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Atmospheric Lighting for Public Space

TU Delft THESIS REPORT - INDUSTRIAL DESIGN ENGINEERING

Preface

"We can easily forgive a child who is afraid of the dark; the real tragedy of life is when men are afraid of the light."
— Plato

I have to admit, about a year ago I didn't know much about light. In retrospect, I am happy that I took up the challenge and did not go for the safe choice. Although I am a team player by nature, I have seen recent months as an itense, but great experience.

For this I would like to thank Sylvia Pont, who introduced me to the world of light and successfully guided me through the process. I also want to thank Makiko Higashi for her support and motivation during my thesis.

I would like to thank Iris Dijkstra for her professional support and for the opportunity to gain experience as a lighting designer during my graduation. In addition, I want to thank everyone who has supported me in a professional or personal way for their time, love and positive energy.
I am very grateful to the unconditional support that I have experienced from my girlfriend, my close friends and my family. Through them I feel blessed.

Tomas Daniëlse
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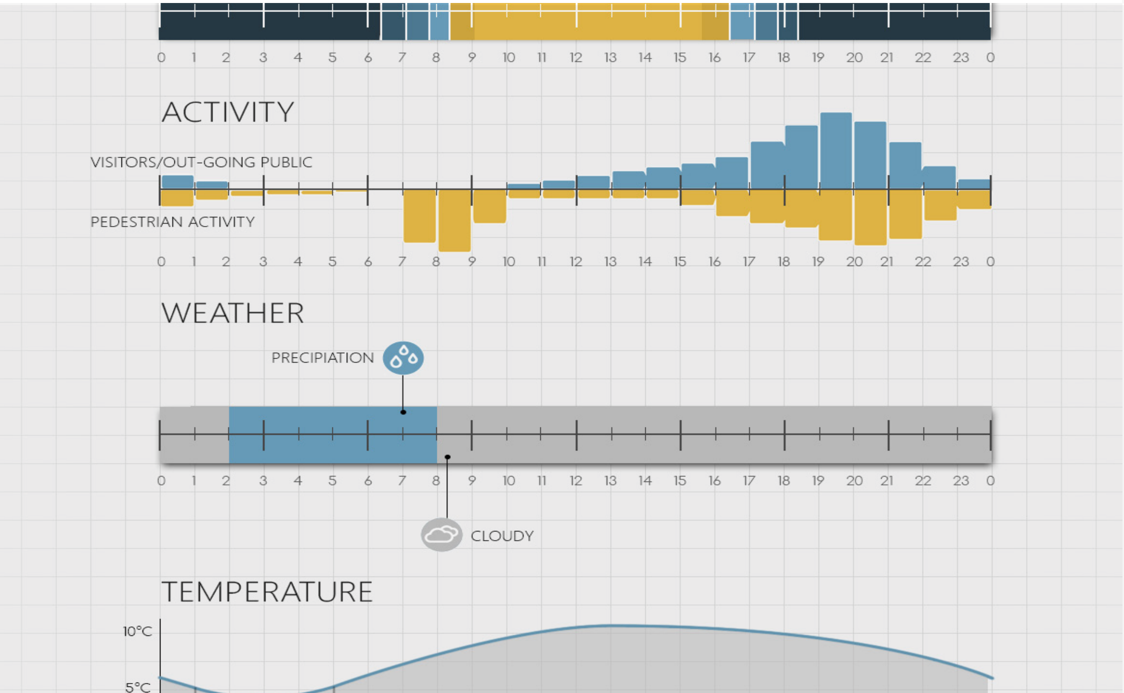
Summary

In this thesis, a luminaire is developed for the public space. The main purpose of this luminaire is to positively influence the state of mind of bystanders and improve the residential quality of the city centre. It does this by creating distinct atmospheres with adaptive light features, based on the use of public space.

To determine all the preconditions of such a design, an extensive analysis was carried out on all facets that are related to light. This covers both the physics concerning light and the (psychological) perception of that light. (Chapter 1 - 6)



After an analysis of the current role of light in the public space, the interests of all stakeholders have been framed. (Chapter 7 - 10) Based on this, a design vision has been drawn up; **"DEVELOP A PROGRAMMABLE LUMINAIRE WHICH HAS THE MAIN FUNCTION OF POSITIVELY INFLUENCING THE STATE OF MIND OF BYSTANDERS BY USING ITS ADAPTIVE LIGHT PROPERTIES TO CREATE DESIRED ATMOSPHERES',**

Within this vision, after several brainstorms, four concepts have been developed. (Chapter 11 - 12) The concept with the most viability has been used as the basis. The "iterative design" method has been applied within the thesis, with multiple models/prototypes being made; at first simple models (spuugmodellen), later more detailed scale models. Hereby, making prototypes has always been seen as a means, not as a goal. Physical models have been used to explore design areas and to validate design choices.

Because designing with light context is very important, a case study has been developed within this thesis; the centre of Tilburg. By dividing the city centre of Tilburg into three areas "residential area, shopping area and catering area", light scripts have been developed that respond to the (subconscious) needs of residents and visitors of city districts with their unique specific functions. (Chapter 13, 14, 18 & 19)

These light scripts are based on the adaptive (programmable) light properties of the developed luminaire. A hierarchical system has been developed for this that can determine light properties based on several external factors. These light properties are converted to a numerical system, which is used as input for programming the luminaire. (Chapter 17, 20)

The impact of the different light properties on the atmospheric perception of the light was determined in a test setup, for which a scale model of the final design was used. In this study, the prototype also functions as a proof of concept. Based on the results of the research, a conceptual model has been drawn up, in which the light properties of the luminaire can be determined on the basis of the desired atmosphere. (Chapter 21)

The thesis concludes with a feedback on the established preconditions, whereby a proposal is made for future research. (Chapter 22)

Although an attempt has been made to make the thesis report as visual as possible, it is difficult to transfer certain (dynamic) light effects to paper. To accommodate the reader in this loss, a folder has been created in which all (test) photos and videos are placed. This includes a summary video of 3 minutes. This folder can be found by scanning the QR code.

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1. Light and Perception

This first chapter will discuss how we as humans convert figures around us into the perception of our environment. The first thing that will be discussed is the psychology behind perception. Hereby the two most important factors are discussed that assist us in shaping this perception; contrast and order. (Where the latter will be discussed on the basis of gestalt principles.)
Thereafter, physiological aspects of light perception will be discussed. To what extent does our biology influence how we experience our environment?

Everything we see around us we perceive with the help of our eyes. Light is what makes all of this possible; The way in which it is distributed in the spaces around us determines how we perceive those spaces and the objects in them. Well installed (artificial) lighting ensures that we can perform certain tasks safely and effectively, but it also creates a certain atmosphere around us. The subjective perception of this atmosphere influences our state of mind.

1.1 Our Eye as a Camera

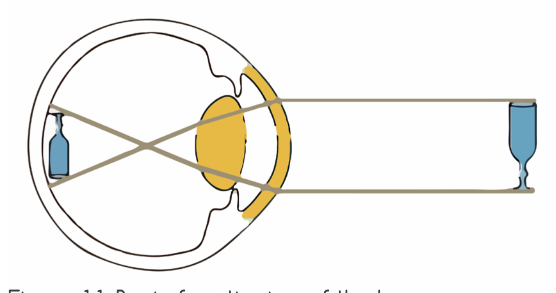


Figure 1.1: Basic functioning of the human eye

Similar to a camera, an figure of our environment is projected on the retina on the inside of our eyes. A deformable lens, together with the cornea, ensures that this figure is sharply rendered at all times. The iris acts as a diaphragm in this case; it determines how much light enters the eyes. The retina at the back of the eye contains photosensitive nerve cells, which send signals to the brain. These signals are then converted to an figure.

1.2 Perceptual Psychology

That final step, converting the information to our perception/impression of our environment is indispensable. When converting the signals, the brain uses prior experiences concerning perception. These prior observations are used as a reference for the perception of things around us. Information about our environment that can not be seen with the eyes, but is vital to evaluate our surroundings, will be complemented with memories.

When observing the environment, everything revolves around contrast. One of the tools that helps with this are differences in brightness. Brightness is perceived as the contrast between an object and its environment. Context also has a big influence on perception; A gray area on a white wall appears darker than the same gray area on a black wall, an effect called 'color contrast' (E. Adelson, 2000). The perception of lightness therefore is relative.

Figure 1.2: Relative color gray

The aforementioned contrasts are not only recognized on static figures. One of the things that we as humans are programmed to do is to detect temporal and spatial changes of objects in relation to each other within our field of vision. We use the recognition of shapes and brightness levels to do this.

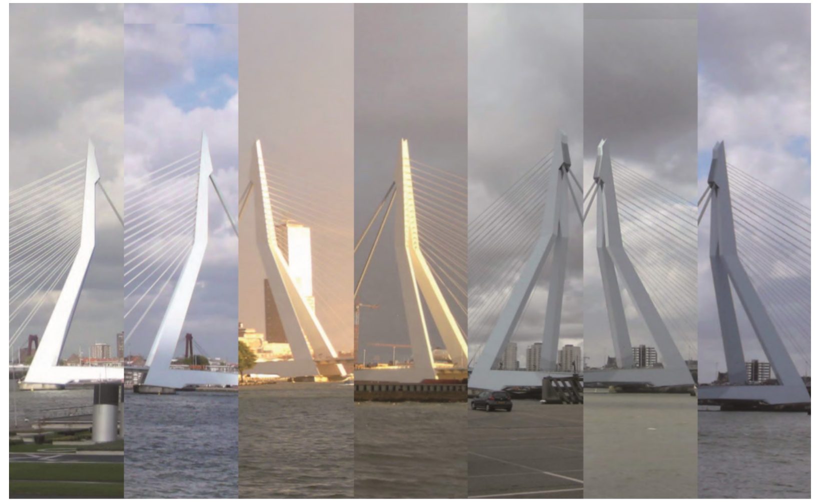


Figure 1.3: Rotterdam's Erasmus bridge under different weather conditions

By observing the light reflection of certain surfaces, we observe objects in relation to their environment. Although this visual perception of objects strongly depends on the light that shines on it, we as humans can put these differences in perspective.

In figure 1.3 you can see the Erasmus bridge of Rotterdam. Although the perceived color of the object differs greatly, the light reflection of the object, in this case the concrete construction of the bridge, is experienced as constant. This is because everything is seen in relation to the environment. In cloudy circumstances we expect the white concrete to look gray, but since we are able to discount the circumstances quite well, we still perceive it (in this case; the bridge) to be white. This ability of the human visual system is called 'color-constancy'. (Foster, 2011)

Unless the environment suggests otherwise, this perception subconsciously assumes that the light comes from above (Gregory, 1970). This is because most references can be linked to daylight (assuming the person is on the ground), where objects are illuminated from above.
This phenomena causes light that shines from below to change our perception of objects, in this case it's elevation and depth. This becomes clear when looking at the figure below. (The left image is perceived as convex and the right as concave, whilst it is the same image, rotated)

Figure 1.4: Perception of depth is based on assumptions

1.2.1 Gestalt Laws

An other thing that we subconsciously are programmed to do is looking for order. To make the complex perception of the environment easier, the brain is constantly looking for patterns. When designing with light, you are expected to take this phenomenon into account. This phenomenon is described in the so-called "gestalt" (German for "organized") psychology.

