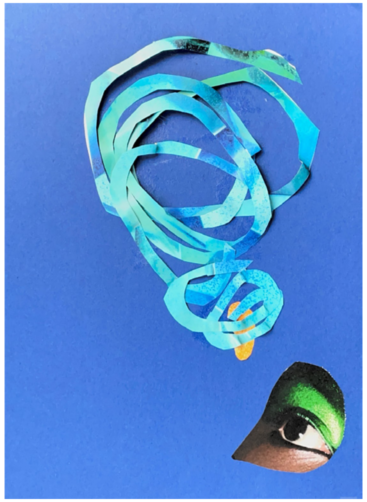
Many visitors sit in the park during their break; eating/reading/chatting mostly. By designing some form of furniture/places to sit will make it easier to facilitate interaction between users during their break. Reconnecting with each other is mostly done by having some form of communication with each other. A benchmark of existing products that do this can be found in figure 23.

Interaction with nature is another component. With the right placement of furniture, you already surround yourself in nature. However, to reconnect requires a more active form of interaction.

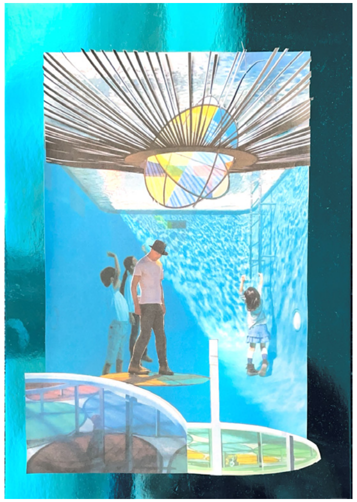
To reconnect with nature, you need to be able to 'override' the other stimuli present in that context. This is possible by designing a stimulus that is immersive and mesmerising. This lets you forget the other stimuli around you for a while. To visualise mesmerising and immersive, I created a collage for both. Following this collage, I made a final collage with public furniture items that are immersive and mesmerising (see figure 24).

Figure 23: Interactive products benchmark

Immersive



Mesmerizing



Final collage

Figure 24: Interaction collages

Each interaction has certain qualities that can lead to specific experiences and have meaning related to emotions. These emotional qualities come from how people experience and interact with my design. They are shaped by a mix of physical, sensory, and psychological factors. For the interaction I am looking for, these are:

- Calmness

A feeling of calm can be produced by utilizing reflective surfaces, light patterns, and organic shapes. Soft and fluctuating reflections of the natural light mimic well-known, calming natural phenomena like flowing water or moving leaves.

- Curiosity

The effects of shifting light attract attention and encourage exploration. Visitors are encouraged to observe subtle changes and interact with their surroundings when reflections change in response to light movement.

- Connection

Shared moments are created by the design. In addition to seeing their own reflection, visitors can also see others', which can result in impromptu conversations and a feeling of being present with others.

- Playfullness

Interactive elements, such as light responding to movement or position, make the design engaging. Therefore, making the space feel more open to exploration.

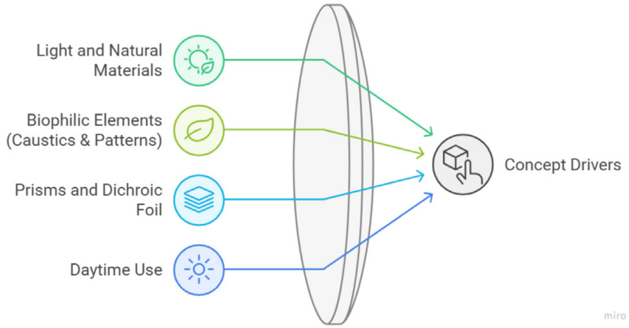
- Reflection

Like staring at water or the starry night sky, you can have a quiet moment of reflection and contemplation when you see your own shadow and reflection in changing light. It allows for a slower, more concentrated experience and room for individual interpretation.

Figure 25: (Clockwise) Calmness, Playfullness & Reflection, Curiosity, Connection

In addition, there is a natural stratification in nature. Imagine a canopy of leaves above you. Shade and shelter is an important element for public space. Humans are predisposed by evolution to seek out places where they can see but not be seen. We are naturally drawn to areas that provide a view (Prospect) but also a sense of safety (Refuge) (Akcelik et al., 2024). As shown by Whyte (1981) in his documentary: City Spaces, Human Places; the favourite spot of people to take a break is under the trees. In addition to our psychological need for shelter/shade, it also enables visitors to stay outside longer, protected from bad weather and over exposure to sun. These elements can be combined into a kind of movable/movable, shelter/shade with stencils of leaves providing a nature-inspired shade on the furniture.

Finally, as described in Appendix B, the (perceived) colour of the sun changes due to the different angles of incidence of sunlight through the atmosphere. To reconnect with nature, you want to immerse (immersive) yourself in natural phenomena. The same applies to dichroic material. The projected and reflected colour changes with the angle of incidence of light. By using dichroic material in the canopy, I enhance this natural phenomenon.



6.3 Conclusions

After the experimentation, I have come to the following conclusions/aspects, which I am going to combine into different concepts to elaborate on next.

- Majority of users visit/use my concept during the day
- I want to use dichroic material
- For users to reconnect with each other and nature, interaction is needed, a simple installation all over the park will not suffice
- I want to combine this all into a public furniture installation

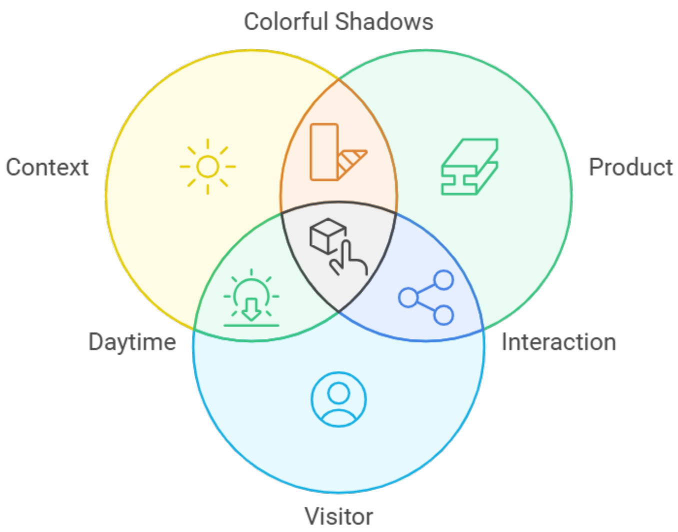


Figure 26: Concept drivers

7. Design development

In this chapter, I will first show the final design so you can see what it has become before I explain how I got there. After that, I'll go through the design process step by step, sharing the choices I made, the challenges I ran into, and how things developed along the way. This way, the design speaks for itself first, and the process helps to make sense of how it all came together. I end this chapter with a conclusion and reflection.

Figure 27: Final maquette in context

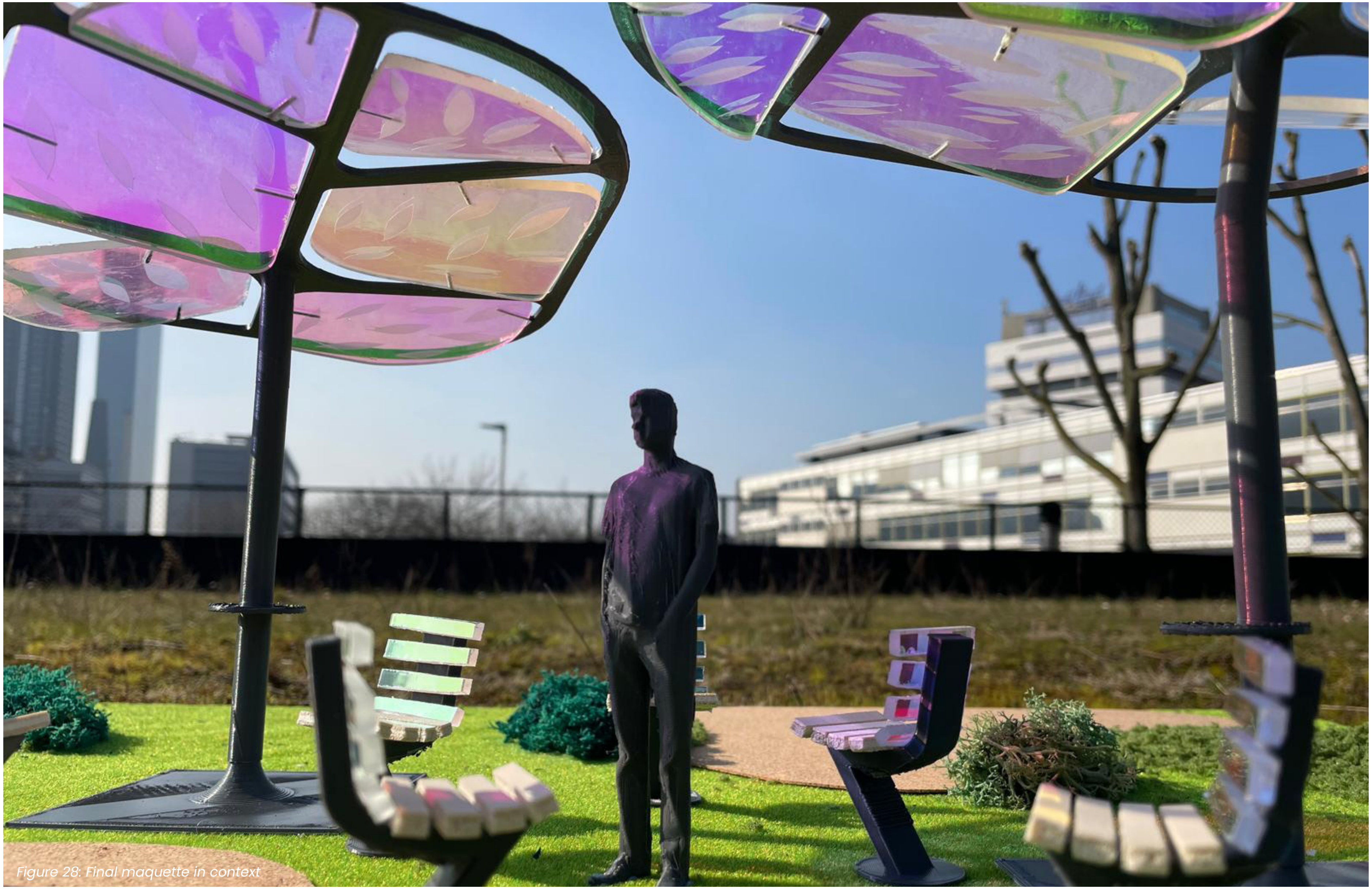


Figure 28: Final maquette in context


Figure 29: Final maquette in context

7.1 Final design

Illuminate and Elevate focuses on creating a space where urbanites/visitors can take a break from the city and can reconnect with nature and each other. It features dichroic plexiglass canopies that respond to the movement of the sun and reflect natural forms and light, and turnable chairs that provide a place to sit down and reconnect with other visitors The design reinforces the natural phenomenon of the changing colours of the sun/moon due to its position in relation to the earth. In the mean time it gives more colour to the Hofbogenpark and city life.

Figure 30: Final maquette in context

Figure 31: Final maquette in context

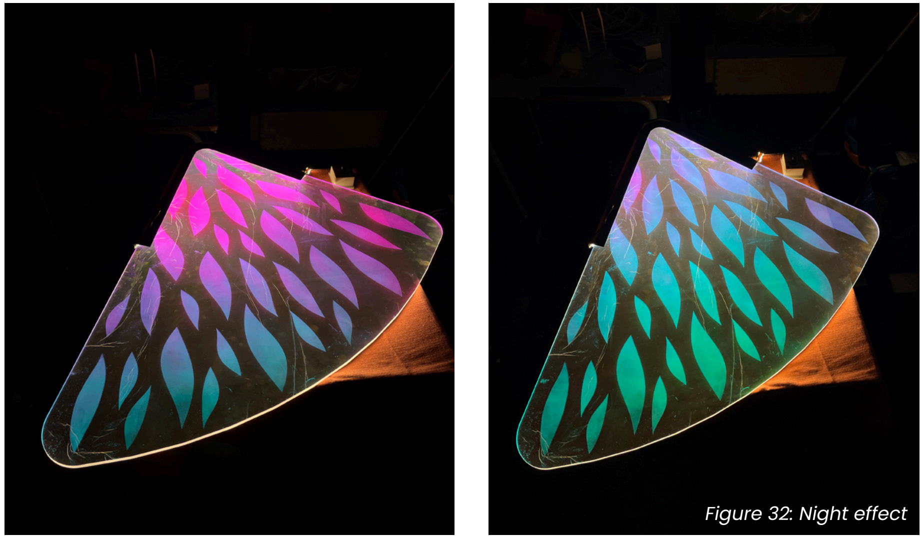


Figure 32: Night effect

Figure 33: Final maquette overview

7.2 Design details

<u>Materials and finishes</u>
The main materials for this design are steel and dichroic plexiglass. Steel provides the strength needed for an outdoor structure, while its simple look works well in a park setting. Dichroic plexiglass was chosen for its light, colourful effects, which can change based on the angle of light and viewing. This adds a playful and natural feel, echoing the change of colours of natural (sun)light (see figures 27-33). Another reason for the use of plexiglass is because it is 25 times stronger than glass and does not shatter into sharp shards, which is more safe for this context.

The steel is powder-coated in antracite to protect it from rust and various weather conditions. This also gives it a simple, non-reflective surface that doesn't compete with the dichroic light effects, and blends in well with the Hofbogen context.

The 6mm thick plexiglass panels are made up of mulitple "layers". First, the abstract leaf pattern is sandblasted onto each panel. By sandblasting the plexiglass, you create small dents in the plexiglass, so to speak. These 'dents' cause the light to refract differently at this spot, and make it look matt. If you then shine a light on it, the patterns light up. (see figure 32). Afterthat, a dichroic film is placed on the other side of the panels. Both sides are protected by another layer of protective film, which provides protection for the outdoor environment.

This combination of materials and finishes keeps the design both simple and inviting for people to enjoy.

<u>Form and aesthetics</u>
The abstract form of a leaf is represented by the design's simple, geometric shapes and easily comprehensible lines, which blend in perfectly with the park setting. The steel poles have a subtle sense of movement due to their slight 10 degree angle, which makes them resemble tree branches leaning into the wind. By tilting each plexiglass panel, you get a (more intense) light and shadow play that changes with the change of the sun's position.

The shapes and arrangement of the poles and dichroic panels are meant to create a calm and open space where people feel welcome to explore or rest, reconnecting with eachother and nature (see figure 33). The angled poles and transparent panels work with the surroundings, catching light and reflecting parts of the environment, like nearby trees, buildings and the sky. This gives the installation a somewhat unexpected or novel feel while also connecting it to the park.

Light and reflection

Both artificial and natural light are intended to interact with the installation, in a day situation and a night situation. Sunlight filters through the dichroic plexiglass panels during the day, causing the ground and surrounding surfaces to change colour with leaf patterns. These dynamic effects encourage visitors to stop and take in their surroundings by simulating natural phenomena like light passing through leaves and changing colour.

When natural (day)light is not present, the panels continue to reflect and refract light in a softer, more ambient manner thanks to subtly placed LED strip that is integrated into the structure (see figure 32). With this, there is a distinction between the day and night, which again, is a omnipresent natural phenomenon.

The plexiglass panels reflect parts of the environment, such as trees, clouds, or people walking by. As a result, the installation and the park have a soft interaction that gives the impression that it is a living component of the area. Additionally, the reflections make people pay attention to details like the shifting leaves or the shifting sky that they might otherwise miss.

Whether it's a sunny afternoon or a calm evening, the emphasis on light and reflection helps establish a connection between the visitors, the installation, and the surrounding natural elements.

Technical construction

The steel frame of the installation is held up by angled poles that are firmly fastened to the ground, however, still able to be turned 180 degrees by visitors. These steel frame is made to support the plexiglass panels' weight while remaining stable in the face of external factors like wind and weather variations. Strong, weather-resistant fittings that permit a small amount of movement to lessen material stress are used to connect the frame and panels. The LED cables are also integrated into this fitting, and functions as a custom lightprofile and mounting of the plexiglass. More on the technical construction can be found in the next chapter. Technical drawings and dimensions can be found in Appendix G.

Cost estimate

The total cost per canopy is: 18.337,41 EUR. To arrive at this rough estimate, I used the built-in costing tool in Solidworks 2024. This tool calculates with a price of 3.01 euros/kg Plain Carbon Steel, and uses a proprietary template in which manufacturing costs are automatically included and estimated. The costs for this, of course, vary by country and manufacturer. So the price is a rough estimate, since the biggest parts of the design are custom made. For a more detailed break down see Appendix H.

Biophilic design

Throughout the design process, I explored how natural elements could shape both the experience of the space and the way people interact with it. Rather than applying biophilic design principles as fixed rules, I approached them as a set of ideas to experiment with, testing how materials, light, and reflections could create a stronger connection between people and their surroundings. Some aspects were more straightforward—using reflective surfaces to capture movement and filtering of natural light. Other elements required more testing, such as how structured or organic the forms should be.

One of the biggest challenges was working within an urban environment, where the presence of nature is always shifting and sometimes subtle. I questioned whether adding certain natural effects, like reflections and materials that change with light, would be enough to create a meaningful sense of connection. I also considered how people might engage with these elements in different ways, depending on the time of day or season. Looking back, the design doesn't strictly follow a single strict approach to biophilic design, but rather a reflective process where I often referred back to this chapter during the design phase to put the main points alongside my design. Precisely because biophilc design cannot go through one kind of roadmap, it is important to remain reflective and critical of your design in its context.

In the final design, these biophilic ideas come through in both direct and subtle ways. Light plays a key role, not just as illumination but as an element that shifts, reflects, and interacts with its surroundings.

The use of caustic effects, for example, introduces a dynamic quality. These effects aren't just decorative; they create a changing atmosphere that responds to natural conditions, like the position of the sun or the presence of people moving through the space.

The materials also contribute to this connection with nature. The use of dichroic plexiglass, for instance, captures and transforms light in a way that mimics natural colour shifts, similar to how the sky changes throughout the day. Meanwhile, reflective surfaces amplify movement and interaction, creating a sense of fluidity rather than fixed structure.

The social aspect of the design ties back to biophilic ideas as well. Rather than being a passive installation, it encourages interaction, whether through the way light responds to movement, or through the placement of swivelchairs that invite people to gather, pause, or engage with their surroundings. In this way, the design is not just inspired by nature but actively recreates some of the qualities that make natural spaces feel engaging and restorative.

7.3 Design process

Before I started designing the shape of my concept, I first designed the interaction. Changing the shape can often be easier than adding another interaction. Since I decided to design public furniture, I thought the first step would be to test with users how they behave using different arrangements of chairs. The research question here was, can you influence people's (seating) behaviour by a certain chair arrangement, and does this stimulate social comfort?

Since testing different chair setups was not doable in proper context, I conducted this experiment at the faculty of industrial design engineering (see figure 34). All results and tested setups can be found in Appendix I.

The main finding of this test is that the users started turning the chair on their own. Sitting directly opposite a 'stranger' does not feel comfortable. This is why I choose to design an arrangement of movable chairs. Besides, moving a chair also gives a form of autonomy.

In the 1980s, William Whyte and his group of researchers conducted research on the use of parks and plazas in New York City. They discovered that when given the choice, people will nearly always move a chair before they sit, even if it only slightly and doesn't seem to have any effect.
Maybe people are motivated to move the seat because they feel like they have control and ownership over it, Whyte thought. That chair becomes yours when you push it forward an inch and take a seat (Whyte, 1981).

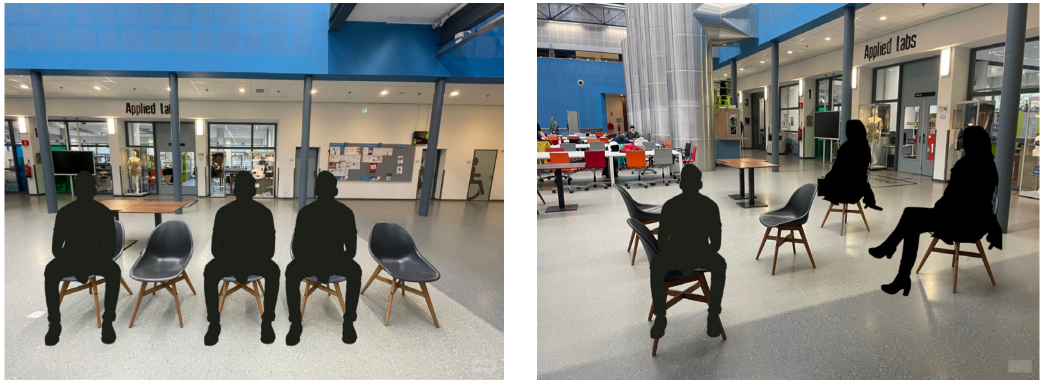


Figure 34: Testing seat configurations

In addition, seating that is accessible, comfortable, well-maintained, and located in the right places is critical to successful placemaking. Clustering public furniture attracts people and activity, and helps to increase peoples' level of social comfort. Social comfort can, in turn, help to facilitate spontaneous social interactions and activities (Project for Public Spaces, 2008).

However, completely detached furniture is not safe in the context of the Hofbogenpark. There is a high possibility that this furniture could be thrown over the railing and be stolen. While walking to the supermarket in Rotterdam, I came across already existing turnable chairs (see figure 35). I therefore decided that the furniture should be turnable instead of, completely detached. With this feature, people will still have a feeling of being in control, and increase social comfort.

Figure 35: Swivel chairs in Rotterdam

I started designing simple swivel furniture made of dichroic material. The right angles of this chair gave beautiful light play of reflections and coloured shadows. Since weather conditions are often not the same, I tested the chairs under different light conditions and surfaces (see figure 36).

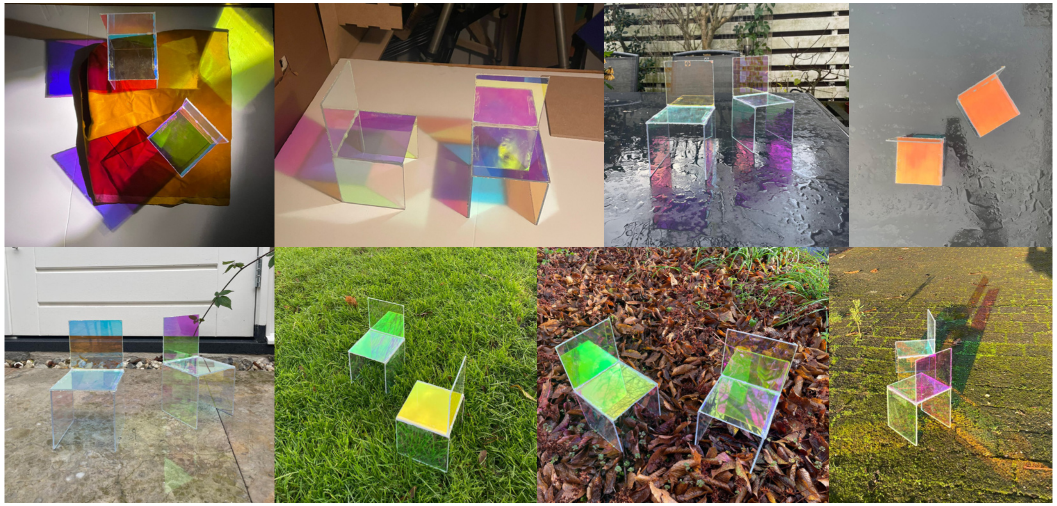


Figure 36: Testing dichroic chairs

I presented this concept in a vision and concept presentation to urban planners and landscape architects from the Municipality of Rotterdam. They saw a lot of potential in the canopy sketch and mood boards I had shown (see figure 37 on next page). Partly because of the foundation of the park, 'real' trees will not grow to maximum height. My canopy is an alternative to these trees, and fits well with the vision of the Hofbogen: "De Hofbogen verbindt". So I decided to focus on designing a canopy.

The three components that are integrated in my design are:

- Sitting comfortably
- Aesthetics
- Light effect

In addition, the canopy does not serve as protection against rain. Parks are often not visited during bad weather. Also, the current pergola also suffices as a canopy should park visitors want to take shelter from sudden bad weather.

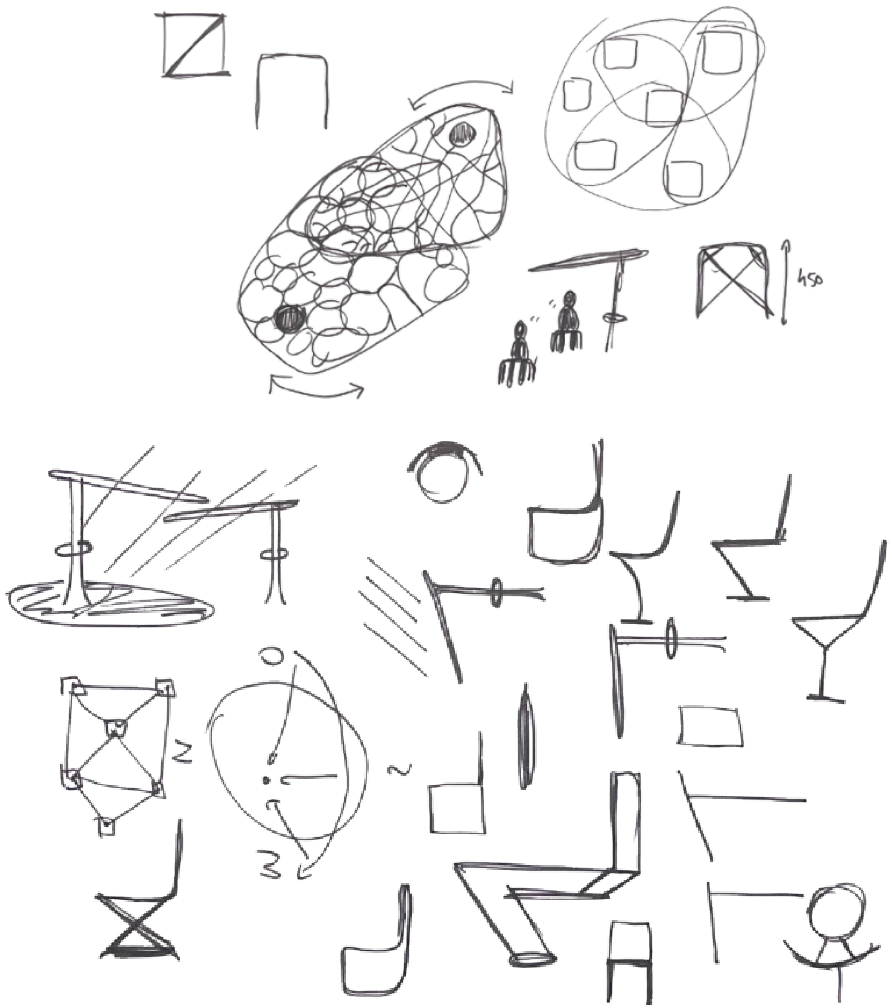


Figure 37: First canopy sketches and moodboard

Prototypes were built and tested to explore how the materials interacted with light and the swivel chairs. Different heights and angles for the poles were tested to find proportions that felt natural in the park environment.

During testing, it became clear that some initial ideas needed refinement. For example, certain angles didn't create the intended light effects, so they were adjusted.

Prototyping was an important part of the process, providing a way to learn from hands-on experiments and gradually shape the final design (see figure 39).

Steel leaf frame
The final shape of the leaf pattern went through several iterations. By experimenting with prototypes to scale, I tried to find the right ratio between abstract, geometric and organic design. The final design is assymetric with rounded shapes. This abrades the design, and keeps users captivated longer, as they try to make it 'make sense' in their heads. To me, these are hallmarks of good biophilic design.

Steel pole
For the design of the pole, I chose to keep it mostly simple for two reasons. Saving costs, as the dichroic plates and steel frame is already quite pricey, and the pole should not draw attention away from the top frame. In the overall picture, the pole has a more functional role. Visitors to the park can rotate the canopy 180 degrees using the pole. This should be able to be done in an intuitive way and this needs to be tested in a user evaluation.

Sandblasted pattern
The stencil I designed that are sandblasted onto the plexiglas sheets is an abstract combination of water and leaves. As the sun shines on this during the day, you create shadows on the ground, these remind you of sunlight shining through trees. In the evening, the shapes are lit up by the integrated light. It almost looks like a starry sky of leaves. By applying direction to the stencil, this again resembles the veins/cells of a real leaf.

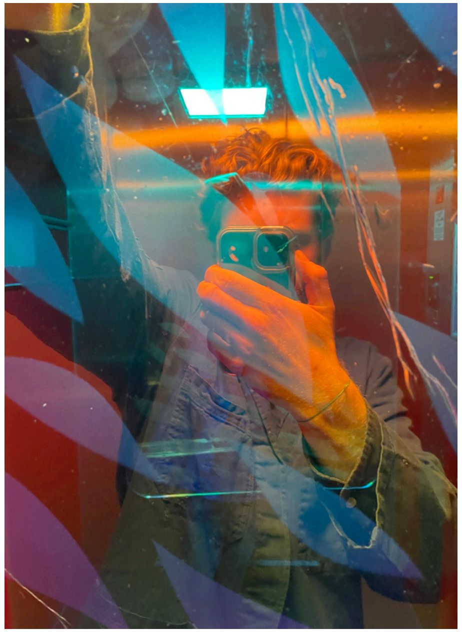


Figure 38: Sandblasting prototypes

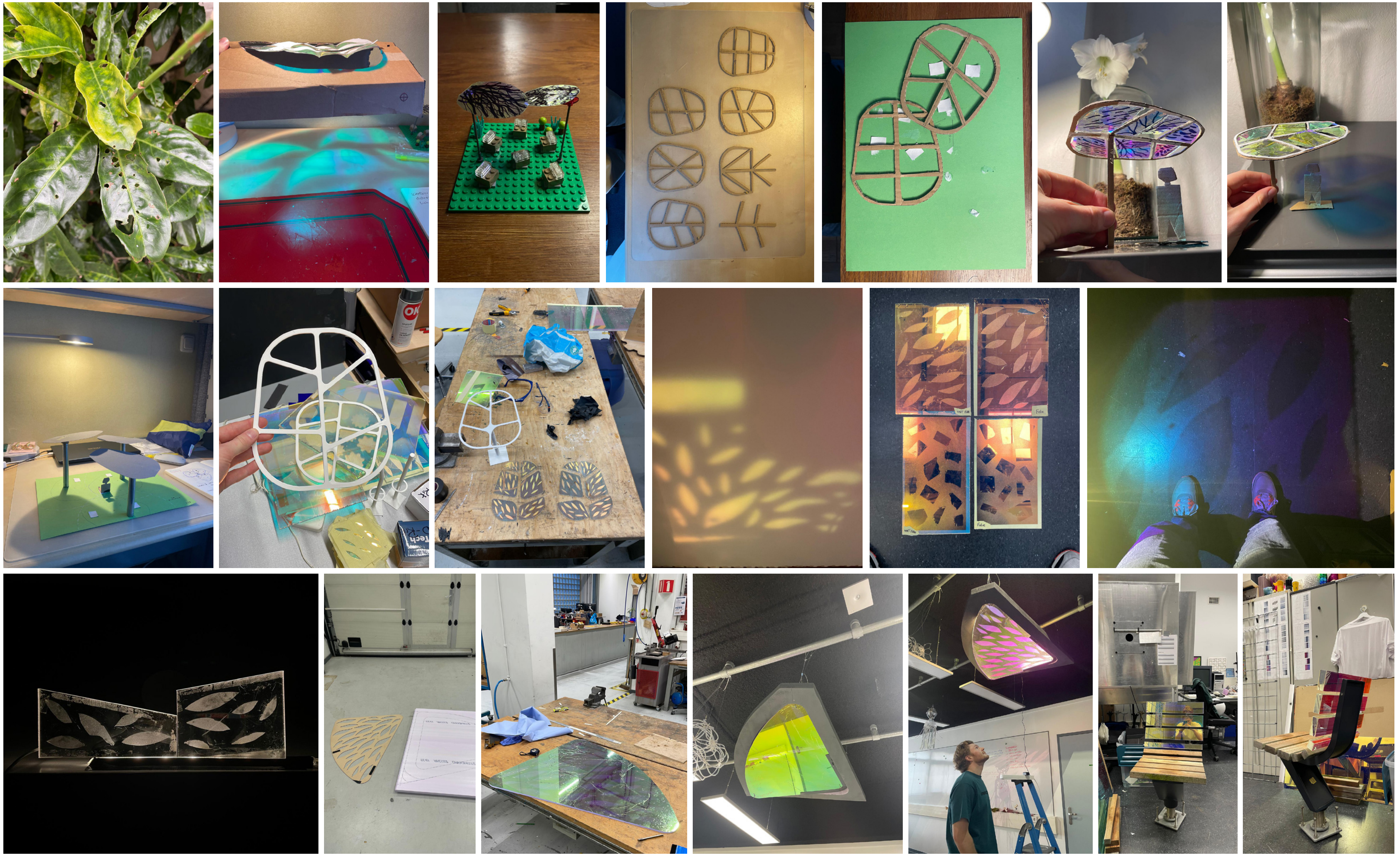


Figure 39: Prototyping evolution (left to right)

Turning handle
The design of the handle plays a crucial role in how visitors interact with the installation. After multiple sketches and mockups, a circular shape was chosen (see figure 40). This, to ensure that the movement feels intuitive and natural. The round form invites a turning motion that people instinctively associate with rotating mechanisms, making it easy to understand and operate without the need for additional instructions.