Gestalt psychologists have discovered that our brains create three-dimensional representations of two-dimensional figures. The principles of this are based on shape, color, distance and movement of objects in their environment. Seven relevant principles for lighting design will be explained.

- Principle of proximity (grouping)
- Principle of similarity
- Principle of closure
- Principle of good continuation
- Principle of common fate
- Principle of common region
- Principle of element connectedness

1. **Principle of proximity.** All elements that are close to each other are considered as a unit or group and are separated from elements that are further away from each other.

Figure 1.5: Example of principle of proximity

2. **Principle of similarity.** Elements that resemble each other (and are close to each other) are considered as a whole.

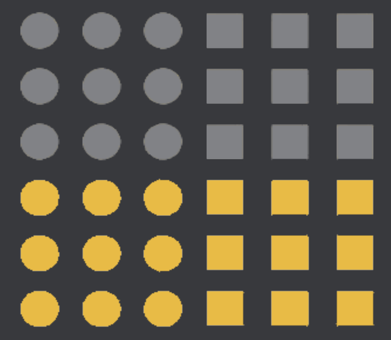


Figure 1.6: Example of principle of similarity

3. **Principle of Closure.** Uninterrupted and neatly finished figures are preferred to incoherent or interrupted figures. In such cases the brain itself will give an ideal interpretation to this figures.

Figure 1.7: Example of principle of closure

4. **Principle of good continuation**. We follow lines, even when they seem to be interrupted.

Figure 1.8: Example of principle of good continuation

5. **Principle of common fate.** When objects move in the same direction, these objects are associated with each other.

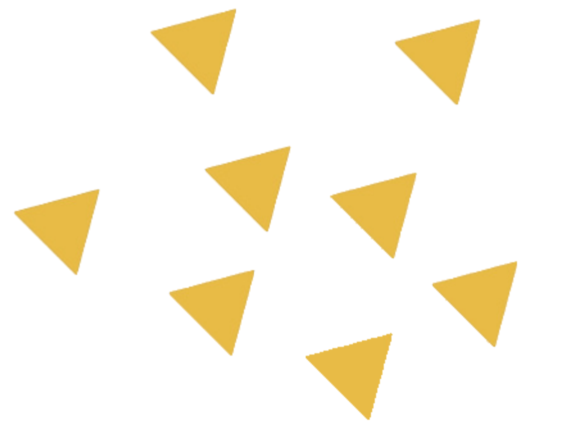


Figure 1.9: Example of principle of common fate

6. **Principle of common region.** Elements in a closed region are grouped.

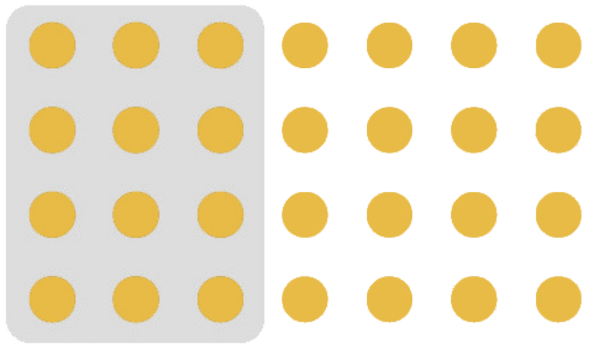


Figure 1.10: Example of principle of common region

7. **Principle of element connectedness.** Elements that are linked by other elements are grouped.

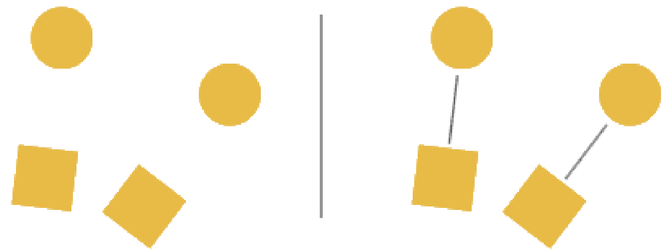


Figure 1.11: Example of principle of element connectedness

These principles are based on the one hand on innate properties of our visual system and on the other hand on the aforementioned references of the memory. Based on previous experiences and visual references, the brain can group and segment patterns existing of multiple elements.

1.3 Perceptual Physiology

Although the perception of an environment is different for each person (inter alia due to congenital and individual differences, partly created due to differences in references that come to mind when processing figures), there are a number of biological issues that apply to all people regarding the perception of our surroundings.

1.3.1 Visual Field

In order to be able to properly perceive what we see, a person filters part of his / her field of view. Within this field of view, it will search for objects, figures, and changes. While movements can be observed within 188 degrees, details can only be discerned within the foveal vision; the part of the retina that permits full visual acuity.

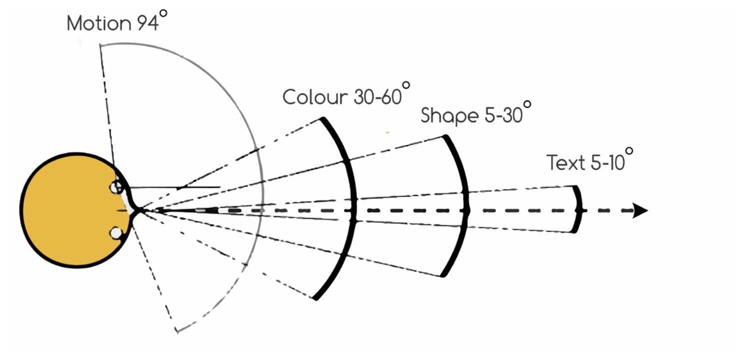


Figure 1.12: Field of View; our focus determines the amount of information we evade from our surroundings

This field of view is important when it comes to functional lighting. The visual performance (and therefor also the field of view) is dependent on the luminance levels. Functional lighting is built to support certain (visual) tasks. It is very dependent on whether it is about movement-related movements and whether details or small contrasts in brightness or color should be perceived.

1.3.2 Visual Performance

The quality of vision and illuminance are strongly connected. To a certain extent, increasing light intensity is equivalent to improving visual performance. With visual performance, the extent to which things are visible in relation to their environment and the extent to which visual tasks are considered.

The visual performance increases in relation to the increase of the illuminance up to 1000 lux, above 1000 lux, it stagnates. If the illuminance is too high, it drops considerably, since the luminance is considered overexposed. For workplaces often values between 1000 and 2000 lux are recommended. Visual acuity is measured to assess visual performance. The figure below shows the illuminance influences this. It has also been given that visual acuity decreases as people age. (Figure 1.13)

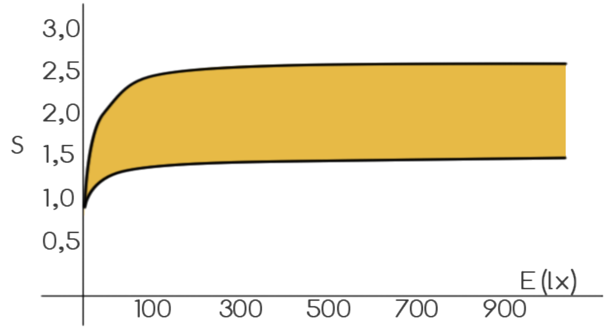


Figure 1.13: Visual acuity in relation to illuminance

To create optimum visibility, luminaires should provide the right amount of contrast. Spaces with little contrast are experienced as boring and uninteresting, whereby spaces with a lot of contrast are perceived as annoying and over-stimulating.
When determining the optimal distribution of light, one must look beyond the properties of the luminaires. The relationship between it's light and the objects it illuminates is the basis for the brightness that we experience. It is therefore necessary to observe this symbiosis for each space. Furthermore, the aforementioned gestalt principles must also be taken into account when placing luminaires.

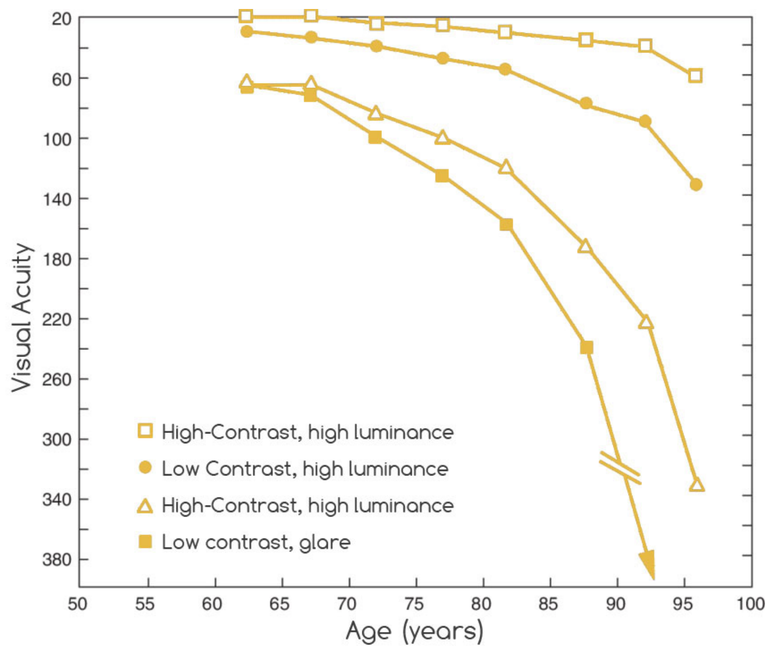


Figure 1.14: Visual acuity in relation age (This is a representation of the aquity. In reality is it highly user dependent and context plays a significant role)

1.3.3 Photopic view

As discussed before, the extent to which we are able perceive our environment greatly depends on the amount of light around us.

Within sensory physiology, the vision is subdivided into three categories: photopic, scotopic and mesopic vision.

- **Photopic vision** describes viewing your surroundings in a well-lit environment (luminance level 10-10^ 8[cd/m^2]). Within this view, perception of color is possible and there is a high visual acuity.
- **Scotopic vision** describes viewing in a poorly lit environment. Hereby the pupil is wide and colors are hardly distinguished. There is a significant decrease in visual acuity compared to photopic vision.
- **Mesopic vision** covers the transition region between photopic vision and scotopic vision.

Exact values between these different types of vision cannot be given, since the boundaries are smooth and differ per person.

The difference in perception can be linked to the difference in receptors that are active. The cones in the eye ensure photopic vision. The bars, which are a lot more sensitive, provide scotopic vision. Naturally, both receptors are active in mesopic vision. Because the bars are more sensitive, there is a difference in color perception between photopic and scotopic vision.

The figure shows the light sensitivity curve, where the scotopic light sensitivity curve is shown in blue and the photopic in red. It can be seen that with photopic vision the maximum light sensitivity lies in the green part of the spectrum, where the maximum with scotopic vision lies in the blue/green part of the spectrum.