In addition to its functionality, the circular shape of the handle aligns with the overall visual language of the installation, creating a sense of cohesion in form. The handle's placement was deliberately set just off-center. This slight asymmetry makes it easier to push and turn, offering a more ergonomic and responsive experience. The off-center position also creates a small, flat surface that makes placing small objects like a water bottle possible. This playful detail encourages creative engagement and adds another layer of interaction.

Figure 40: Early turning handle sketches

Height evaluation
The height of the canopy was determined by studying natural and human built structures. Trees with a comfortable, inviting height were photographed and sketched in as references (see figure 41). Human-made structures like bus shelters and garden pergolas also provided useful comparisons.

A height of between 2.5 and 3 metres provides sufficient protection while not feeling confined. This is similar to the height of a pergola or a bus shelter, which most people find comfortable. As described in chapter 6.2, a sense of security is strongly linked to being able to oversee one's surroundings (Prospect and Refuge). If structures are too low (below 2.2 metres), people can feel enclosed. In contrast, structures that are too high (above 4 metres) lose their sheltering effect, which does not contribute to a sense of security. In public space pergolas, light installations or canopies with a height around 2.7-3 metres are often chosen. At this height, there is a subtle feeling of protection without being to isolating.

I tested these heights with several people to justify my findings (see figure 42). Using a simple piece of cardboard at different heights, I found that a height of 2.8-3.5 metres was perceived to be the most comfortable. Therefore, this height was chosen to create a space that feels open but still offers a sense of shelter.

Of course, this cardboard is not proportional to the dimensions of my design and, besides, also not in the right context. Outside, the perception of these volumes and dimensions will be different.

Figure 41: Height study

Figure 42: Height test

7.4 Recommendations

This chapter shares a set of recommendations that come from the work I've done in this project. They're meant to help improve the design, make it easier to put into practice, or inspire further exploration of similar ideas.

Light effect
In the next steps. Different ways of integrating lighting to improve its visibility during different weather conditions can be done. In addition, sensors should be added in order to be user triggered. When no visitor is in the park, there will be no lighting at night. This to minimize artificial lighting at night.

Also, the light effect during night could also be enhanced with an extra dimension such as a pulsing effect when more people are enjoying the canopy.

Redesign LED profile
One of the next steps of this project is to redesign the LED profiles on the plexiglass sheets. In the current design, this is still quite geometric (see figure 43), making it less in line with the organic shape of the plexiglass sheets. In addition, the tipping points are now incorrect.

In the next iteration, I propose to make a longer profile that slowly tapers towards the end (see figure 44). This not only creates a more organic look, but also creates more unity between the profile and the plate within the steel frame.

The LED profile not only serves as the housing for the LED strip, but is also the connecting piece between the plexiglass panels and the steel frame. The wiring of the LED strips can also run through this, making this look neat from the outside. However, these should be made easily accessible and/or demountable to allow for repairs and component replacements.

The design of such a LED profile and custom LED fitting is something which within this project, there was no time to work it out completely.

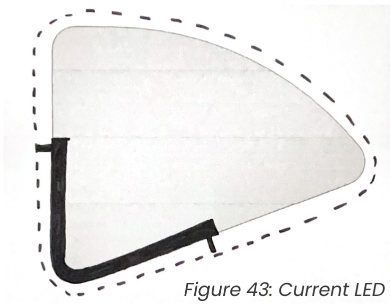


Figure 43: Current LED profile

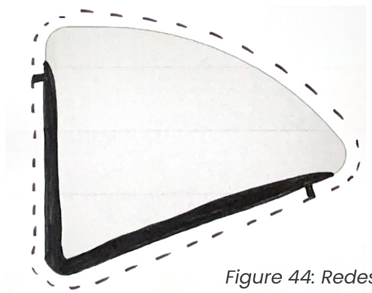


Figure 44: Redesign of LED profile

Costs
The current cost estimate is still missing important components. It is very difficult to do a accurate estimate for this project because almost all parts have to be made by hand/custom. Atelier LEK has experience with this and told me that an estimate is often given by the structural engineers who also work out the construction together with them.

Construction

To bring the design to a producible state, several steps need to be taken. First, the technical drawings must be refined to ensure they include precise measurements, material specifications, and clear assembly details. This will help translate the concept into a workable production plan. Next, it is important to test the structural stability of the design, especially the connections between the steel frame and pole and the plexiglass panels to the steel frame, to ensure the installation can withstand outdoor conditions over time. There will be a number of points within the design that will need attention. These can be seen in very simplified static FEM analyses I have done (see Appendix J). These confirm my suspicions of areas of attention.

This also means that calculations have to be done regarding wind loads. In several discussions with structural engineers, it did turn out that placing the plexiglas sheets at an angle within the steel frame is favourable for the wind load.

The construction of the canopy in the ground, will also have to be worked out in more detail. My first ideas for this are a stelcon plate (concrete) on which a steel construction/connection piece can be made into which the base for the rotating pole can be fitted. Because the area around Hofplein Station is built on an arched construction, the ground here is a limiting factor. A suitable solution will have to be found together with the landscape architects and structural engineers.

Since the canopy rotates 180 degrees, some kind of stopper will have to be made to stop it from spinning. I suggest a combination of plastic and some kind of spring. Rubber I advise against, as this deteriorates more easily over time especially with outdoor conditions, and so will need to be replaced sooner. This combination will ensure that the pole can continue to rotate smoothly, and a gently blocked to stop it spinning through. In addition, the stopper will also be able to take the hit of vandalism when turning hard. This is beneficial for the construction and suspension of the plexiglass panels. Overall, safety is an important aspect. How do I ensure that visitors cannot easily hang/climb on the canopy?

Material sourcing is another key step. Finding reliable suppliers for the steel and dichroic plexiglass, while considering durability and sustainability, is essential. In addition, consideration could also be given to reusing old rails/materials from the municipality itself. It may also be necessary to explore different production techniques, such as laser cutting for the panels and welding for the frame, to ensure accurate and consistent results.

Finally, a full-scale prototype should be produced to test the design and identify any adjustments needed before final production. This stage will also allow for checking how the light interacts with the structure in real conditions and whether the intended experience is achieved. Working together with the lighting/artwork managers from the municipality of Rotterdam is also important, to ensure that the repairability of the design is easy, should a component need to be replaced.

These steps will help ensure that the design is both practical to produce and functional in its intended environment.

8. Personal reflection

In this chapter, I look back and reflect on my process and the final outcome.

Research

The first few weeks of this project were all about completely immersing myself in light and public space. Because I had already laid a good foundation for this quite early in the process, I was able to fall back on it more easily in the later stages of the design process. I came across many contradictions, especially in the field of colours and emotions. Science does not yet agree whether and in what way this has a relationship. However, Sylvia's extensive knowledge allowed me to easily navigate through the large amount of information available.

A big part of my research was also into biophilia theory and biophilic design. I found that the connection between humans and nature, is much more complex than it seems at first glance. Here, therefore, I found that there is still a lot to learn in this area. In my opinion, the current terms and theories do not yet encompass what biophilic design should be. By including my own opinion in the report, it became clear to me during the design process which choices I had to make.

In addition, I have found for myself a fine way to tackle a design issue. By doing qualitative 'culture' research, especially on the core values and motivations of users/visitors/etc, I really get to the heart of the problem. In combination with Kees Dorst's frame innovation method, I am able to create a design frame. This helps me enormously during the subsequent phases of the design process to have some kind of grip. I definitely want to incorporate this way of researching, and involving the user, in my next projects.

Ideation

One of the most challenging facets of my project was coming up with a concept from scratch, and shaping it. This certainly gave me some stressful moments. Shaping objects/products/installations is something I have encountered very rarely during my education. You constantly see inspiration around you, and are all the time improving or modifying small things. Fortunately, I was able to consult well with my graduation team, and they were therefore often able to keep me on track. Losing overview in such a broad assignment is something that can easily happen.

By making many physical models/tests and prototypes, I got closer and closer to my final design. With each model and test I ran into new design choices. This ultimately ensured that I created a strong design that actually achieves the goal I had in mind and fits well within the context. I have therefore discovered that going through the design process using physical models suits me well.

Project management

Making a good planning and sticking to it is something I don't necessarily find difficult. Because you do this project almost alone, you are much more flexible in the time you spend on your project. I always prepared the meetings with the graduation team and stakeholders well. This ensured that I could get a lot of useful feedback and was never faced with surprises. The collaboration also felt very natural and pleasant, which made the meetings something to really look forward to, whether it was for advice, practical matters or to show something.

Results

Looking back at the result, I am very satisfied with what I put up. Of course there are parts that are not yet well thought out and could be better. I focused mainly on the interaction and design, and spent less time on construction and other practical aspects. Looking back at question I formulated at the beginning of the project, I am convinced that my design is the answer to this:

Is it possible to create a biophilic light(ing) environment within this context, taking into account the desired interaction/experience?

This project is one of the few projects in which I was able to express my own taste and creativity, with no limits. I could not have imagined after my qualitative research that I would end up with this design. I hope to continue the project together with Atelier LEK.

If I were allowed to do this project again, I would definitely have chosen the same direction again, but I would have involved a structural engineer more from the beginning, so as to also be able to work out the technical and structural part of the design more.

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Appendices

Appendix A: Psychology of light

This chapter explores how different types of light influence our physiology, cognitive processes, and overall well-being

1 Light as a cognitive map

We tend to cognitively try to find a match in our memory that fits the new environment, when we are exposed to a new environment (Kaplan & Kaplan, 1988). This helps us interpret and understand a new environment, and might make it seem less daunting or intimidating. Finding familiarity in the unknown helps us adapt (e.g. a structure that reminds us of our childhood).

Here's where lighting plays a role. It can be applied to draw attention to recognizable building features, textures, etc. Finding recognizable items and structures can be made easier for people to find by highlighting certain parts of the surroundings.

As shown in figure 45, no obvious highlighted structures can be seen during the day apart from the sun reflecting in the tall buildings surrounding the park. The remaining elements of the railway line are illuminated in the evening by an integrated LED strip. As a result, these elements stand out well, and catches your attention. However, in my opinion, these shapes now look like gallows because of the geometric lighting.

In addition to being a cognitive driver, light is also able to induce specific cognitive skills within the perceiver (Flynn, 1977).

Figure 45: Station Hofplein

2 Perception based lighting design

People's dissatisfaction with lighting based on luminance technology or quantitative lighting design is primarily due to their rigid adherence to a physiologically oriented understanding of human perception (see Appendix E). From this perspective, only a small part of the complex perceptual process (which includes the eye and an abstract understanding of the environment) can be analyzed; the subject of the eye and the importance of the perceived objects are ignored.

The conditions necessary for the processing of visual information and all the variables influencing the correlation between the perceiving human/ non-human: the perceived objects and light as a medium for permitting perception to occur, can only be fully understood when we look beyond the physiology of the eye and examine the psychology of perception in greater detail.

Perception-based lighting design, can no longer only be described by terms relating to illuminance and the distribution of luminance (see Appendix D). Therefore, a new framework has been made (Ganslandt & Hofmann, 1992).

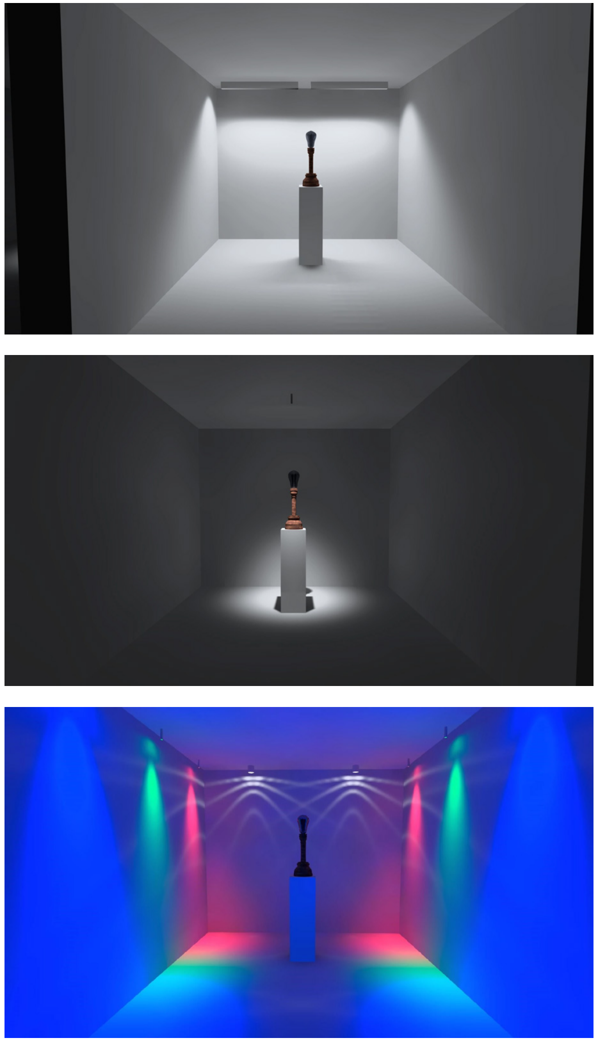


Figure 46: Richard Kelly's three layers of light.
From top to bottom: Ambient , Focus , Brilliance

3 Three layers of light

The renowned lighting architect Richard Kelly created such a frame work and described light with three layers, named "ambient" (ambient luminescence), "focus" (focal glow), and "brilliance" (play of brilliants). In otherwords: light to see, light to look at something and light to view. A clear overview of the three layers of light can be found in figure 46. This decomposition of light is comparable to a physically relevant perceptual decomposition of the distribution of light in a space, according to research at the faculty of Industrial Design Engineering (Pont & Smit, 2023). Furthermore, by conducting various experiments it was found that it could also be coupled to the primary characteristics of light that have been shown to be sensitive to human observers and that are clearly related to how objects appear (see figure 47).

Light can be described using these three primary layers of light, which can also be used to systematically build up a lighting plan. As a result, it offers a "language" for analysing and planning lighting in an area. It offers handles/a framework for the actual design of the light. In other words; any luminous environment can be captured optically and decomposed mathematically in such layers, and also composed in design. These layers also have direct perceptual meaning and can be adjusted and tuned independently to give form to the light qualities.

With this more human-centric approach that took into account various psychological effects that light had on people, Richard Kelly altered the language and the prevailing mindset about luminance and architecture. He was able to show that lighting design is both an art and a science to the industry globally.

In addition, a light source's direction has the ability to change an area and affect how people feel in it. Lighting that is above eye level can impart a sense of constraint and formalize the environment. Conversely, lighting that is below eye level can evoke a sense of personal significance and foster a more relaxed atmosphere (TCPI, 2017).

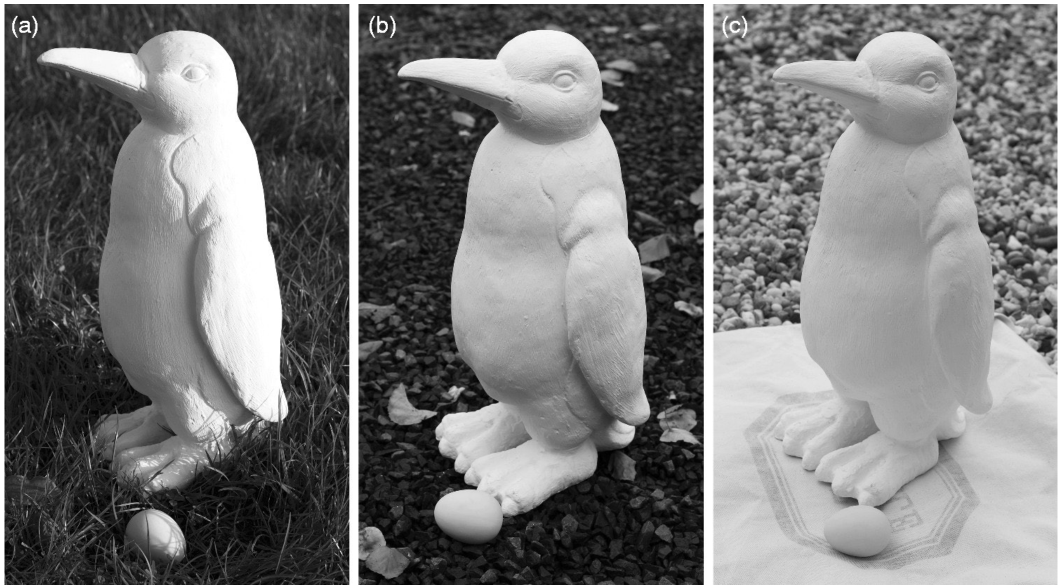


Figure 47: Object under different light conditions

Appendix B: Natural light

In this chapter, sun-and moonlight are discussed and how the perception of this natural light changes during the day. Moonlight is the reflection of sunlight along with stars coming down to earth. Even though this is not a direct light source, the optical properties are still very interesting to name.

1 Sunlight

Spectral composition of sunlight
Generally speaking, sunlight consists of three main components: infrared radiation, ultraviolet light, and visible light (see figure 48). Almost half of the radiation that reaches the Earth's surface is in the visible spectrum. Despite making up a very small fraction of all radiation, UV light is a crucial component. For humans, animals and even plants to generate vitamin D, it is essential . However, a huge amount of the ultraviolet light from solar radiation is lost due to pollution in the atmosphere over big cities. Infrared radiation is responsible for its heat-producing quality. Infrared radiation makes up over half of all solar radiation that reaches Earth's surface.

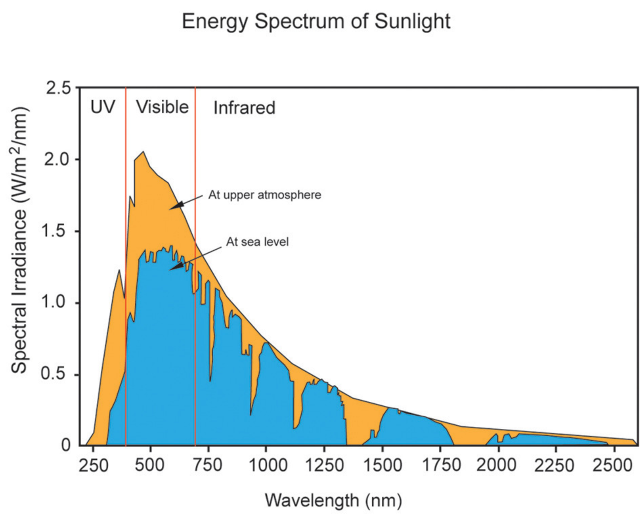


Figure 48: Energy spectrum of sunlight

Colours of the sun
Solar radiation is absorbed and diminished by a variety of atmospheric constituents as it passes through the atmosphere. Dust particles and molecules of air also disperse it. Blue and other short wavelengths scatter more readily than red, which has a longer wavelength. The sky's changing colour throughout the day is caused by this phenomena. As can be seen in figure 49-50, the sun is perceived as white when being viewed from space, but a more yellowish colour when viewed from earth.

Figure 49: Sun viewed from earth

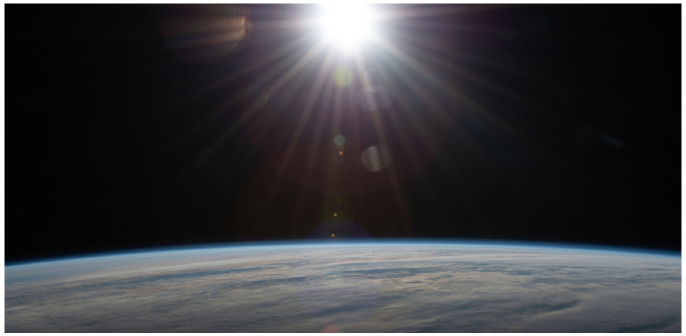


Figure 50: Sun viewed from space

<u>Sunrise and sunset</u>

During sunrise and sunset, the colour of the sunlight changes. This is caused by the angle of the sun's rays. At sunrise and sunset the sunlight enters the atmosphere at a smaller angle (see figure 51). The rays must therefore pass through a bigger/ longer portion of the atmosphere. As a result, most wavelengths are reflected by atmospheric molecules, with the exception of those in the red region of the spectrum (also called Rayleigh scatter) , as previously mentioned. Rayleigh scattering refers to the scattering of light by small gas molecules (in the atmosphere), with shorter wavelengths (blue light) being scattered more effectively than longer wavelengths (red light). The higher energy portions of the light spectrum, or smaller wavelengths, are scattered more intensely than the larger wavelengths because this scattering of light is wavelength dependent. In other words, the air molecules scatter the blue light more efficiently than the red light. As a result, blue light scatters more when the sun is high in the sky, and when we look up at the sky, we see the diffuse blue light from the Raleigh scattering of sunlight. For the same reason, shadows of objects also appear more blueish.

Our viewing angle shifts in the evening as the sun sets or descends on the horizon, allowing us to see sunlight that has penetrated a significantly larger portion of our atmosphere, much of which is denser near the earth's surface. As a result, a sizable amount of blue and green short and medium wave light is scattered out of the observer's field of vision. Red, which is the least energetic and has a longer wavelength, scatters the least. As a result of the longer wavelengths being retained and the shorter wavelengths being eliminated, the light appears more reddish, creating the famous sunset.

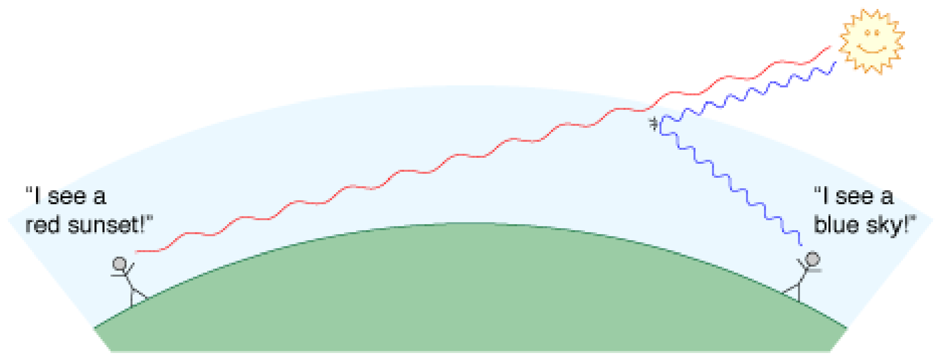


Figure 51: Rayleigh scattering explained

Sunrise and sunset can be divided into 3 different stages:

- Civil twilight

During civil twilight, the geometric centre of the Sun's disk is at most 6 degrees below the horizon. In the morning, this twilight phase ends at sunrise (civil dusk); in the evening it begins at sunset (civil dawn).

- Nautical twilight

During nautical twilight, the geometric centre of the Sun's disk is between 6 and 12 degrees below the horizon. The visibility is greatly reduced in this phase; the horizon is faintly visible during this phase.

- Astronomical twilight

During astronomical twilight, the geometric centre of the Sun's disk is between 12 and 18 degrees below the horizon. To the naked eye, and especially in areas with light pollution, it may be difficult to distinguish astronomical twilight from night time. Almost all stars are visible during this phase.

1 Moonlight

Spectral composition of moonlight
Moonlight arises from sunlight reflecting off the lunar surface. When the moon is "full", the side facing earth receives direct sunlight and reflects about 12% back, this ratio of reflected light is called albedo. The lunar surface reflects only such a small percentage because of the composition of the moon's surface: namely dark grey like rocks and debris. The light of the night sky originates from the following main natural sources together with moonlight as described above (in order of brightness): light from stars and planets, the Milky Way, zodiacal light, airglow, and the light from these sources scattered by the earth's atmosphere. Light pollution from artificial city lighting also affects many sites' night skies.

Colours of the moon
There are nights when the moon appears to have a different colour, despite the fact that its surface is always the same composition of materials and colour. The moon's actual colour is an off-white brown-grey when its dusty surface is sunlit. There are several reasons for this, all of which are related to the atmospheric conditions that are present. Italian photographer Marcella Giulia Pace has captured lunar variations for 10 years. The 48 selected different colours of the moon can be found in figure 52.

Figure 52: Colours of the moon

The most important moon colours are explained below:

- Blue

Blue moons can happen when moonlight passes through an atmosphere that contains particles of smoke and dust. People are most likely to see a blue moon after a volcanic eruption.

- Pink/Red

The moon can occasionally appear pink or red; this is referred to as a "bloodmoon." A total lunar eclipse occurs when earth passes between the moon and the sun, obstructing the majority of light that would otherwise reach the moon and causing this colour shift. Light with shorter wavelengths, like blue and violet, scatters before reaching the moon. This leaves only longer-wavelength colours, like red, to reflect back at us.

- Yellow/Orange

"Harvest moon" is the name for a yellow or orange moon. A harvest moon usually occurs when the moon is close to the horizon, meaning that the light reflecting off the Moon has to travel through more of the atmosphere. As with a total lunar eclipse but less intense, short-wavelength colours scatter, causing us to see longer-wavelength colours like orange and yellow.

In the Netherlands, cloud cover is common. This also has an effect how we see moonlight. Moonlight reflected by the sun shines on the top of cloud cover on earth. If those clouds are thin then you see the moon through them (translucent like frosted glass), if there is a hole in the cloud cover, then you see the moon itself, but also the illuminated edges of the clouds around the edge of the hole (see figure 53).

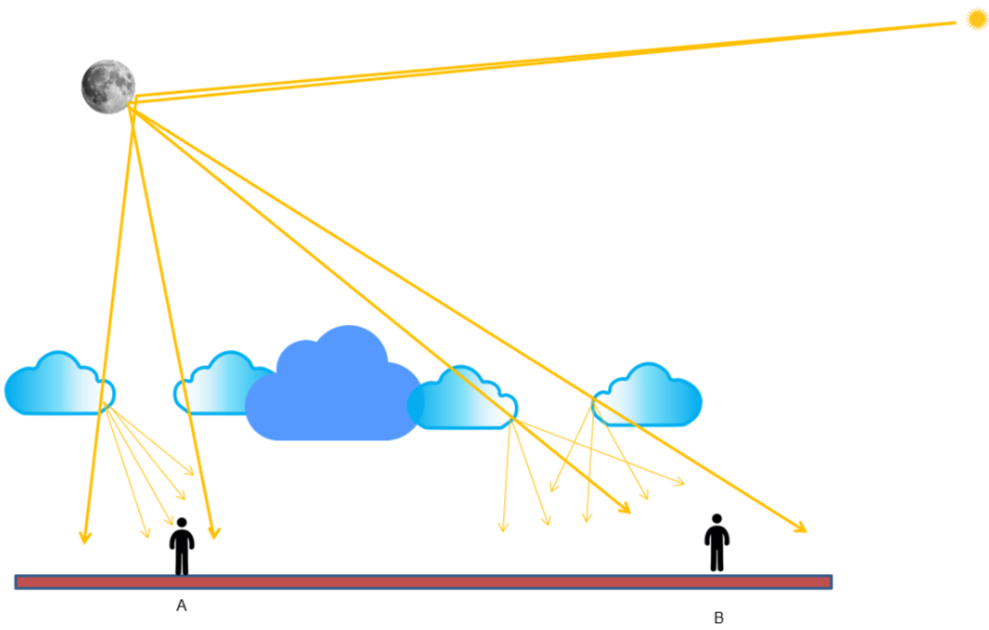


Figure 53: Moonlight and cloud cover

3 Light pollution

Direct glare, continuously elevated lighting levels, and unforeseen lighting variations are all considered forms of ecological light pollution. Almost every ecosystem has light pollution sources, such as streetlights, security lights, sky glow (figure 54), illuminated buildings, and lights on cars. The term “avoidable light pollution” describes nighttime light emitted by artificial light sources that are either unsuitable for their intended purpose or insufficient in intensity, direction, and/or spectral range, e.g. light flow directed at the sky (Rajkhowa, 2014).

Cities are kept bright by these light sources, but they also alter life’s natural rhythms in ways that we may not always be aware of.

Humans, animals, and plants are all impacted differently by light pollution. Overexposure to artificial light at night can disrupt sleep and have negative health effects. Disorientation can make it difficult for animals that depend on natural light patterns, such as insects and birds, to locate food or navigate. Growth cycles may be disturbed in plants, particularly those that rely on seasonal variations in light (Rajkhowa, 2014)(Gaston et al., 2013).

Figure 54: Skyglow by greenhouses in the Netherlands

4 Reducing light pollution

There are several ways to reduce light pollution. Therefore, the best approach to reducing light pollution depends on the specific issue at hand and the situation. Aspects to keep into account while designing/working with light are:

- Using light sources with the least amount of intensity required to achieve the light's intended function.
- Turning lights off using a timer or sensors when not needed.
- Improving lighting fixtures, directing their light more accurately towards where it is needed, and preferably downwards (see figure 55).

It highlights the need for creative solutions for urban lighting and, more generally, fresh ideas for how cities will look at night. Otherwise, we run the risk of being stuck with a new generation of outdoor lighting that doesn't realize sustainable urban (nighttime) futures and worsens existing effects.

"Designing for darkness" is one of these emerging creative solutions. Designing for Darkness reframes darkness as a desirable and positive aspect of nightscapes. This is a significant change in perspective because, although darkness/shadow have long been used in lighting and architecture design, darkness is given positive aesthetic and moral meaning in this context. It aims to lessen the effects of light pollution and increase public awareness of this environmental problem (Stone, 2024). Design for darkness is, in my opinion, a crucial aspect of biophilic (lighting) design.

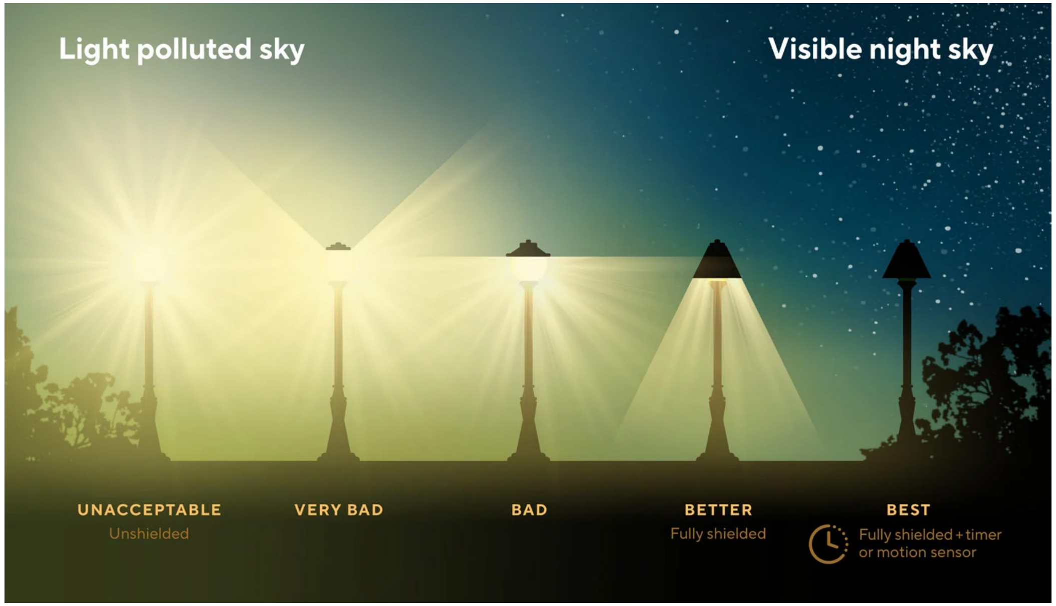


Figure 55: Reducing light pollution of streetlights

Appendix C: Research approach qualitative study

To find out what are the specific motivations of Rotterdam residents to go to a park in the city, I wrote down beforehand 10 motivations that were common from the literature.