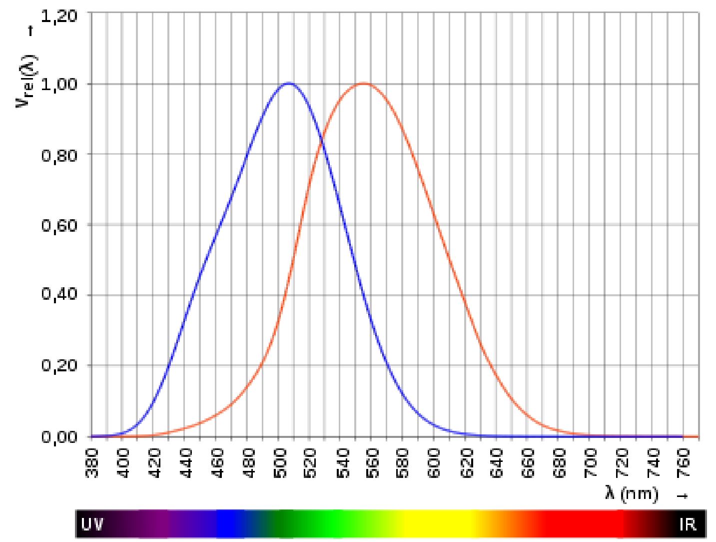


Figure 1.15: Light sensitivity Curve

Because the light sensitivity shifts to the blue side of the spectrum, shades of blue appear brighter in dark surroundings. Because of this we perceive moonlight more blue (colder) than it is; It is actually more red. Such occurrences are also called the Purkinje effect.

Because rods are insensitive to red light, this light can be used to illuminate surroundings without causing adaptation of the eye. An example of this application of red light can be found in submarines or other ships; A machine room during night is illuminated with red light. All buttons are therefor visible, but when one has to go outside at night, the eye does not have to adapt to the darkness

Figure 1.16: Red light in operation room submarine

1.3.4 Light and Dark Adaptation

Reducing the sensitivity of the eye when entering an environment with a lot of light from a dark environment (think about the opening of curtains in the morning) takes about 5 minutes. The majority of the conversion however, already takes place within the first 20 seconds. Dark adaptation on the other hand takes about 10 minutes. It can take 30 to 40 minutes for the bars to be completely in rest position (these are brought into rest position because no colors can be seen in the dark).

With people with a disorder such as night blindness, it may take longer for vision to be fully adjusted. Also smaller viewing areas can be experienced in relation to daylight, or a degree of myopia to be formed during night hours. When designing light for public spaces, one must take into account the limitation of light and dark adaptation. Often in tunnels this is not yet properly applied and the transitions from light to dark and vice versa are considered abrupt. This can have adverse consequences for perceptual- and road safety.

1.3.5 Glare

There are two types of glare: indirect and direct glare. In the first-mentioned, undesired light sources interfere with the perception of the environment by means of glimmering. (e.g., the reflection of sunlight on someone's jewelry or watch directed in your eye) In the latter, light sources with high luminance levels cause a lack of visual performance. (Looking directly into the sun). The latter is also called "disability glare".

Figure 1.17: Indirect glare created by the reflection of materials

Because the transparency of the eye changes over time, older people are more sensitive to glare than younger people. Certainly when it comes to traffic safety, this fact must always be taken into account when placing light sources. Discomfort glare is glare that undesirably attracts attention and prevents us from observing what we focus on.

Figure 1.18: Glare created by direct (sun)light

2. The Quality of Light

This chapter will explain how the quality of light can be determined by quantitative measurement values. It forms a physical view on decomposing light and determining the quality of light sources.

2.1 Light Spectrum

Visual light is only a small part of the entire electromagnetic spectrum. The spectrum ranges from cosmic waves (10^6 - 10^3 [nm]) to audio frequencies (> 10^14 [nm]).
The visual range, which can be seen below, lays between 380 and 780 nm, can be linked to the light distribution of sunlight.

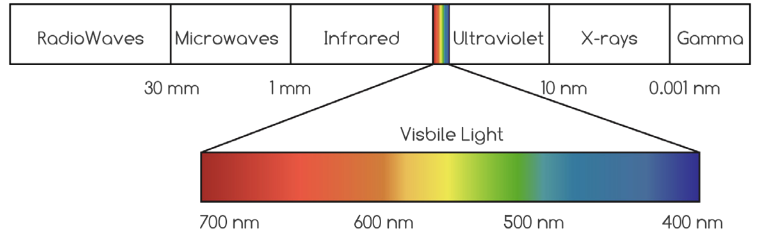


Figure 2.1: The visual spectrum

2.2 Luminous Color/Color Rendering

Our eyes are able to make an impression of the spectral composition of a beam of light. With this the light can be seen as a color. This is called "luminous color". The extent to which certain objects can absorb colors and the way light is filtered through these objects is also visible. The spectral composition that is radiated by such an object is called "object color." (A red t-shirt does not emit red light, the material has the properties to absorb certain wavelengths of the light, so that the composition of the reflection that remains is experienced as red.)Multiple systems have been developed for describing colors. The two most used will be briefly explained.

2.2.1 Munsell System

The munsell color system is a color space that specifies colors based on three properties; the hue, the value (lightness of the color) and chroma (the purity of the color).Figure 20 shows that hue is measured in degrees (on horizontal circles), value by a point on the Z-axis (0 = black and 10 = white) and chroma is measured by the length of the radial.

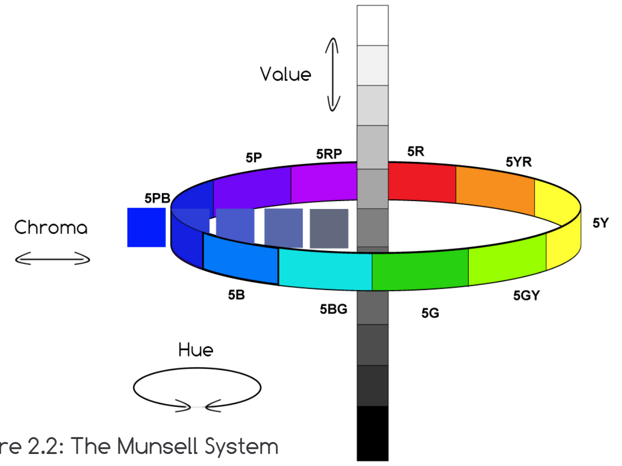


Figure 2.2: The Munsell System

2.2.2 CIE's Chromaticity Diagram

This diagram is a 2D representation of the quality of colors. The colors is defined by the hue, saturation and brightness

- The hue is represented as an angle; In the middle of this diagram the "white point" can be seen. When straight lines are connected to the corner points through this point, one can determine the hue by the position in which the vector is located.
- Next to this, a second quantity is defined; the saturation (this, for instance, can indicate the difference between pale and bright blue). Colors that are described as points on the outer edge of the diagram are the colors with the highest saturation, colors close to the "white point" are considered colors with low saturation. Additive combinations of colors lie on the lines that connect these two color loci. E.g.; a combination of green and red light can create yellow light.
- A third dimension, which is not shown in Figure 2.2, described the brightness of a color. This brightness can be defined by an axis that is perpendicular to this 2D representation of chromaticity (which does not include brightness)

The curve that can be seen on the diagram and shows the chromaticity of a black body radiator. The linear lines drawn through this curve are used to describe the color temperature of luminaires

- X < 3300 K = warm white
- 3300 K < X > 5000 K = neutral white
- X > 5000 K = 'daylight white'

(When this color is linked to objects instead of light, we refer to the result of spectral composition of light being reflected by an object, and thus we look at what wavelengths an object absorbs)

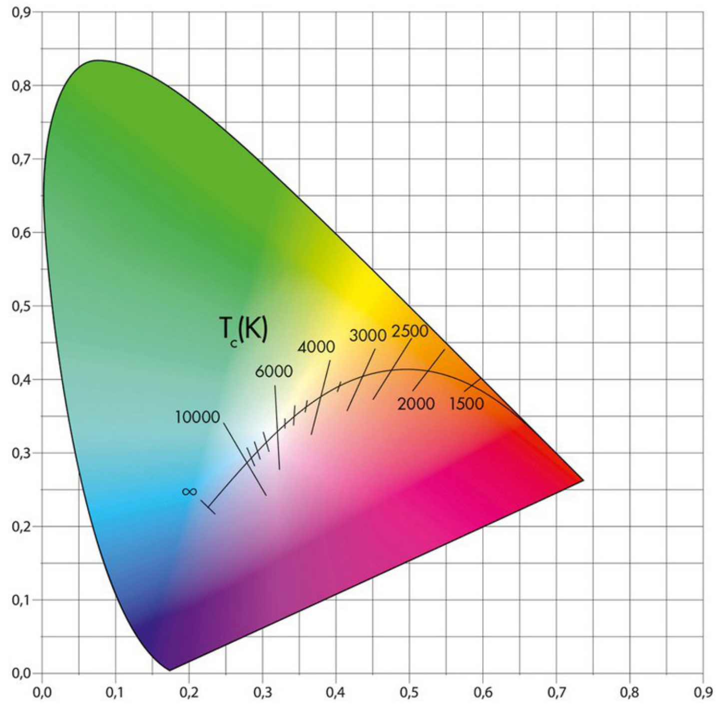


Figure 2.3 CIE chromaticity diagram with black body radiation curve

As discussed before, the human visual model perceives objects as being the same color, although it is illuminated by different colored light. This feature is referred to as color constancy of chromatic adaptation.

2.3 Preference Color Temperature

One of the assessment models prepared for determining the color temperature for functional lighting is the kruithof curve (Kruithof, 1941). The Kruithof curve connects the illuminance of light sources compared to their color temperatures. It can be seen that warmer light sources are generally preferred when the illuminance is low.

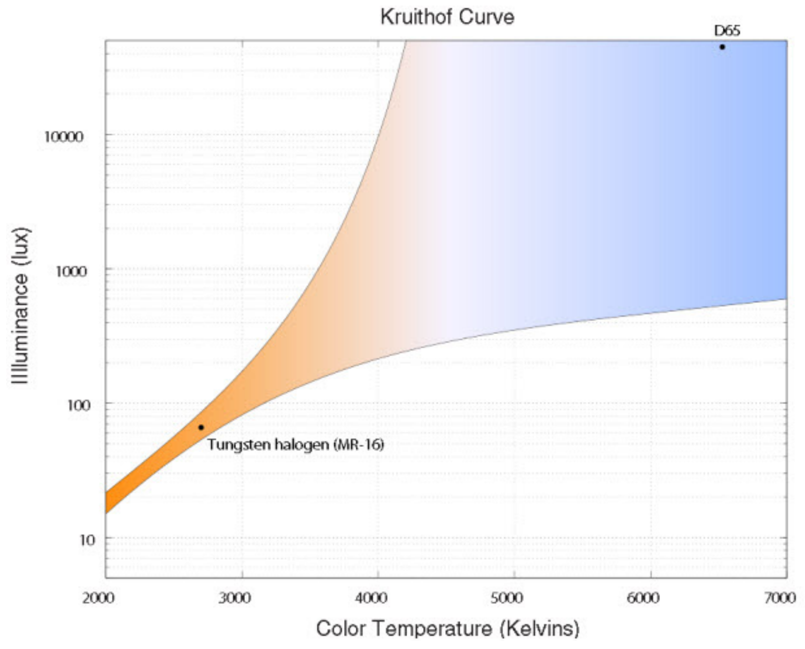


Figure 2.4: The Kruydthof Curve

2.4 Luminous Flux

The luminous flux is the total amount of light that is emitted by a light source. Where normally Watts could be used as a measurable unit, this is measured in Lumen to include the sensitivity of the eye in the calculation. 1 Watt of radiation flux at 555 nm produces 683 lumen. At other wavelengths the luminous flux will be lower. (This can be seen by the light sensitivity graph). As discussed before, this is dependent on whether the light is within the scotopic of photopic range.