- Spend time with friends/family
- Relax
- Taking a break
- Escape from the city
- To be surrounded in nature
- Exercise
- Passing through
- Observation of wildlife
- Get inspiration
- Walk with dog/child

15 participants ranked these 10 motivations from 1 to 10 (most often the reason to least often the reason)

To find out the value behind these motivations, I asked deeper into the underlying reasons. The interview procedure was as follows:

1. What does this park mean to you?
2. How do you take this with you in your daily life?
3. What are the top 3 motivations for you? What values do you think are behind these?
4. How is this expressed in your daily life?
5. What does (value 1) specifically mean to you?
6. What does (value 2) specifically mean to you?
7. What does (value 3) specifically mean to you?

Appendix D: Quality of light

The concept of light is something humans can understand to some extent. What exactly is light? How is light created? Can light actually be perceived? This chapter explains what light is and how to determine the quality of light.

1 What is light?

What makes light unique is that it can be divided into two groups, visible and non-visible light. Light, often known as visible light, is the general term for electromagnetic radiation that is visible to the human eye. From low energy radio waves with wavelengths measured in meters to high energy gamma rays with wavelengths less than 1 x 10^{-11} meters, the electromagnetic spectrum as a whole is incredibly broad (see figure 56).

As the name implies, electromagnetic radiation explains variations in the electric and magnetic fields that carry energy across a vacuum at the speed of light, or around 300,000 km/sec. Another way to think of light is as a stream of photons, which are massless energy packets that move at the speed of light and have wavelike characteristics. The light colour can be related to a certain wavelength. This wavelength, in turn, has a unique property in relation to its influence on humans. For humans, it is possible to perceive some of these waves, this makes it possible to experience a colour of an object. "Object colour" is the term used to describe the spectrum that such an object emits. A red chair doesn't actually emit red light; instead, the material's ability to absorb specific light wavelengths causes the mixture of the remaining reflection to appear red.

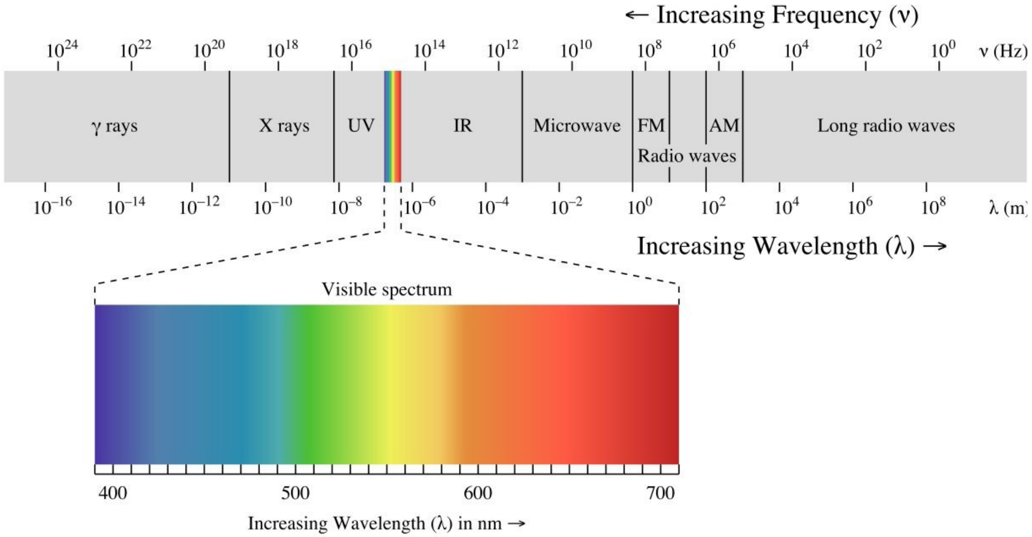


Figure 56: The electromagnetic spectrum

2 Describing colour

Munsell Colour Theory
The Munsell colour order system (see in figure 57) is based on a three-dimensional model.
Each colour has three qualities or attributes:

1. Hue – colour such as red, orange, yellow, etc.

   Each horizontal circle is divided into five principal hues: Red, Yellow, Green, Blue, and Purple, with 5 intermediate hues (e.g., YR) halfway between the principal hues

2. Value – the lightness or darkness of a colour

   Value, or lightness, varies vertically, from black (value 0) at the bottom, to white (value 10) at the top.

3. Chroma – the saturation or brilliance of a colour

   Chroma is measured radially from the centre of each slice and represents saturation of the colour with lower chroma being less pure (more vague, like pastel tints).

CIE's Chromaticity Diagram
The chromaticity diagram is a 2D overview of 2 specific colour qualities: hue and saturation.
The hue is shown as an angle; the "white point" is visible in the centre of figure 58. By connecting straight lines to the corner we can determine the hue by the position of the vector. Saturation represented as followed: colours (points) on the outside of the diagram are more saturated, colours closer to the white point have low saturation.

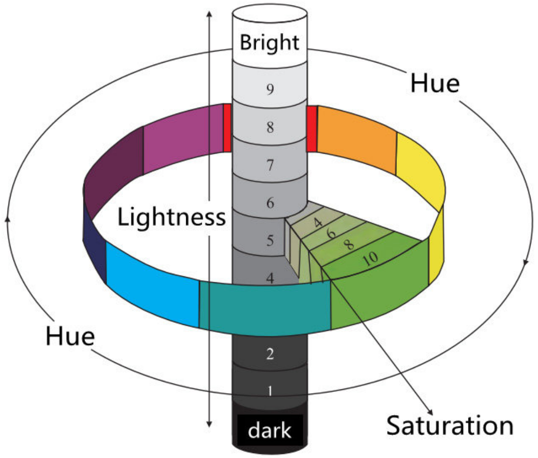


Figure 57: Munsell Colour order system

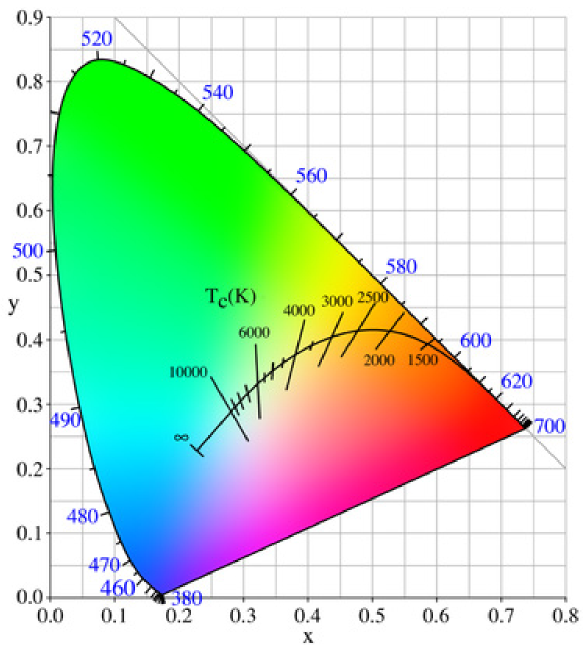


Figure 58: Chromaticity diagram

3 Colour temperature

The colour temperature of the electromagnetic radiation emitted from an ideal black body (see figure 59) is defined as its surface temperature in kelvin (K). Colour temperatures over 5000 K are called "cool colours" (bluish), while lower colour temperatures (2700–3000 K) are called "warm colours" (yellowish).

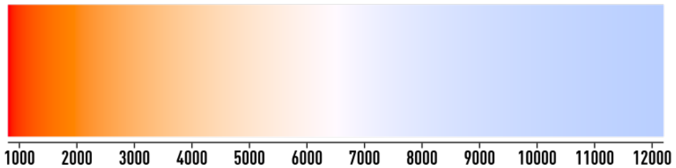


Figure 59: Colour temperature of ideal black body

The Kruithof curve is one of the evaluation methods created to ascertain the colour temperature for functional lighting (Kruithof, 1941). The relationship between the colour temperature and illumination of light sources is shown by the Kruithof curve (see figure 60). As can be seen, warmer light sources are typically chosen in low-light conditions.

4 Luminous flux

Luminous flux is a measure of the power of visible light produced by a light source or light fitting. It is measured in lumens (lm). Luminous flux only relates to the visible spectrum of light. Lumens are calibrated to the sensitivity of the human eye, for example, 1 Watt of radiation flux at 555 nm produces 683 lumen. The luminous flux will be lower at other wavelengths as can be seen in figure 61.

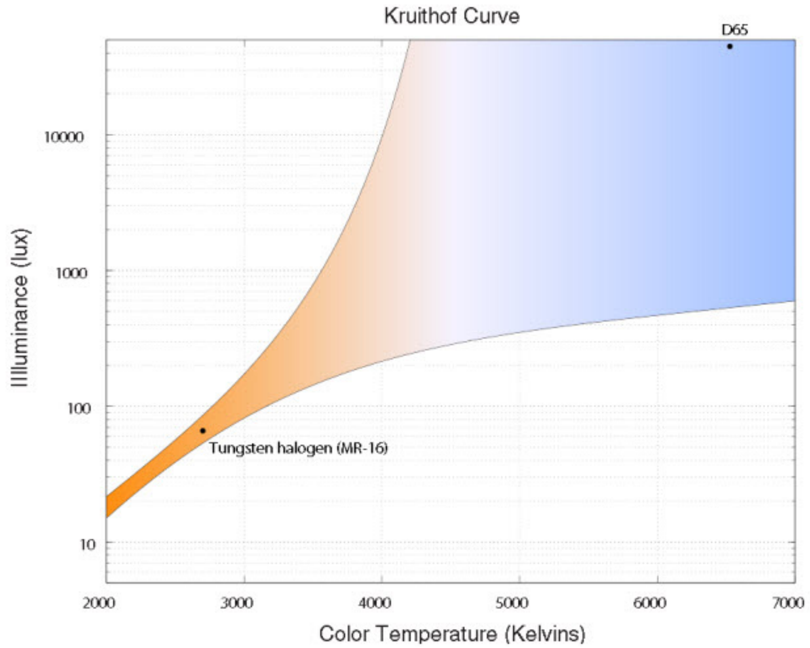


Figure 60: Kruithof curve

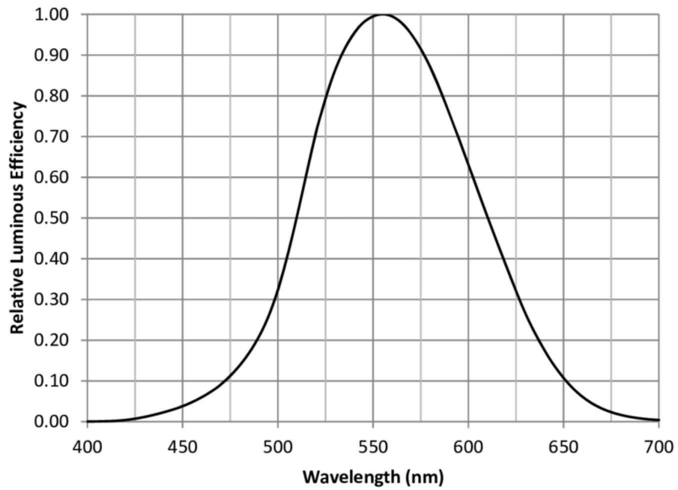


Figure 61: Luminous flux

5 Luminous efficacy

Luminous efficacy is a measure of how well a light source produces visible light. It is the ratio of luminous flux to power, measured in lumens per Watt (lm/W).

6 Illuminance

Illuminance is the intensity of light falling onto a surface, in other words, how much luminous flux is spread over an area. A source's overall output of light is determined by its luminance. According to SI, this luminous flux is expressed in lumens per square meter, or lux (lm/m2). The amount of light falling on a surface can be measured with an illuminance meter. They can ascertain the precise number of lux by positioning it in the region where light is falling.

7 Luminance

The amount of light that a surface emits, lets through, or reflects is known as its luminance. Consider a lamp that is shining in a pitch-black room. The amount of light that is coming through the bulb is known as luminance.

Luminance is expressed in terms of luminance intensity, which quantifies the brightness of a light beam directed in a specific direction. To express brightness, candela per meter square (cd/m2) is used in the International System of Units (SI).

Figure 62 summarises and cleary shows the differences between the concepts introduced above.

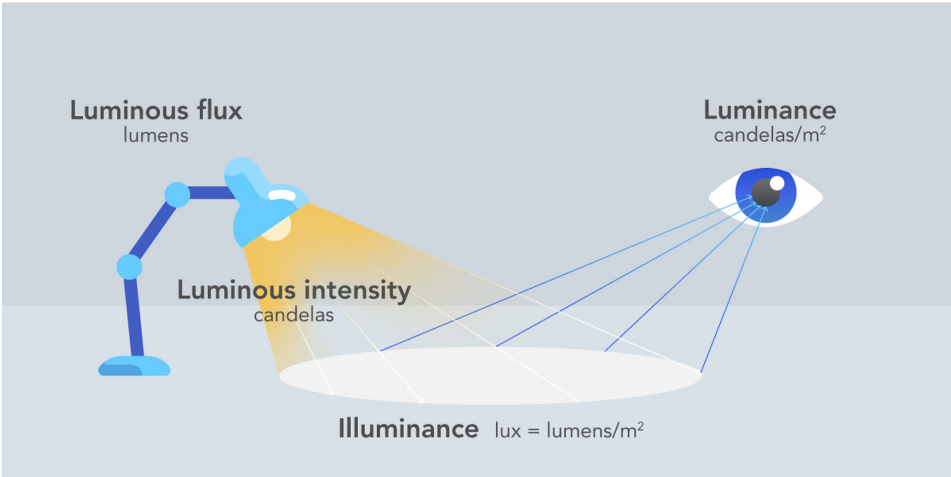


Figure 62: Difference between illuminance and luminance

Appendix E: Perception of light

To implement biophilic design, you need to understand how light impacts humans (and animals, and plants). Both visual and non-visual physiological aspects. This chapter delves into the complex mechanisms by which light is perceived, examining the physiological and neurological processes that convert these electromagnetic waves into (individual) visual experiences.

1 The visual system

Our eye works like a camera. An image of our surroundings is projected onto the retina on the inside of our eyes (see figure 63). A deformable lens and our cornea ensure that this image is sharply rendered at all times. In this instance, the iris functions as a diaphragm, regulating the amount of light that enters our eyes. What light exactly is, how it can be created, and how it can be perceived can be found in Appendix D. The retina at the back of the eye is made up of photosensitive nerve cells. The rods and cones, which are the 2 main specific photoreceptive cells of the retina that detect light photons and produce nerve impulses in response, are responsible for sending signals to the brain where they are translated into an image. In addition to the rods and cones, we have an additional photoreceptor. This photoreceptor was first found in 1927 when blindfolded mice (lacking rods and cones) still responded to changing light conditions (Keeler, 1927). These retinal ganglion cells, unlike our rods and cones, are primarily photosensitive due to the presence of melanopsin, a light sensitive protein (Hoang & Yau, 2010). They appear to be of little or no importance for forming images, but rather for regulating our circadian rhythm, regulating pupil size and the production of melatonin (hormone that supports our circadian rhythm) by the pineal gland.