Φ = Lumen (lm)

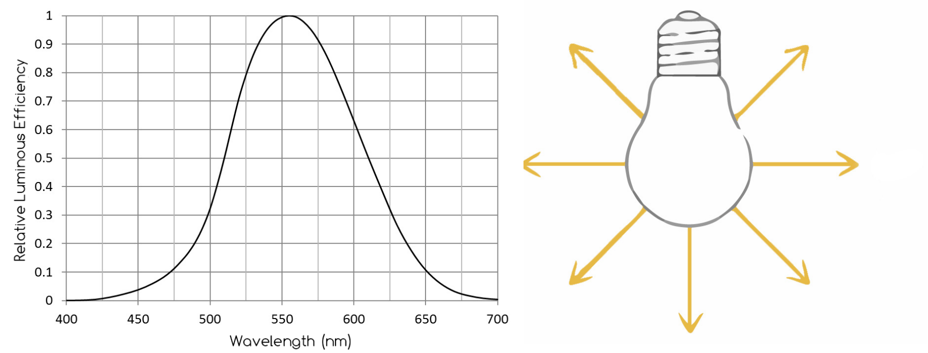


Figure 2.5: The luminous flux is dependent on the sensitivity of the eye.

2.5 Luminous Efficacy

The light efficacy is the ratio between the luminous flux and the consumed power and is therefore a property of the light source. It is expressed in terms of lumen/watt.

If a lamp delivers 200 lumen with a consumed power of 3 watts, the luminous efficiency is 200/3 = 66.6[lm/W]

2.6 Spatial Light Distribution

Where a theoretically ideal point-light distributes the flux uniformly around itself, this is often different in practice; the emitted light is not uniform. How a particular light source spreads its light is indicated by the spatial distribution. This depends on the design of the light source and the way it is directed. The unit in which this is measured is Candela (cd).

The ratio between horizontal and vertical light has strong influences on the luminous texture, highlights and shadows. However, the extent of these influences can only be determined when looking at the environment of the light source.

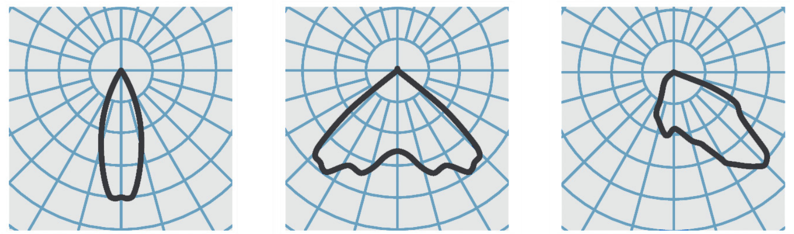


Figure 2.6: examples of spatial light distributions

The distribution of a light source can be represented in a three-dimensional diagram. When the light sources have axial symmetry, a two-dimensional diagram is sufficient. Above you see three examples of 2D spatial light distribution from different light sources. From left to right, these are respectively examples of a narrow light source, a wide light source and an asymmetrical light source.

To make comparisons between different light sources, an output of 1000 [lm] is taken as standard. Desirable light distribution must be determined per environment. For example, an art gallery often contains more horizontal light (to frontally illuminate the objects), whereas this is far from desirable on for instance a football field. (Due to the prevention of glare when playing sports)

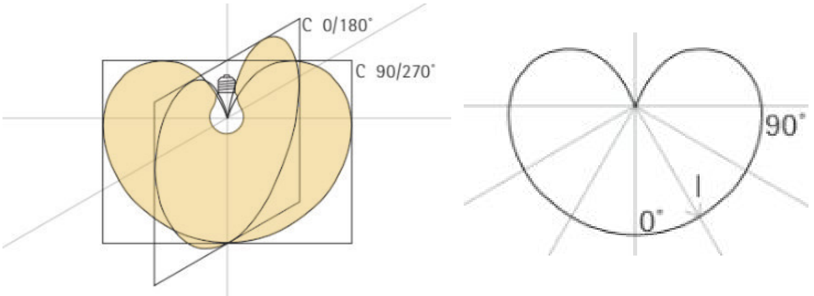


Figure 2.7 Light distribution (3D on left, 2D on right)

This example of a classic light bulb shows that the light source has an axial symmetrical light distribution. It can also be seen that the lighting is uniform (and ambient); there is just as much horizontal lighting as vertical lighting.

2.7 Illuminance

Illuminance describes the amount of luminous flux that falls on a certain surface. This surface can be both real and fictional. The illuminance is often divided into horizontal and vertical illuminance, as can be seen in the figure below.

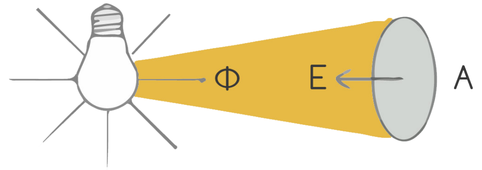


Figure 2.8: Illuminance

2.8 luminance

Luminance is the brightness of an object from which light is emitted. This is described as the luminous intensity in relation to the surface (Cd/m^2). Luminance forms the basis for describing the perceived brightness.

The luminance of an illuminated surface is proportional to the illuminance and the reflection of the object

3. Light in Nature

In this chapter, sunlight is discussed and how the perception of sunlight changes during the day. Next, it is discussed how light manifests itself in nature and how the properties of this light can be copied to design biomimic light.

3.1 Sunlight

3.1.1 The spectrum of sunlight

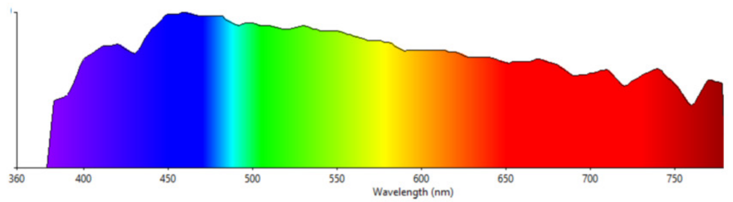


Figure 3.1: the spectrum of sunlight

Figure 3.1 shows the spectrum of sunlight. It is a combination of all wavelengths together. Through additive color mixing of light colors, these colors are together experienced as white light. As can be seen on the image below, the sun is perceived as white when being viewed from space.

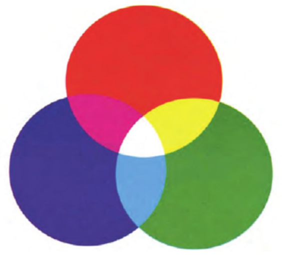


Figure 3.2: Additive Color mixing

Figure 3.3: an image of the sun from outside the atmosphere

However, here on earth we see the sun as a yellow sphere. This is because the different wavelengths of sunlight are scattered by oxygen and nitrogen molecules, which are present in our atmosphere to a large extent (21% and 78% respectively). In this occurrence, called Rayleigh scatter (named after scientist Rayleigh), the smaller waves (blue part of the spectrum) are scattered more than the longer wavelengths (the red part of the spectrum). This occurrence can be seen in the image below.

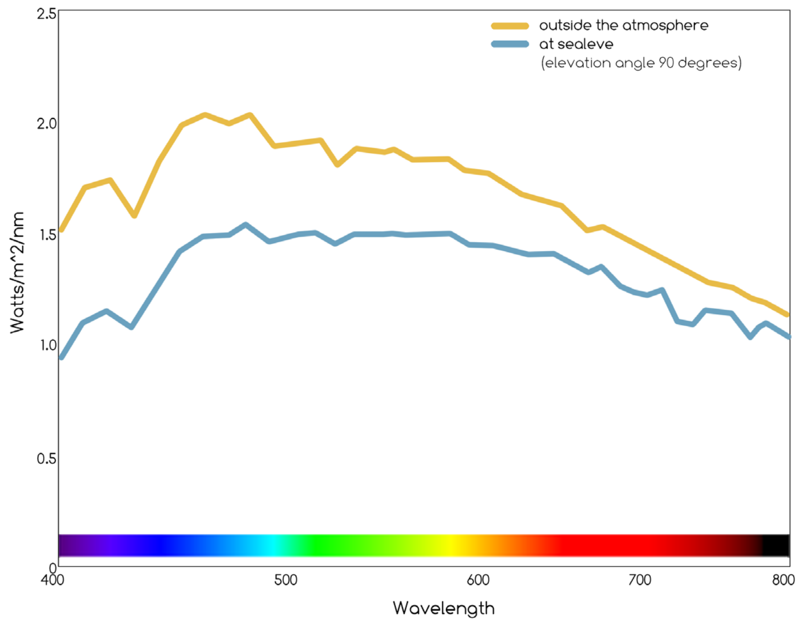


Figure 3.4: The spectrum of sunlight inside the atmosphere versus outside the atmosphere

Because a part of the blue light is reflected by these molecules, we perceive our atmosphere as blue and we perceive the sun as a yellow sphere from the earth's surface.

3.1.2 Sunrise and Sunset

During sunrise and sunset (of which the characteristics are indistinguishable), the color of the sunlight changes. This is caused by the angle of incidence of the sun's rays. At sunrise and sunset the sunlight enters the atmosphere at a smaller angle.

Figure 3.5: A timelapse of the sun during sunset

As a result, the rays have to travel through a larger part of the atmosphere. Therefore most wavelengths, except those in the red part of the spectrum, are reflected by molecules in the atmosphere. This can be seen in figure 3.4 and 3.6.

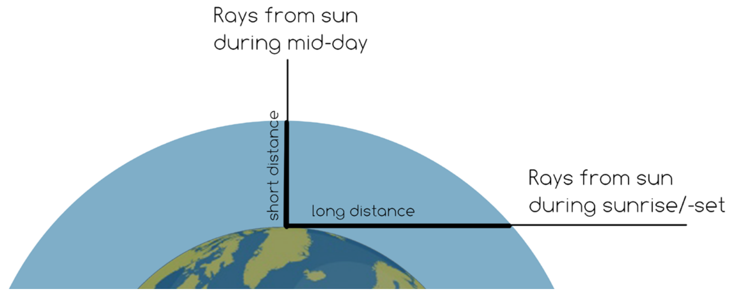


Figure 3.6: angle of incidence of sunlight

The sunrise and sunset can be divided into 3 phases;
the civil twilight, including the golden hour, the nautical twilight and the astronomical twilight.