The circadian rhythm, is our internal clock. It influences melatonin secretion, cortisol activity and alertness. Mistimed light exposure disrupts the circadian rhythm in humans, potentially causing further health impacts (Tähkämö et al., 2018). Red light raises melatonin levels, assisting our bodies in preparing for sleep, while blue light suppresses melatonin levels, keeping us awake and conscious.

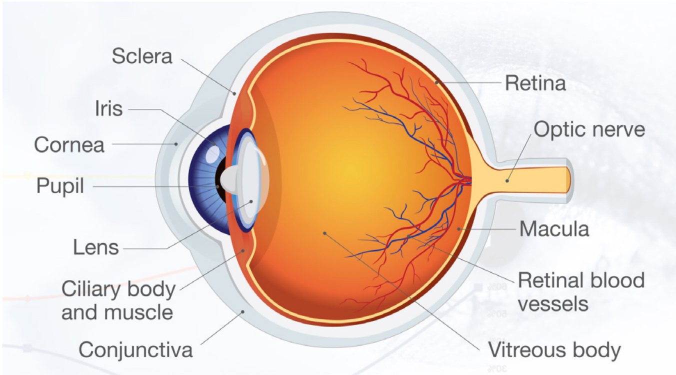


Figure 63: Human eye

People who don't get enough melatonin may experience sleep issues, which may eventually cause behavioural changes. Blue-tinted light should be avoided in the evenings in order to maintain healthy levels. The limbic system can be impacted by circadian rhythms in addition to our day-night cycle. This system regulates a person's feelings of happiness, sadness, anger and other emotions. These and other emotions can be adversely impacted by a disturbed rhythm.

Another effect of light on our bodies is the production of vitamin D. During exposure to sunlight, 7-dehydrocholesterol in the skin absorbs UV-B radiation and is converted into vitamin D3 (Wacker & Holick, 2013). One of the functions of vitamin D is helping the body absorb calcium and phosphate from food.

2 Visual perception

In this last step , converting the information to our perception of our environment is called visual perception. Visual perception is the ability to see and interpret (analyse and give meaning to) the visual information that surrounds us. Acuity, or the capacity for clear vision, is not the same as perception. It is in this last step that our individual knowledge and experiences (from the past) are used as reference for the visual perception, and therefore, may differ from person to person. We typically navigate and manage in a three-dimensional (3D) environment with great accuracy and automaticity, but occasionally our ability to perceive where objects are in 3D breaks down. What perceptual cues for perceiving a space are there in natural scenes like the Hofbogenpark?

We use a number of depth-cues to determine how far away we are from things and how far away they are from us. The most important cues are binocular disparity, binocular convergence, and accommodation. They are all linked to the visual sense system's physiologic structure as explained in sub chapter 1. Therefore, they work according to bottom-up processing.

Accommodation is when an out of focus image triggers a change in lens shape to accommodate, or bring the image into focus on the retina. We have multiple eye muscles that make the shaping of our lens possible.

Binocular convergence is the amount of inward rotation required by the eyeball muscles to bring an image to rest on the corresponding regions of the retina in each eye. The closer the distance to an object, the more inward rotation there is.

Binocular disparity, another name stereopsis, is a depth cue that arises because the closer an object is to the observer, the more difference there is between the views that each eye receives of it. As a result, the brain can calculate an object's distance using this metric. Stereopsis is often used by VR systems (glasses) to provide a sensation of depth.

For more distant objects and surfaces, the ability to judge depth and distance relies on a different set of cues known as pictorial cues. Most pictorial cues are susceptible to top-down influences because their efficacy is predicated on prior experience. Some pictorial cues are:

Converging parallel lines (like the road) in the direction of farther-off points is known as linear perspective (see figure 64).

The concept of relative size is based on the understanding that an object that appears smaller is farther away if two objects have the same actual size (see figure 65).

The way that closer objects block out farther-off ones is known as interposition (see figure 66).

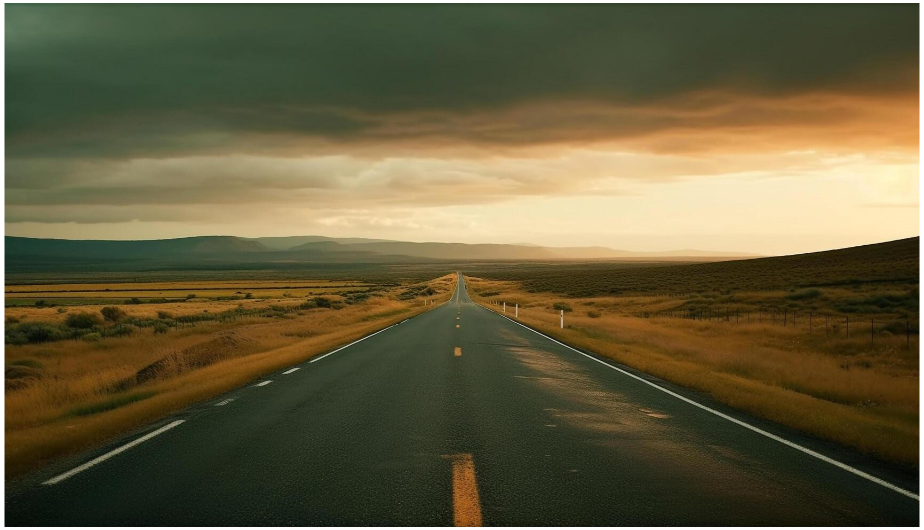


Figure 64: Example of linear perspective

Figure 66: Example of interposition

Figure 65: Example of relative size

The concepts of light and shading relate to how 3D objects reveal reflections from illuminating light and cast shadows. Their location, form, and distance are all demonstrated by these lighting effects (see figure 67).

Any textured surface will exhibit a gradient or change in texture density throughout the visual field when viewed from an oblique angle. The more distant area is indicated by the finer texture (see figure 68).

Visual Perception System

The conditions in your surroundings determine the systems your eyes need to use. Are you seated in a windowless, dark room? Do you spend the day outside? Both your perspective of what you're seeing and the visual skills you require will change. There are three sorts of visual systems:

- Photopic vision

Describes your ability to see during daytime or in an environment with adequate lighting. In these conditions, cone cells in the eye are activated, perception of colour is possible, and there is a high acuity.

- Scotopic vision

Describes your ability to see in dark or low light environments. In these conditions, rod cells in the eye are activated, allowing for better visual data interpretation even in low-light settings.

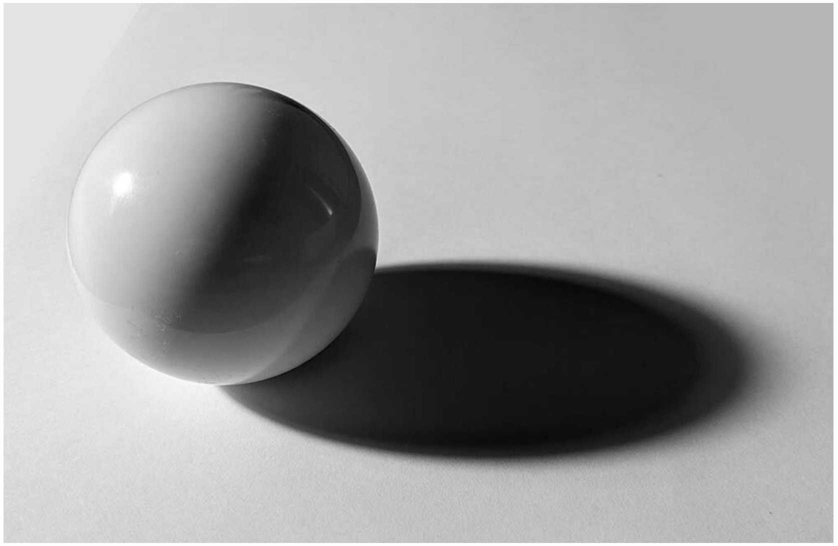


Figure 67: Example of light and shading

Figure 68: Example of texture density

- Mesopic vision

Describes your ability to see in partially dark environments. This visual system will be activated by nighttime street illumination, outdoor nighttime situations, and other environments with lower-light lamps. Mesopic vision combines the use of rod cells and cone cells.

Depending on the situation, your eyes use different skills to receive information from your environment. How well these systems work (e.g. colour-blindness) varies from one person to another. Because the rods are more sensitive, there is a difference in colour perception between photopic and scotopic vision.

In figure 69 below, you can see the sensitivity of our photopic and scotopic vision. As you can see, we are most sensitive to lower wavelengths (blues) in lower levels of illumination, and we are more sensitive to higher wavelengths (reds) in higher levels of illumination. This is called the Purkinje shift. Because of this, in lower levels of illumination, we perceive colours as more blueish, and vice versa.

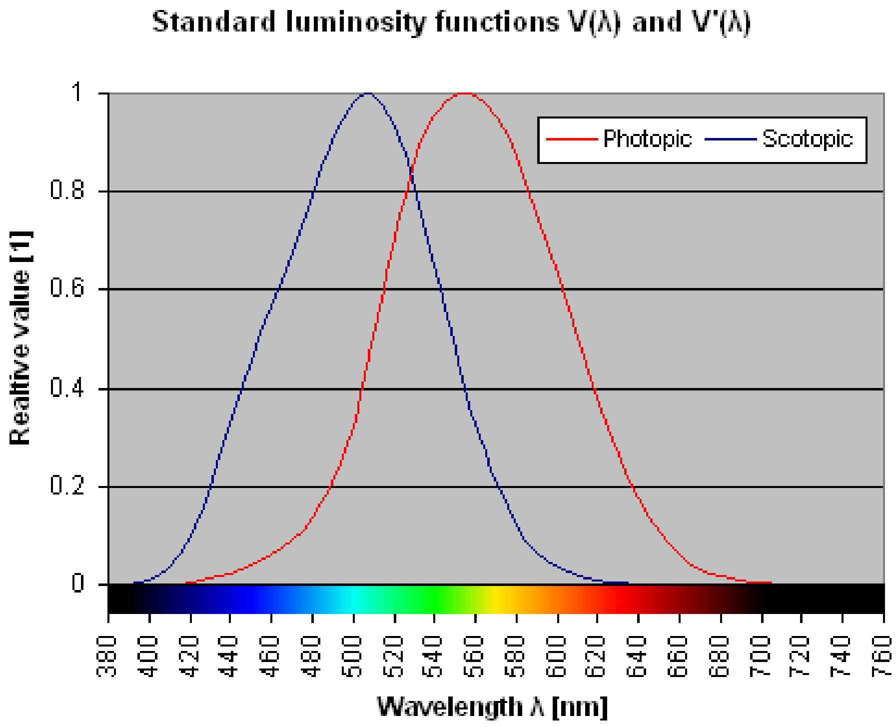


Figure 69: Purkinje shift explained

<u>Retina adaption</u>
The retina's ability to adjust to light and dark is among its most vital functions. As the level of surrounding light changes, all of the visual neurons must continue to "stay sensitive". The narrow response range of neurons in the non-spiking cells of the retina (-80 mV to +50 mV of graded potential) presents a challenge to the nervous system. This issue is resolved by the retina's ability to adjust to the lighting conditions. The visual system adjusts almost instantly to variations in light level, even if they are relatively slight. On the other hand, the eye takes a while to acclimate if there are significant fluctuations in the light level.

When you step into a darkened room after being outside on a sunny day, you initially barely notice anything. But, after spending some time in the dark room, you become used to the reduced lighting and find it quite simple to navigate around. This is known as dark-adaptation.

Dark adaptation takes roughly ten minutes, and it might take up to thirty or forty minutes for the cones to fully come to a rest (since no colours can be seen in the dark). In contrast, light adaptation (your retina adjusting from a dark environment to a well-lit environment) takes only about five minutes.

<u>Glare</u>
The term "glare" refers to any loss in visual performance or disruption of perception brought on by high luminance or brightness contrasts in a visual environment. Glare can be caused by the light source itself (direct glare) as can be seen in figure 70 on the right, or by reflection of the light source (reflected glare).
The phenomena known as "indirect glare" occurs when unwanted light sources distort how the environment is seen by reflecting off of other materials or objects. Direct glare is the phenomena of light sources with high luminance levels causing a lack of visual performance (e.g. looking directly into a street lantern). In the eye, light from a glare light source (direct glare) is interfering with the luminance pattern of the actual visual task, thus impairing the eye's ability to perceive. In lighting design we have to take glare into account, in order to make sure there is no discomfort glare. Discomfort glare is glare that undesirably attracts attention and prevents us from observing what we focus on.

Figure 70: Direct glare

Appendix F: Controlling light

In this chapter, controlling light directions by lenses and reflectors are discussed.

1 Reflectors

Specially designed reflectors can direct light in desired directions. For example, to amplify a light source in a certain direction or to prevent glare. The degree of reflectivity varies depending on the kind of material; light (coloured) and metallic materials work best in general. Examples of light sources with parabolic reflectors can be seen in figure 71:

Figure 71: Parabolic reflector

2 Lenses

A lens is a transmissive optical device that uses refraction to focus or disperse a light beam. Refraction is the redirection of a (light) wave as it passes from one medium to another e.g., air and water. An example can be seen in figure 72. The following figure 73 illustrates how the structure of the lens and the distance from the light source affect how a lens breaks down light.

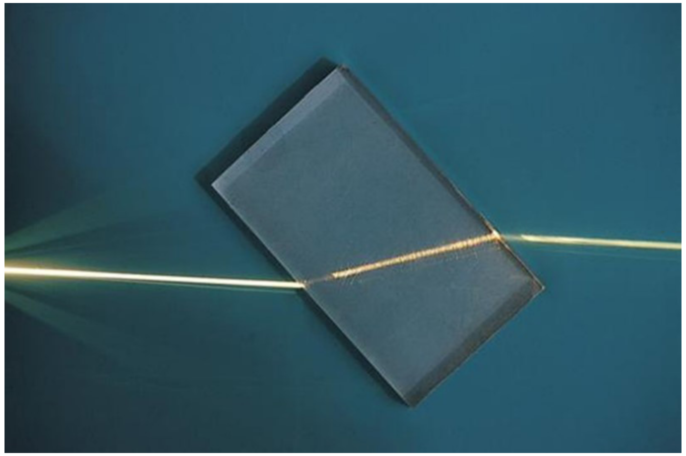


Figure 72: Refraction of light

A special kind of lens is a prism. A prism is a transparent material, such as glass, that has been precisely cut with plane faces and angles. Colours can be extracted from white light using a standard triangular prism. The amount to which each colour is bent, or refracted, varies; the longest wavelengths are bent least, and the shorter wavelengths most. Prisms can be used to create stunning light effects.

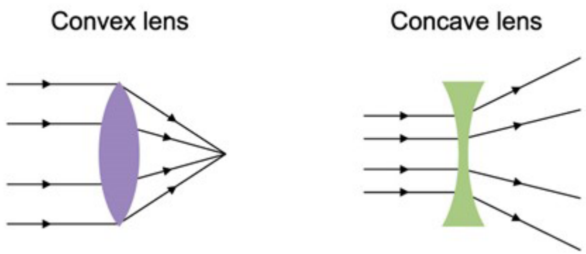


Figure 73: Different types of lenses

3 Filters

A colour filter that selectively allows certain colours of light to pass through while reflecting other colours is called an interference filter, or dichroic filter. Furthermore, rather than the colour(s) of light they pass, dichroic reflectors and mirrors are typically identified by the colour(s) of light they reflect.

Several layers of metal oxides are deposited on a substrate, typically glass or plastic, to create dichroic films. Certain light wavelengths are reflected and others are transmitted when light travels through the film and the metal oxide layers. Depending on the angle from which the light is viewed and the angle at which it falls, this produces a colour shift. Interference is another name for this effect, which produces stunning effects (see figure 74).

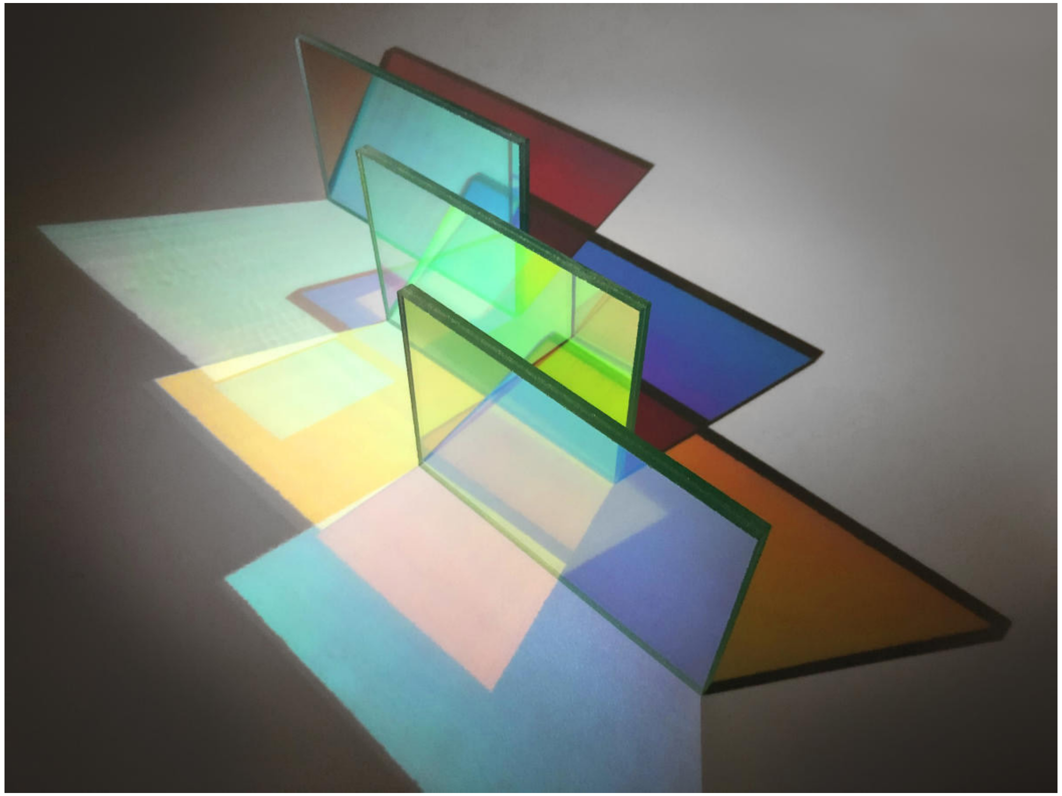
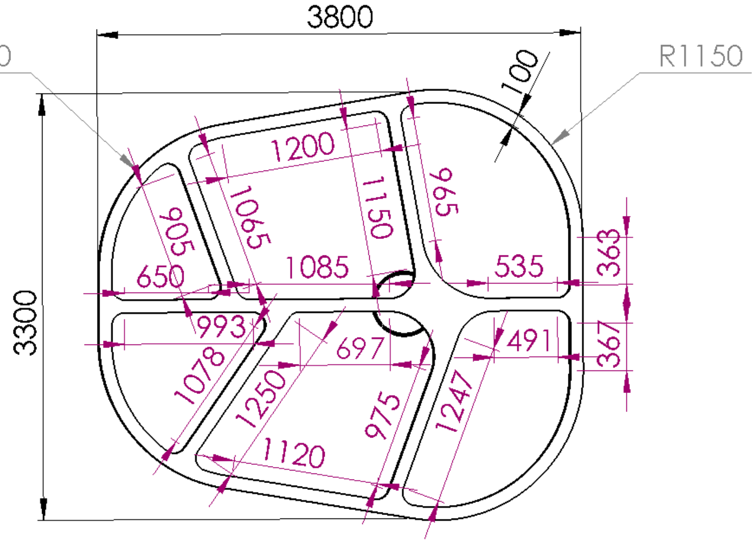


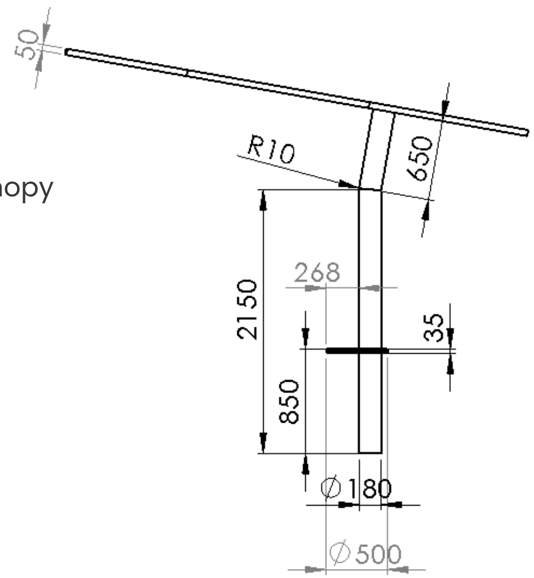
Figure 74: Dichroic reflectors

Appendix G: Technical drawings

Top view M size canopy

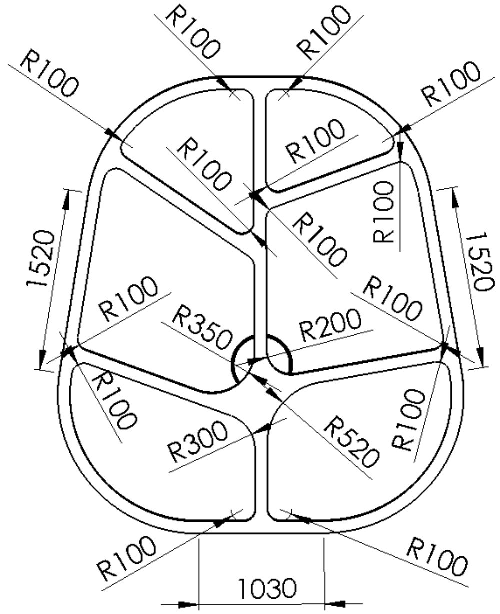


Side view
M size canopy

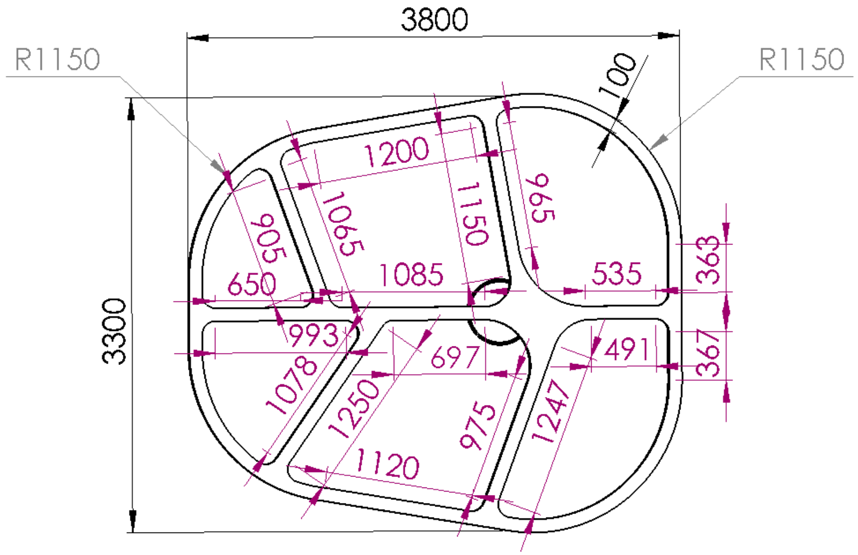


Top view M size canopy

Units mm

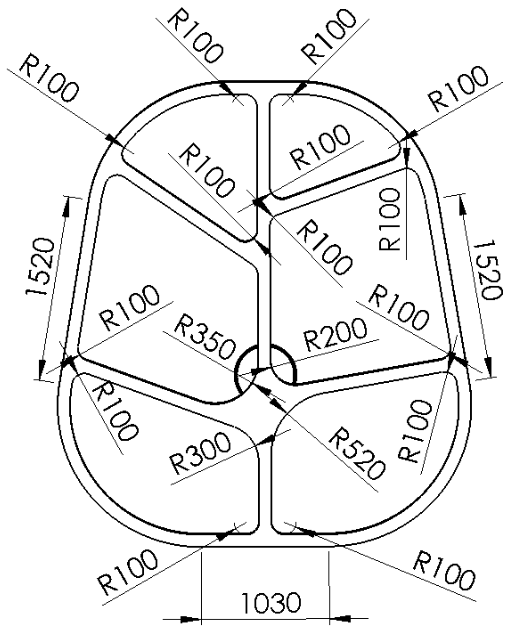


Top view L size canopy

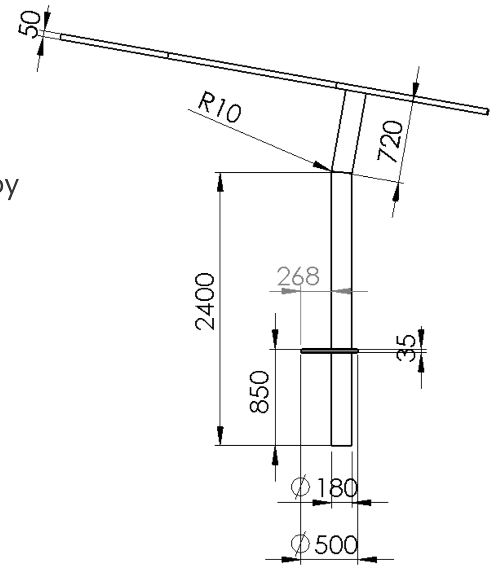


Top view L size canopy

Units mm

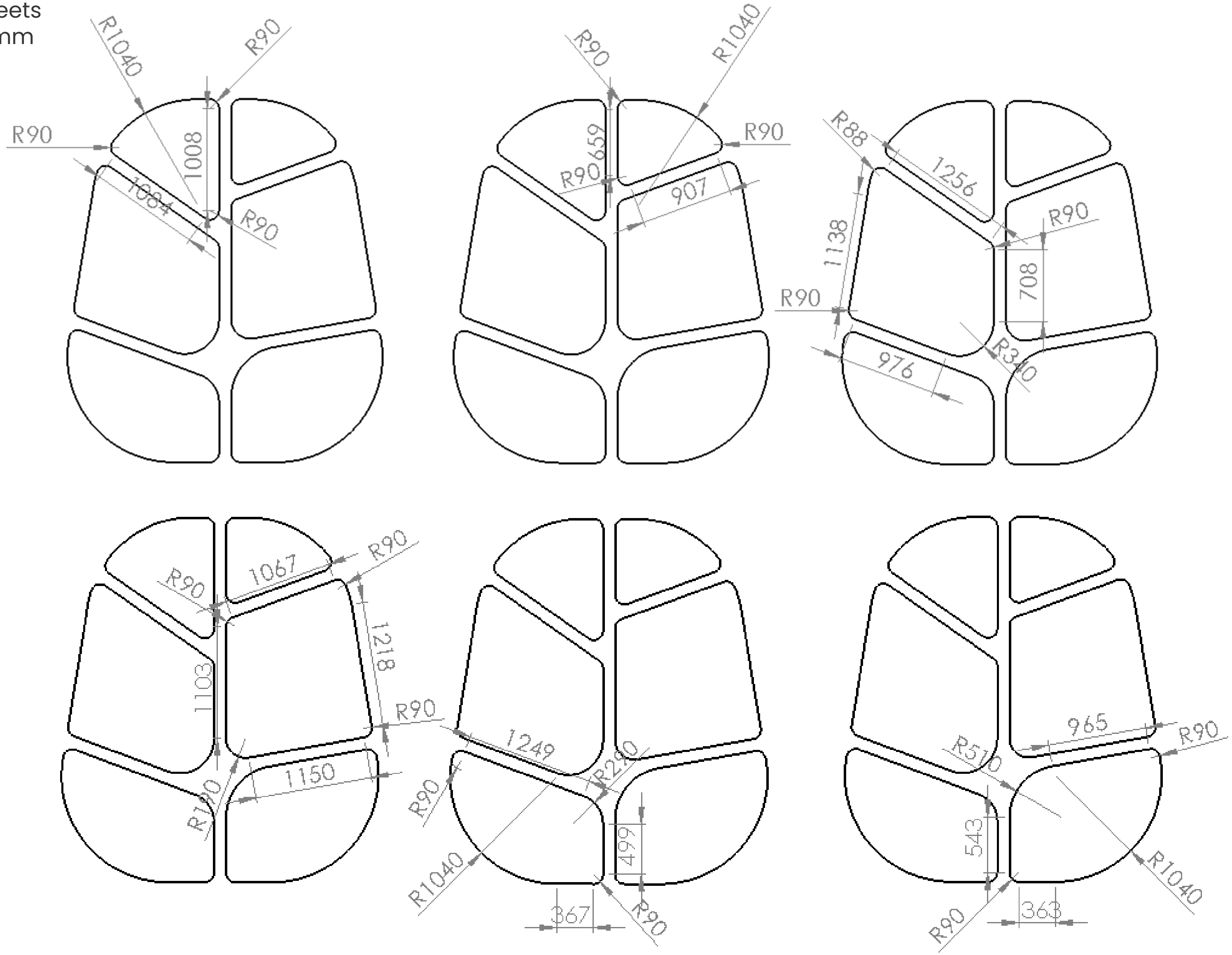


Side view
L size canopy



Top view
Plexiglass sheets
Thickness: 6mm

Units mm



Appendix H: Cost estimate

Cost estimate canopy

Plain Carbon Steel: 3,01 EUR/kg
Plexiglass sheet (6 mm): 84,06 EUR/m^2 (Kunststofplatenshop.nl, n.d.)
Dichroic foil: 32,67 EUR/linear meter (Raamfoliewebshop.nl, n.d.)
Sandblasting: 13,5 EUR/m^2 (Homedeal.nl, n.d.)

Topframe:
Total: 191,08 kg
Material costs: 575,15 EUR
Manufacturing costs: 7.191,17 EUR

Pole + turning handle:
Total: 61,53 kg
Material costs: 185,21 EUR
Manufacturing costs: 9.401,28 EUR

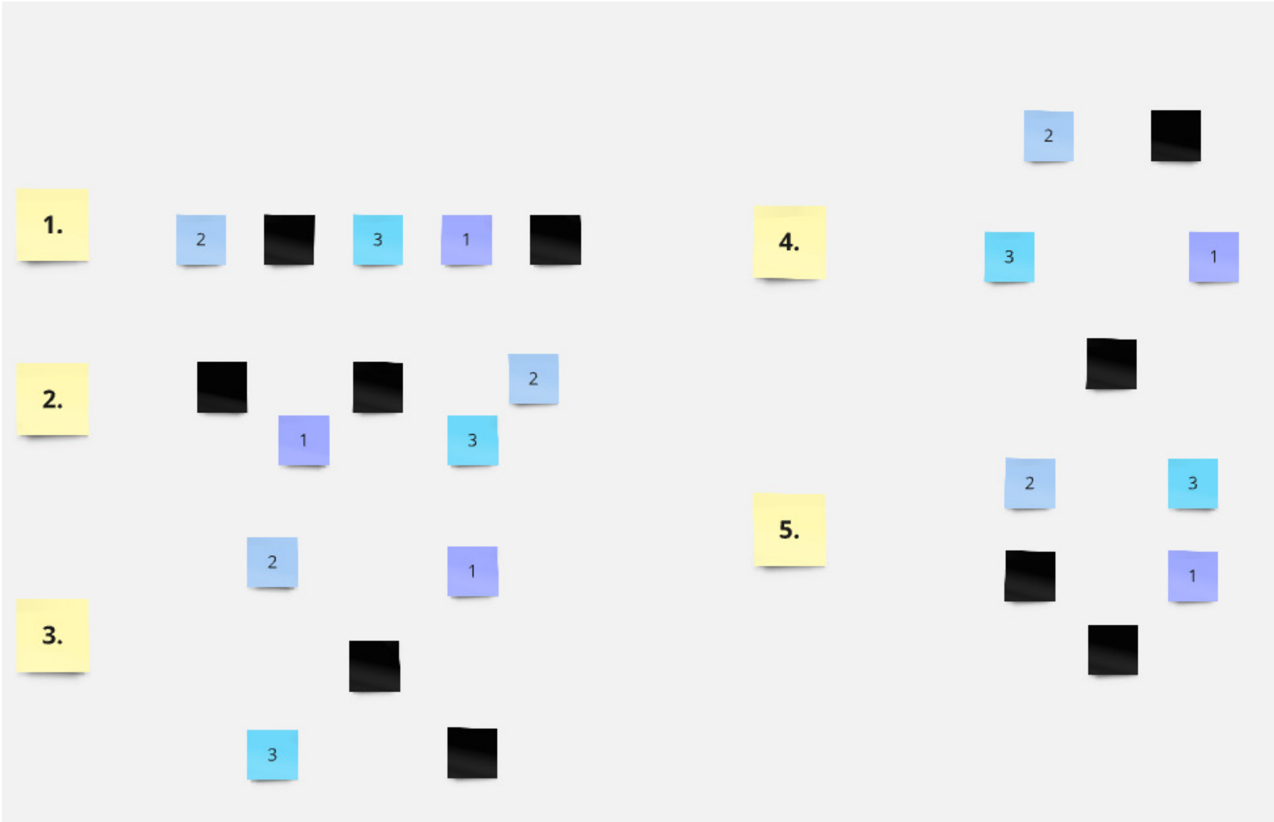
Plexiglass sheets:
Total: 8,12 m^2 -> 682,75 EUR
Sandblasting -> 109,62 EUR

Dichroic foil:
Total: 8,12 m^2 -> 192,23 EUR

Total for one canopy: 18.337,41 EUR

LED strips and LED profiles, as well as the construction in the ground have not been included in this calculation due to the fact that these will have to be custom-made. The same goes for the installation costs and transport costs.