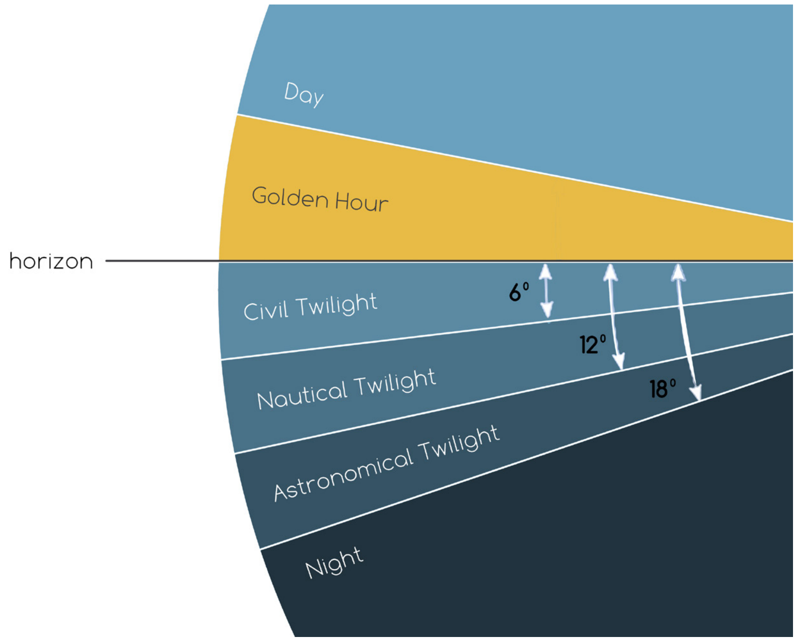


Figure 3.7: A Visual overview of all phases durig twilight

Civil twilight
Until the sun is 6 degrees below the horizon, we speak of civil twilight. Visibility is still good during this phase. It is still possible to read without artificial light.
The period during sunrise or sunset where the sun is above the horizon is reffered to as the 'golden hour', characterized by the warm light of the sun.

Nautical twilight
Between 6 and 12 degrees below the horizon, the civil twilight changes into the nautical twilight. The visibility is greatly reduced in this phase; it is only possible to observe silhouettes.

Astronomical twilight
When the sun is between 12 and 18 degrees below the horizon, the next phase starts; the astronomical twilight. In this phase it is already very dark, there is only some light coming from the north. Stars become visible during this phase. From May to July this is the darkest phase of the night in the Netherlands. The sun is not lower than 18 degrees below the horizon in this period.

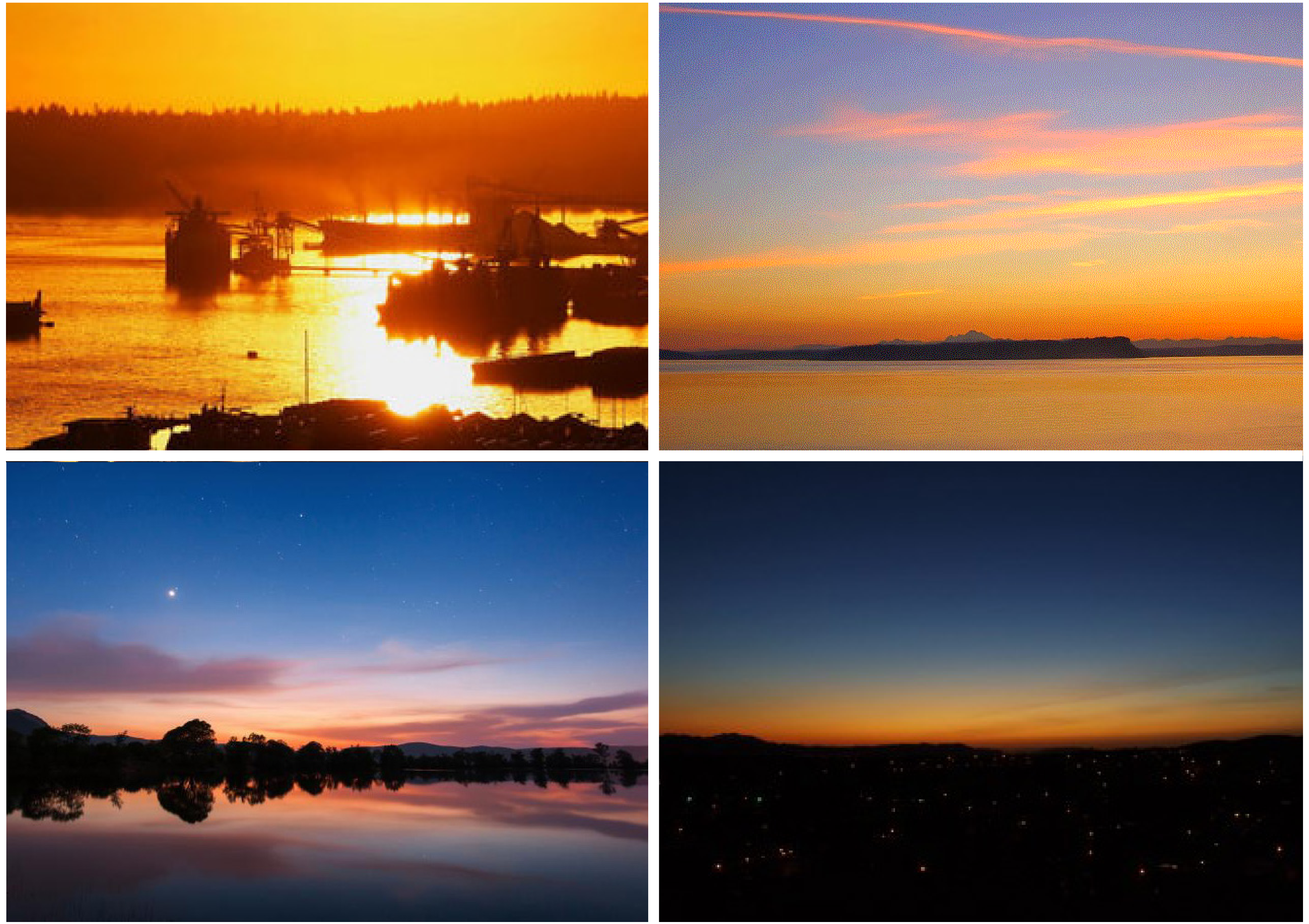


Figure 3.8-11: From top left to bottom right examples of: Golden hour, Civil Twilight, Nautical Twilight & Astronomical Twilight

3.2 Biophilia

Biophilia is 'the innate desire to be connected to our environment and other living things' (Wilson, 1984). A positive link has been proven between biophilia and our mental health. Light can also play a role in this. Light can help us stay in sync with our natural rhythms. But apart from this, biomimetic lighting, mimicking natural patterns, provides the greatest form of pleasure. Helms et. al. 2009)

Natural light can best be simulated by applying the following properties:

- Use light that changes over time; in terms of intensity, color, direction and quality
- Alternate between predictable and unpredictable patterns
- Provide dynamic lighting; create variable visual experiences; according to the time in the day use bright light or vivid colors (as can be seen in sunsets)

Figure 3.12: Light in Nature; sunlight through canopies

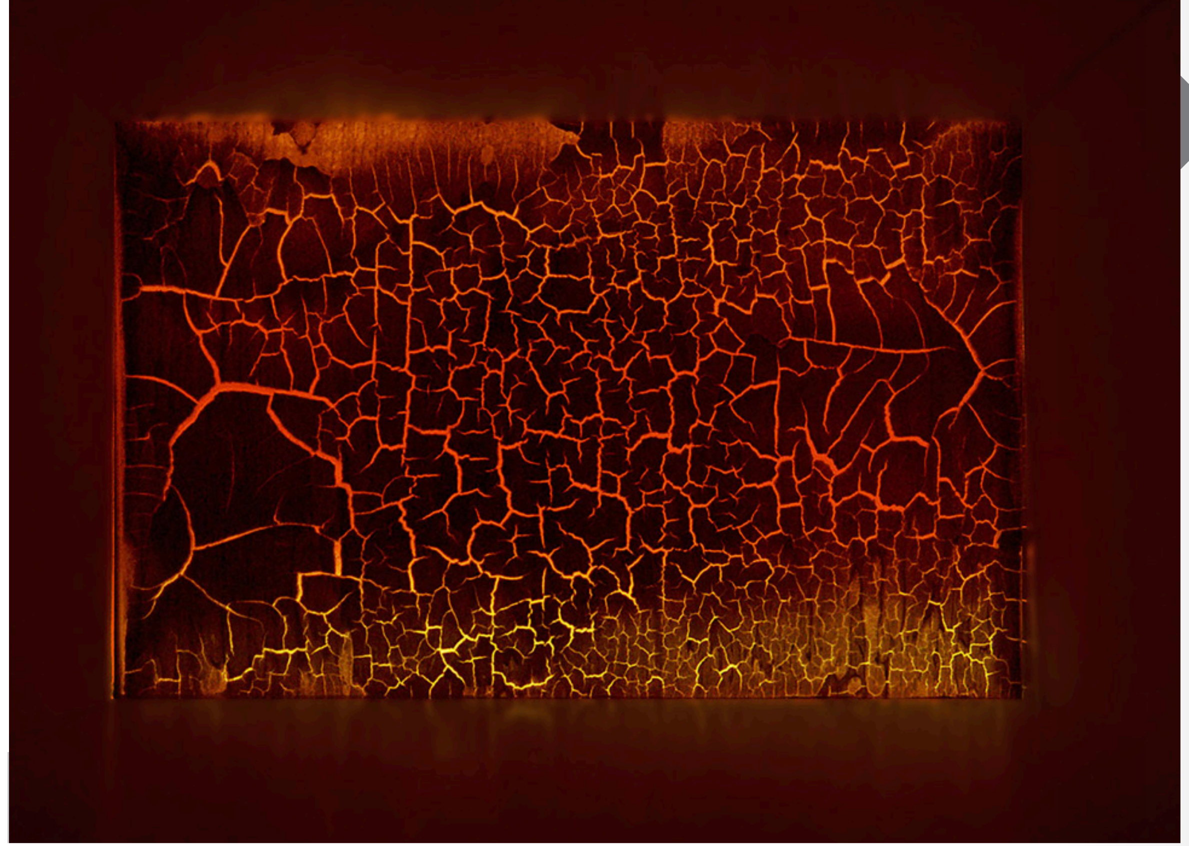


Figure 3.13: Art installation 'as it is cracking' visualizes how the weather outside is changing

Figure 3.14: Skies fromall over the world visualized into 1 figure

3.2.1 Biomimicry in Light Art

Where biophilia is already widely used is light art. An example of an artist who has made biomimetic lighting her specialization is Maja Petric. She translates the versatility of light into nature for inspiration for her dynamic light installations for indoors.

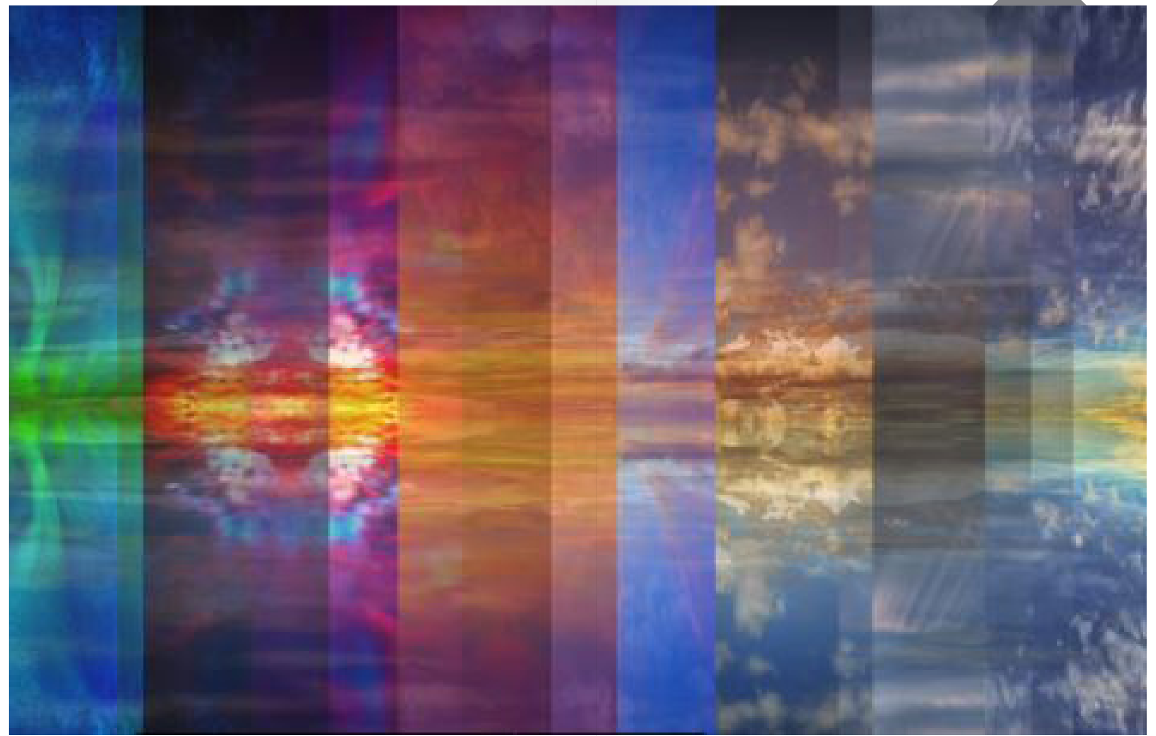


Figure 3.15: Art installation 'SKies' uses projection to create an interactive emotive experience

Figure 3.16: Maja uses light projections and sounds to mimic rain

4. A View on Lighting Design

Two professional lighting designers will be briefly discussed in this chapter; Richard Kelly and William Lam. Both designers are the founders of the contemporary view on lighting design.

Perception Oriented Lighting Design
More and more, designing with light focuses on human perception rather than the physiological view on figure processing. The person behind the eyes is becoming increasingly important.

4.1 Richard Kelly

One of the founders of qualitative light and lighting design as a profession is Richard Kelly. Until the 1950s, lighting was often based on the guideline that uniformity in lighting intensity had to be strived for. Richard Kelly withdrew from this and created his own theory, dividing light into three basic forms; ambient luminescence, focal glow and play of brilliance.

4.1.1 Ambient Luminescence

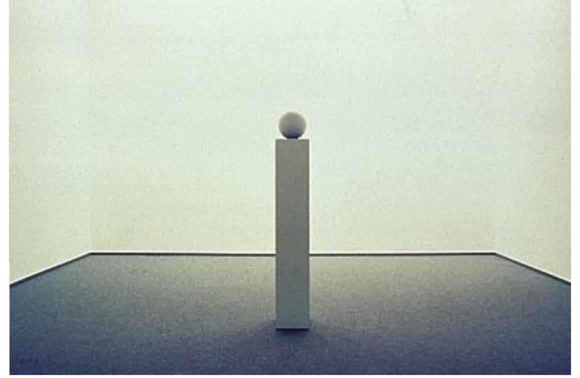
Ambient light forms the basic layer of light. This light is the light that provides the general illuminance of spaces. This base layer ensures the visibility of objects and people around us. This concept therefore largely corresponds to the quantitative lighting design

4.1.2 Focal Glow

So-called "focal glow" can be added to this base layer. As directed light, this layer is very important in transferring information from objects, by creating contrast and focus. It is based on the fact that man's attention is automatically drawn to areas that are more enlightened than its environment. Kelly used these differences in enlightenment, for example, to indicate difference in main- and secondary entrances.

4.1.3 Play of Brilliance

A third form of light in Kelly's analysis is "brilliance". Where focal glow helps to analyze objects around us, brilliance actually contains information. It contains all the reflective effects of light either through reflection of certain materials or through the use of multiple point-light sources. This light can, according to Kelly, provide liveliness and atmosphere to spaces, when used properly.



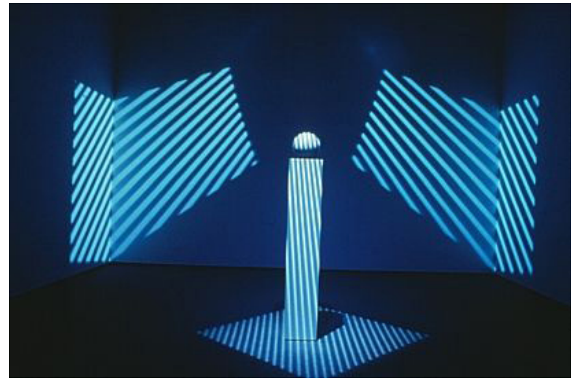


Figure 4.1-3: f.l.t.r. examples of ambient light, focus light, and brilliance

4.2 William Lam

A lighting designer who uses Richard Kelly's theory to design qualitative light is William Lam. Fascinated by psychology, he analyzes the wishes for light from the needs of humans. He divides these needs into several groups.

4.2.1 Activity Needs

This first group regards the need for information. These needs are based on the execution of tasks and the visual information that is required to perform these tasks properly. William emphasizes that an analysis of these tasks is necessary to be able to design customized light.

4.2.2 Biological Needs

A second group of needs are the so-called "biological needs". Where the first group requires the information to perform certain tasks, this is information that meets the psychological needs of people when they are in a certain environment.

These needs are mainly subconscious and linked to emotions and well-being. We subconsciously record everything around us and visual changes in this environment are immediately noticed with the aim of analyzing whether our behavior should be adjusted.

Need for orientation
As a human being, we are constantly subconsciously concerned with our environment and the routes in which we can move in that environment. We also take in weather conditions, partly to offer us a perception of time and potential dangers.
Places where light is absent and this orientation is not possible, such as dark alleys, are experienced as dangerous and undesirable.

Search for structure
We are also constantly looking for structure. Busy spaces can therefore cause over-stimulation. Light can help to create order in the perception of our environment. One of the means of doing so is highlighting important objects in relation to the "background".

Communication & privacy
A third biological need identified by William is the need for social contact (communication) and the need to seclude. Here, both extremes are logically very undesirable. Light can play an important role in fulfilling this biological need.

Figure 4.4: The subway in Boston, one of the famous designs of William Lam, with all biological needs considered

5. Controlling Light & Optimizing Visibility

This chapter will discuss how the quality of light discussed in the previous chapter can be controlled and optimized. After the perception of light is discussed based on how it illuminates objects around us, it will be discussed how luminaires can be optimized to obtain a desired quality. The chapter concludes with the description of all types of luminaires and their properties.

5.1 Diffuse & Directed light

These terms can be well described through weather conditions. Where a foggy cloudy day brings a lot of diffuse light, direct light can be linked to the light and shadow of sunlight on a clear day.
In a room where much diffuse light is considered beneficial, the use of light walls and objects is desirable. Where little light falls on the walls and there are many dark objects in a room, there will be little diffuse light.

Directed light is necessary for recognizing three-dimensional objects. How the proportions of direct and diffuse light influence the perception of forms can be seen in the figure below.

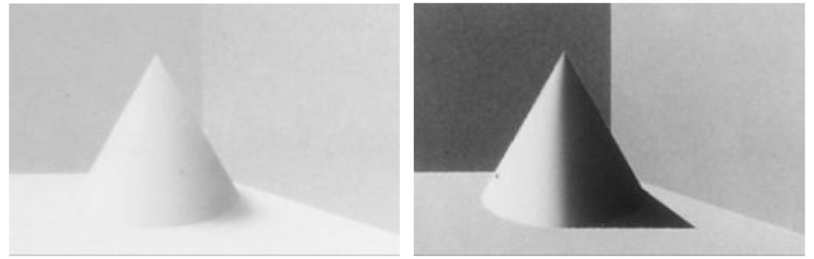


Figure 5.1; A cone lighted by ambient light (left) and focus light (right)

5.2 Brilliance

Brilliance is light from small scattered light sources, which are created by "scattered" small lamps or by the reflectance of gleaming objects. Examples of this are cords with Christmas lights or the reflection of (sun) light on water or metal objects. Direct light can also translate into brilliance.

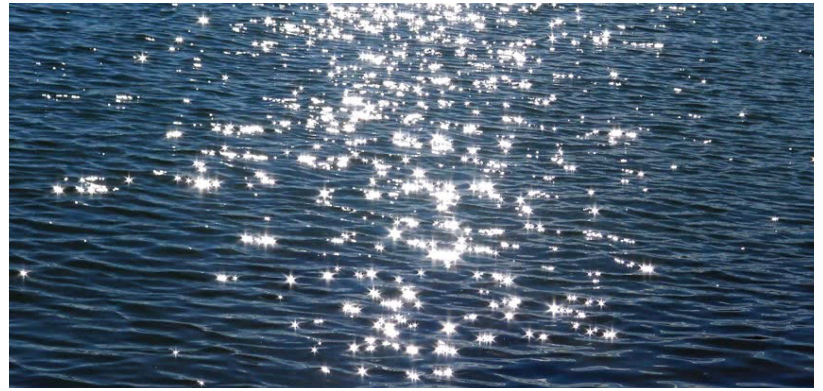


Figure 5.2: Brilliance. Occurrence in nature: sunlight reflected by water
Figure 5.3: Brilliance. Created by multiple point-light sources

5.3 Color Rendering

Color rendering regards the extent to which colors can be displayed under certain light sources. It is an evaluation of the quality of the spectrum of light that it radiates.

Figure 5.4: Example of color rendering

The color rendering index (Ra) are values that are linked to the quality of light sources. Here the lowest value is 0 and the highest value is 100. If high visual performance is required, values above 90 will be desirable. To increase perceptual safety, sources with high color rendering properties may be desirable, since it increases the ability of reading people's faces in public spaces.
The color rendering of light sources depends on the composition of the spectral wavelengths of the light source. colors that are scarcely present in this spectrum cannot be "absorbed" by objects with the same colors.

5.3.1 Spectrum Sodium-lighting

If we take high pressure sodium (SON) lighting as an example, it can be seen that objects that are blue or green will become very pale, whereas objects with the shades of yellow and orange are well displayed.