Appendix I: Research approach seating configurations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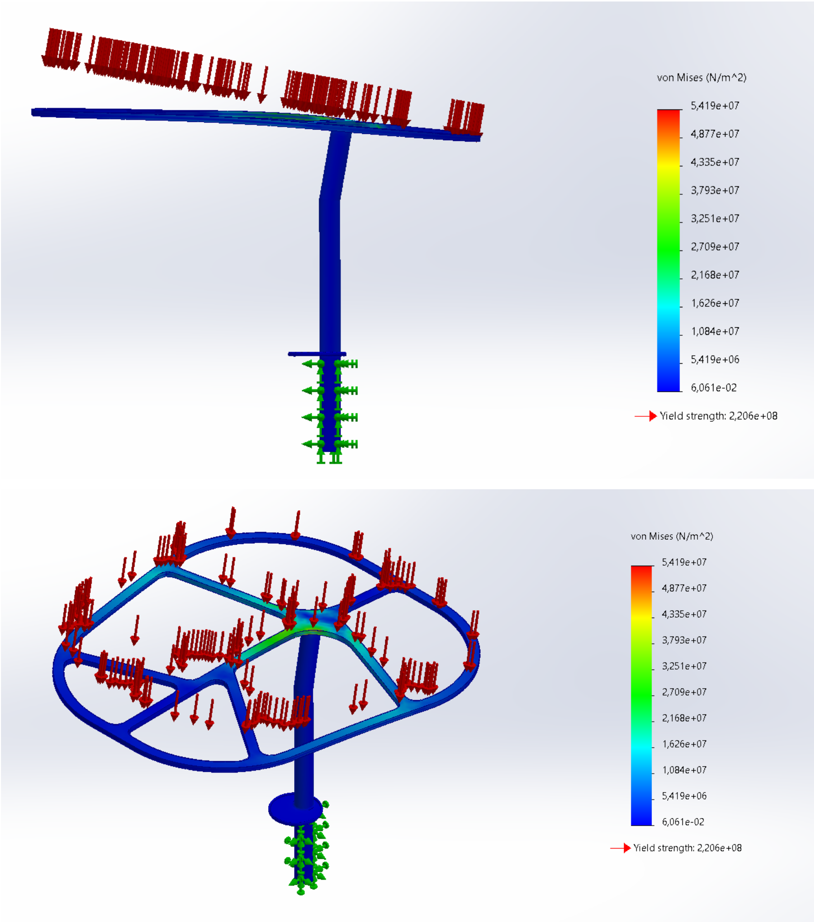
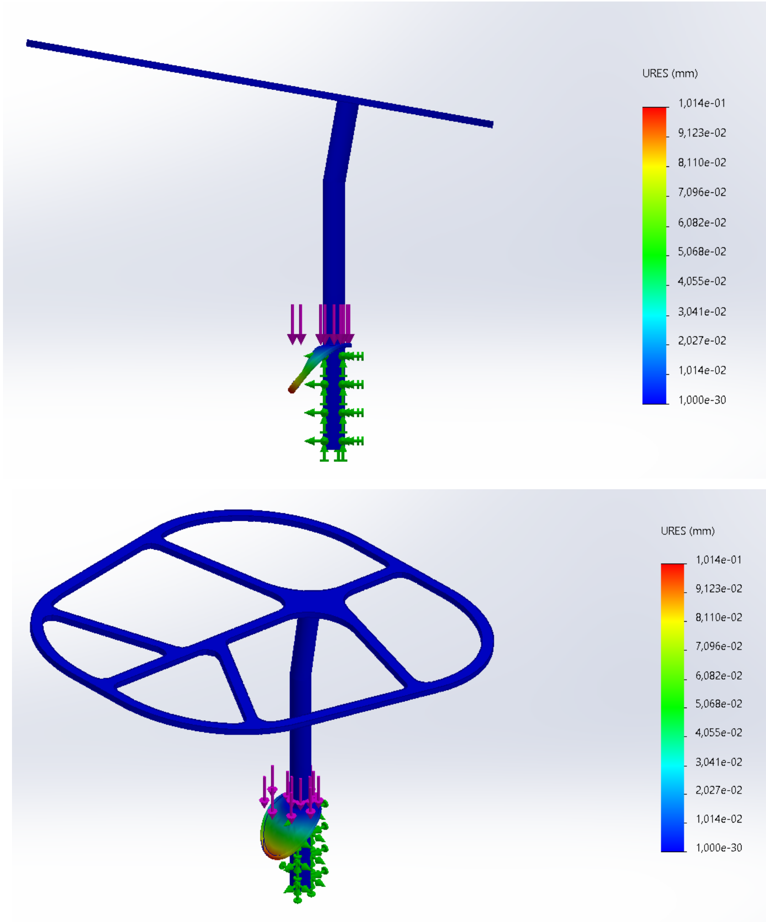
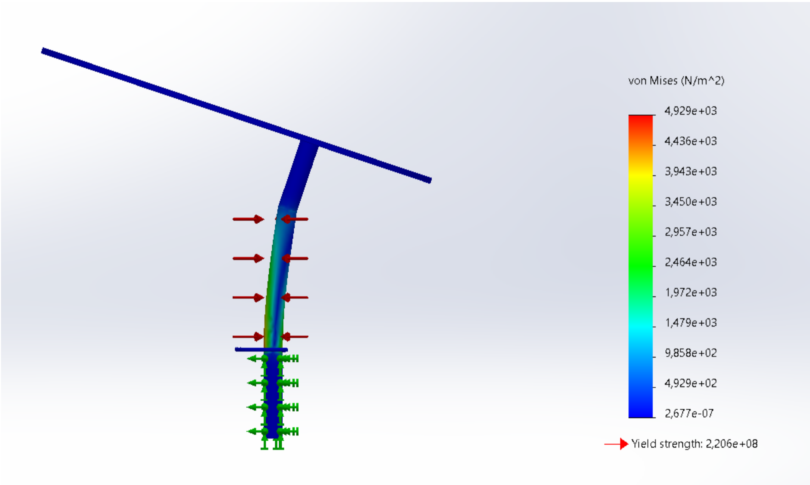
Appendix J: FEM analysis

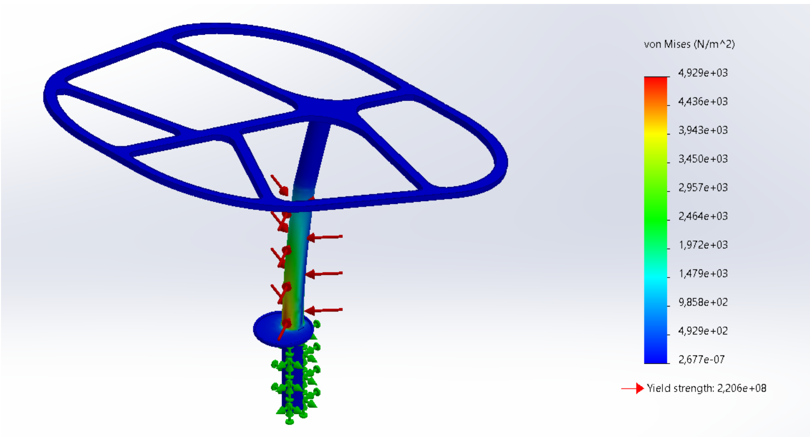


Person of 80kg hanging from the top frame. Notable deformation at the tip of the frame, so reinforcement of the structure (e.g. steel cables from top) is needed.



Person of 80kg standing on turning handle. Deformation of 0,1 mm.





Person pushing steel pole with 80kg of force.

Appendix K: Project brief

TU Delft

DESIGN FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

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

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	de Vos	IDE master(s)	IPD ✓ Dfl SPD
Initials	F.J.C.	2nd non-IDE master	
Given name	Rik	Individual programme (date of approval)	
Student number		Medisign	
		HPM	

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	S.C. Pont	dept./section	HICD
mentor	W. Schermer	dept./section	DCC
2nd mentor	Iris Dijkstra		
client:	Atelier LEK		
city:	Rotterdam	country:	The Netherlands
optional comments			

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

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in by the Chair of the supervisory team

Sign for approval (Chair)

Sylvia Pont - IO — Digitally signed by Sylvia Pont - IO Date: 2024.07.08 15:33:28 +02'00'

Name Sylvia   Date 8 Jul 2024   Signature

CHECK ON STUDY PROGRESS

To be filled in by SSC E&SA (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total		EC
Of which, taking conditional requirements into account, can be part of the exam programme		EC

★	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Rik Ledoux 2024.09.11 15:55:46 +02'00'

Name Rik Ledoux   Date 11 Sep 2024   Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	ALLOWED to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Monique von Morgen — Digitally signed by Monique von Morgen Date: 2024.09.25 10:20:22 +02'00'

Name Monique von Morgen   Date 25 Sep 2024   Signature

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Rik de Vos **Student number**

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Illuminate and Elevate: A biophilic luminaire design for Hofbogenpark

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Public lighting has significantly changed how we view and utilize urban areas at night. Most of the times, public lighting is viewed as primarily a technological problem rather than a human one, relying on mostly visual properties and excluding non visual human experience aspects (Goncalves, 2016). In the book: " The Comfort Crisis", Michael Easters states that happiness and mental wellness is found in experiencing wild nature. We evolved in nature and therefore have been programmed within our genes a need to be in and connect with nature and living things (Kellert & Wilson, 1993). Over the past few decades the time we spend outdoors has declined by 50% (OIA, 2023). The Biophilia hypothesis (Kellert & Wilson, 1993) suggests that nature and its processes are beneficial for humans and therefore, restorative. This includes attributes like natural light and natural materials. However, academic work for these specific attributes and their link to restoration is limited (Gillis & Gatersleben, 2015). The municpality of Rotterdam is currently developing a 2km long roof park (Hofbogenpark) where urban living people have the opportunity to enjoy/seek nature in the middle of the city. When looking at biophilic architectural projects, like the Hofbogenpark project, they are currently dominated by the use of natural forms/materials, lighting is often still very artificial.
This situation presents an oppurtunity to create and research new lighting strategies and products that make (better) use of the biophilia principles to improve the relationship/interaction between users well-being and energy management in a restorative environment. Since we are visually dominant creatures (Spence, 2020), I think designing with light is the most logical step to realise this. Designing for an urban environement has several advantages in comparrison to a rural area: there is higher foot traffic and a more diverse audience, thus a larger number of people can be reached more easily. In addition, there is a richer tapestry of architectual styles, thus more possibility of interaction with these elements. Lastly, a light installation in an urban environement can become part of the city's cultural identity.

An overview of the stakeholders and their interests can be found on the next page.

→ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 'Luchtpark Hofbogen' Rotterdam with its current luminaires

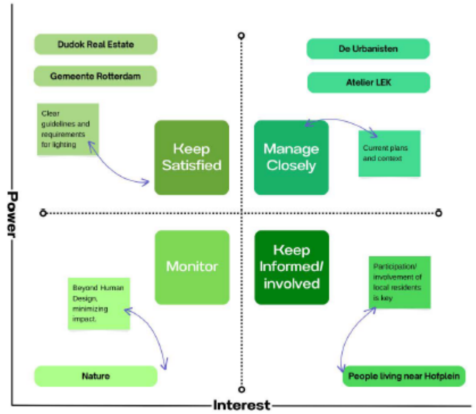


image / figure 2 Stakeholder map

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The current problem with light installations in parks/nature, is that they are mainly intended to illuminate the infrastructure for safety (Sloane et al., 2016), are static and do not promote interaction/playfull elements (in contradiction with nature), as can be seen in figure 1. Rahm et al. (2020) found that urban greenery and street lighting must be considered together, since their interaction influences perceived safety and impacts the walkability of mainly public parks. Since biophilic design has been found to support cognitive function, physical health, and psychological well-being in humans (Kellert & Wilson, 1993), it will be a great starting point for a public light installation and see if it is possible to create a luminaire that contributes to a sense of safety. Therefore, this project will have the following 3 research questions:

- Which factors/aspects contribute to a feeling/the experience of safety with regard to public (park) lighting?
The briefing from the municipality of Rotterdam about the Hofbogenpark shows that participation of local residents is key. Qualitative research fits in well with this.
- Is it possible to create a biophilic light(ing) environment within this context, taking into account the desired interaction/experience.
Biophilic design is often architecture designed mainly with natural materials and shapes with daylight or artificial white light.
- Is it possible to integrate the outcomes of the two research questions above?

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Through extensive research on biophilic design, influence of light in the public space and its contribution to a sense of safety, technological and aesthetic properties of light, I will design a sustainable luminaire in the "Hofbogenpark" that still contributes to a sense of safety and takes the experiential aspects into account, by using biophilic elements.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

First I will be doing research on the biophilia theory and deepen my knowlegde about biophilic design, the technical and optical properties of light. In addition, I will conduct a study on urban culture and its experiential aspects, influence of light in public spaces/parks and what factors contribute to a sense of safety, similar to the Culture study done in ACD. I will then come up with a design vision which will guide me what kind of luminaire I will be going to make.
Secondly, I will have the help of lighting designers and experts at Atelier LEK, Rotterdam, who can provide me with technical and practical insides in the practice of lighting design. I will be designing according to the research through design method, where I will research if I can create a biophilic 'effect' on people, with light in the context of Hofbogenpark. I will bring the results from the culture study and my findings about biophilic light together (working parallel) and see how this can be applied/integrated as a luminaire at the Hofbogenpark. Once I have a clear idea of how and if this results in the desired effects, I will go into the ideation phase. I will work out various concepts and will start prototyping. Once I have finalized my concept(s) I will go into the concept evaluation phase and test my full scale prototypes with real users, in real-life public space (Hofbogenpark).
After the concept evaluation I will make a final prototype and work on my documentation.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting and graduation ceremony****. 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 course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	9 Sep 2024
Mid-term evaluation	18 Nov 2024
Green light meeting	27 Jan 2025
Graduation ceremony	17 Mar 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✓
For how many project weeks	20
Number of project days per week	4

Comments:
In addition to my graduation project, I think it would be very valuable to work 1 day a week on other ongoing projects within Atelier LEK.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

My biggest dream is to later have my own design studio, where I can design objects/products that are not only functional, but also inpsirational. During the Lighting Design elective I took, I found out that I am really interested in the psycological element of light perception. Together with a current important topic, namely the comfort crisis and bewildering of people, I see this project as a perfect opportunity to combine every aspect of design that has intruiged me over the years, and make a real impact.

Since I have been growing up in an urban environement, I have always been thinking about the "Urban Jungle". Bringing more nature in to the concrete structures. I have experienced the positive influence that nature has on humans, and I am motivated to bring this to the city.

In addition, I have done an internship in furniture design and an internship in Industrial design, I found out that I am still curious how the lighting design industry works, so to be working with Atelier LEK is a great opportunity.

> Architects can’t force people to connect, it can only plan the crossing points, remove barriers and make the meeting places useful and attractive.

DENISE SCOTT