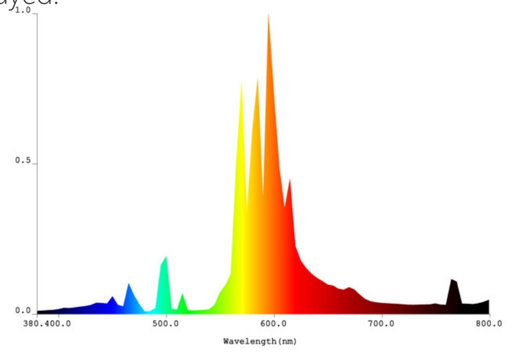
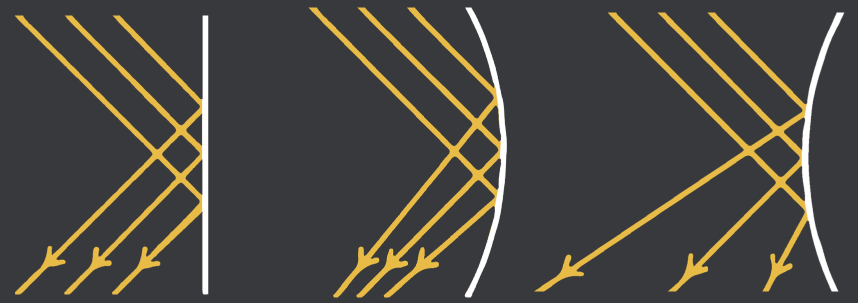


Figure 5.5: Spectrum Sodium lights

Figure 5.6: Color Rendering Sodium Lights

5.4 Lenses and Reflectors

Luminaires have three functions; providing space for light sources and other electronics, protecting users (a.o. against heat) and controlling luminance levels. Lenses and reflectors are indispensable components in controlling light. Specially designed reflectors and lenses can direct light in the desired directions. Examples of specular reflection can be seen in the figure below.



igure 5.7: Light reflection on flat, concave & convex surfaces

The extent to which reflection is possible depends on the type of material. Metals and light (colored) materials generally perform well.

Refraction occurs when light has a transition between two different materials (in which air is also considered material). The light breaks because there is a difference between the density or transmittance and thus the propagation speed of light of the two substances

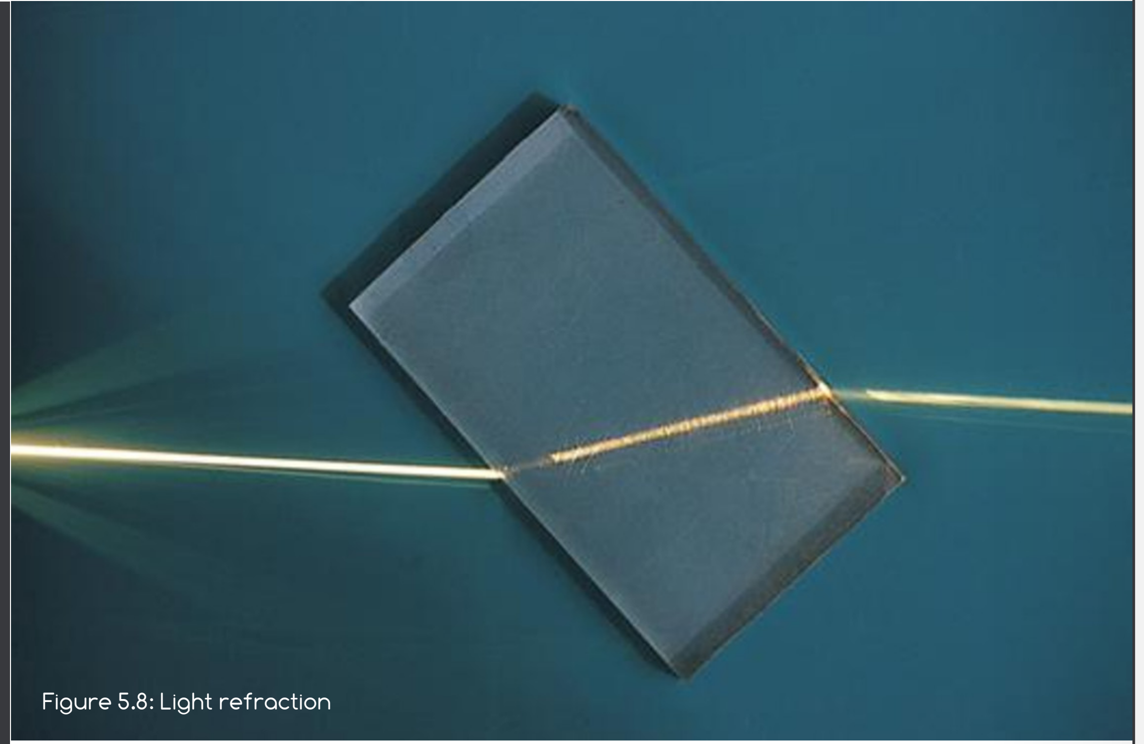


Figure 5.8: Light refraction

Examples of how different lenses each break the light on their own way can be seen on the following pictures

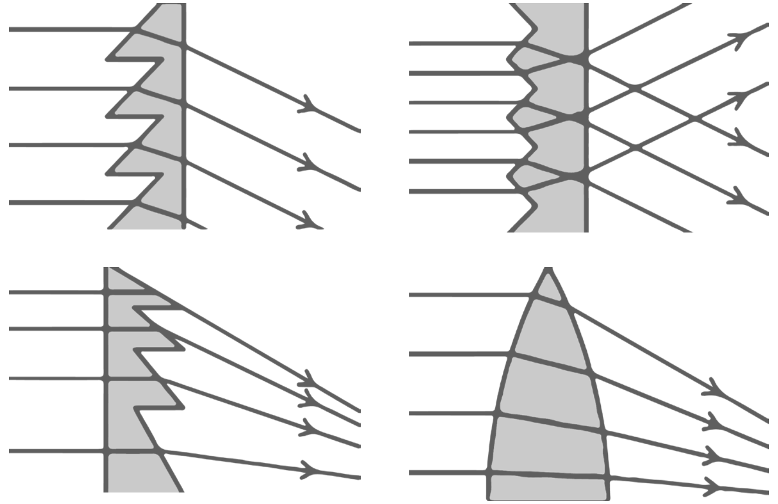


Figure 5.9: Light refraction through different lenses

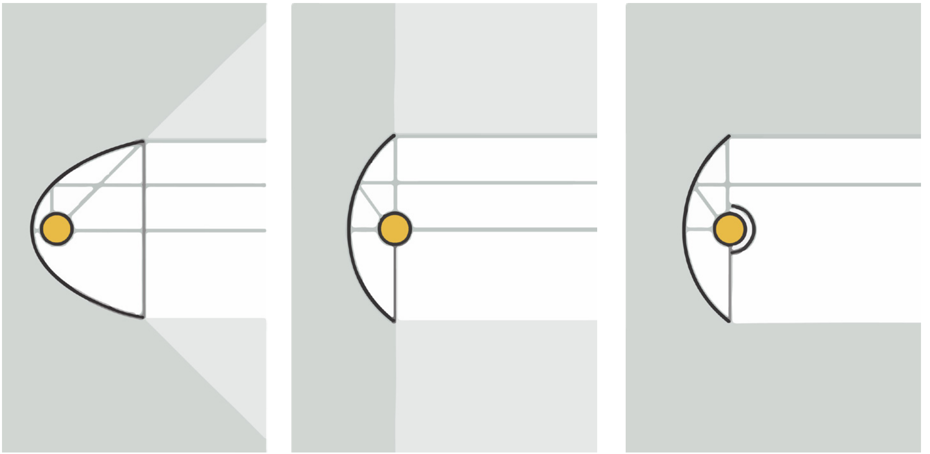


Figure 5.10: Three typical reflectors. On the right a reflector with sperical reflector as shielding element

5.4.1 Reflectors

Parabolic reflectors
Three applications of parabolic reflectors are shown in the figures above. Depending on the application of the light source, a choice can be made.

Dark-light reflectors
To prevent glare in the reflector, reflectors with variable parabolic focal points are used. Examples of how these shapes affect the distribution of light can be seen in the following figures:

Figure 5.11: A dark-light reflector

5.4.2 Lenses

There are several types of lenses available to influence the distribution of light from point light sources. Where previously the type of collecting lens was often used, these are nowadays often replaced by fresnel lenses. The latter consists of a number of concentric rings. The advantage of this is that the lens is flatter, lighter and cheaper than traditional lenses. How the lenses break down the light depends not only on the structure of the lens but also on the distance to the light source, as can be seen in the following figure

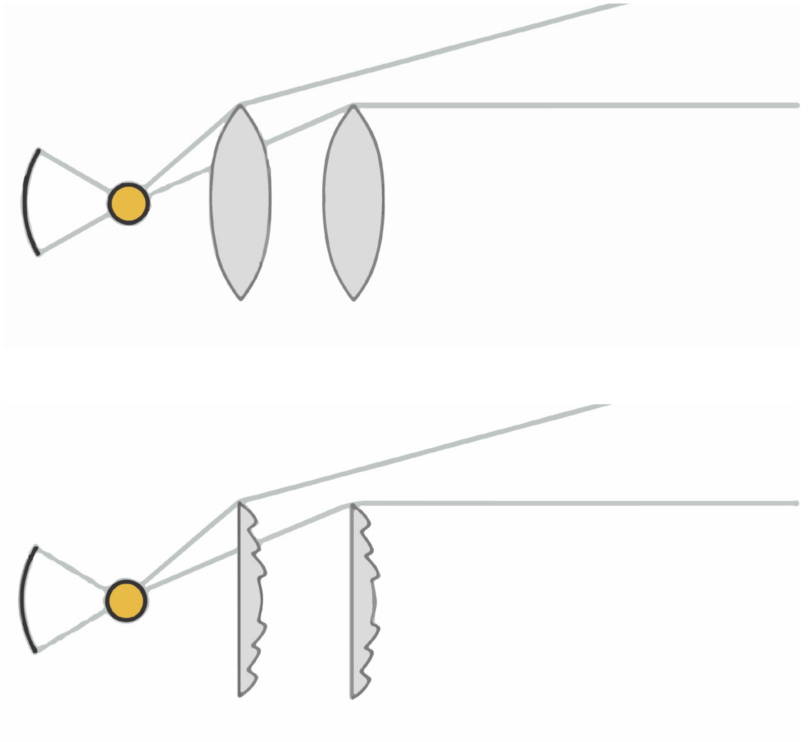


Figure 5.12: Light refracted by a collecting lens (top) and a fresnel lens (bottom)

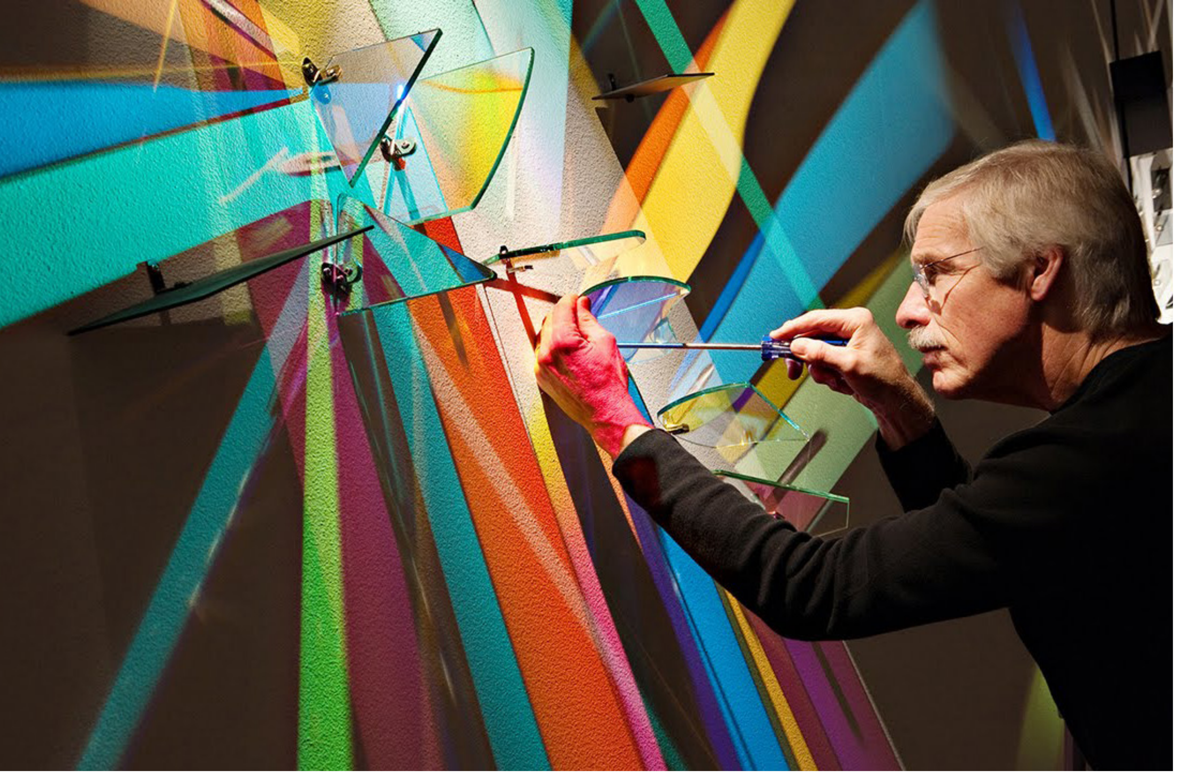


Figure 5.13: Dichroic Art piece by Stephan Knapp

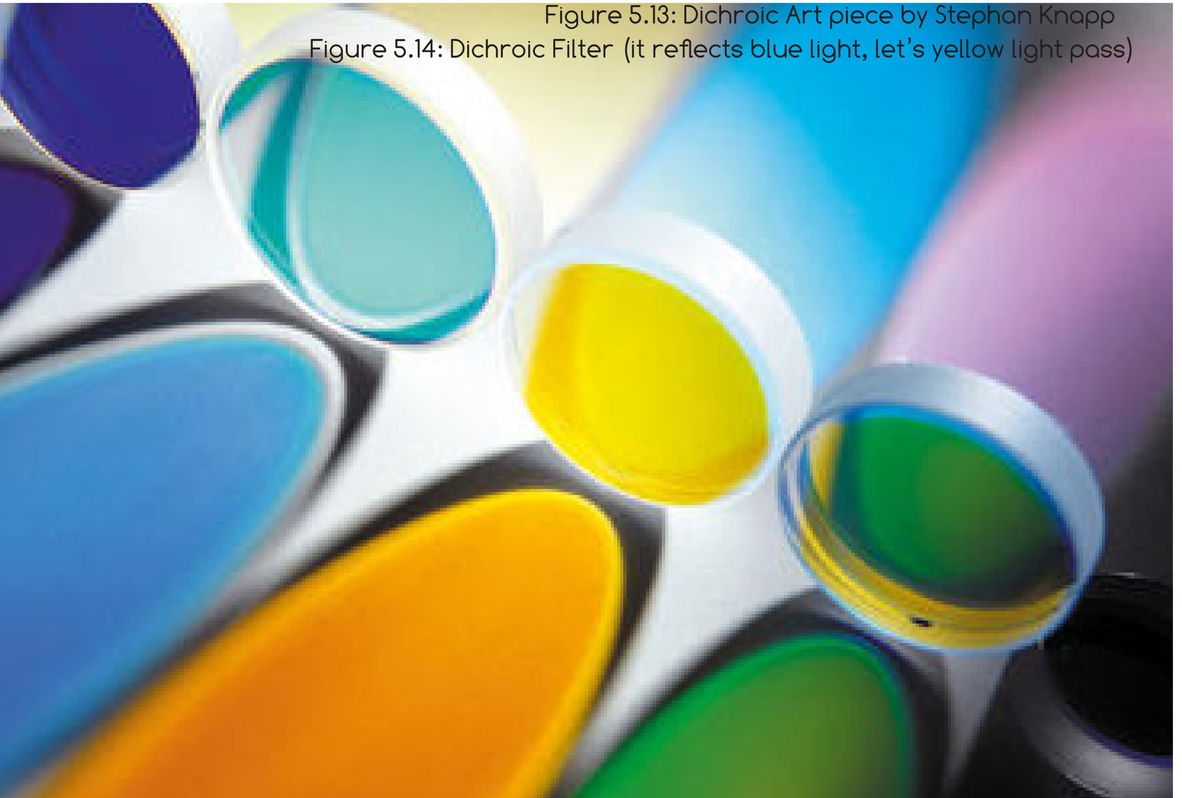


Figure 5.14: Dichroic Filter (it reflects blue light, let's yellow light pass)

5.4.3 Prisms

Prismatic systems are another way to break down light. Examples of them with their function are shown in the figure below.

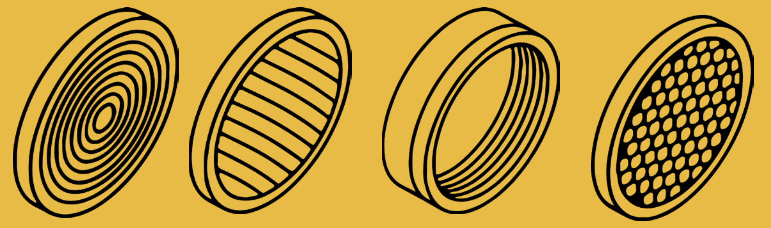


Figure 5.15: f.l.t.r: Flood lens (to widen the beam), Sculpture lens (produce oval beam), Multigroove baffle (reduce glare), anti-dazzle screen (reduce glare)

5.4.4 Filters

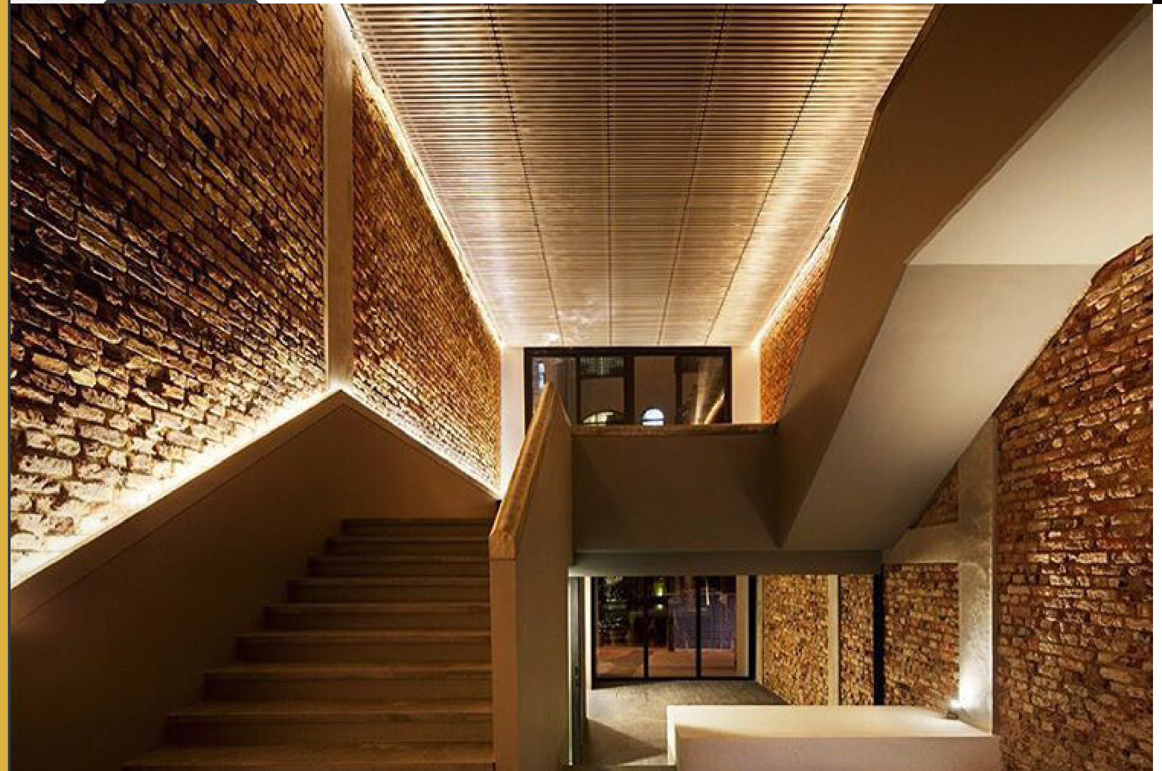
In addition to reflectors or lenses, there are other means to influence light. Filters are an example of this. Dichroic filters, also called thin-film filters, are highly accurate color filters, designed to only transmit light of a certain wavelength range.
These are also often used on the back of luminaires to reflect visible light and to let through ultraviolet and infrared light in order to dissipate heat. Filters that are placed at the front of a luminaire often do the opposite. These ensure that only visible light is diffused in the environment.

5.5 Types of Luminaires
(For functional lighting)

To create a picture of the possibilities, different types of luminaires will be explained briefly. Mere luminaires based on the use of LED lighting will be discussed. After a general overview (originally indoor fixtures), specific applications for public spaces will be discussed.

5.5.1 Washlights

These lights, which can be used for flat surfaces, have the properties to illuminate these surfaces relatively uniformly. Depending on the applications, it can make a space appear higher/lower or wider/narrower. It is also a good application to display brick structures of walls.



5.5.2 Spotlights

These types of lamps can be suspended flexibly and are intended to illuminate a certain area in a room or an object. It is intended to create focus light.

5.5.3 Recessed luminaires

Recessed luminaires can be used to visually conceal the luminaire, thereby placing the focus on the light itself. When we talk about the same type of lamps that are sunk into the ground, we talk about "in-ground" luminaires

5.5.4. Face-mounted and pendant luminaires

When the design of the fixture is a visual addition to the space in which it is placed, it is often opted for face-mounted (fixed to the ceiling) or pendant luminaires. The design of the luminaire thus becomes part of the decor. pendant luminaires are often designed to be flexible in height to a surface/object

Types of street lighting

5.5.5 Floodlights and Wall-washers

These types of luminaires are primarily designed for illuminating buildings and other objects in the public space. Floodlights are spotlights fixed to the ground. These are often placed with a certain distance to a building. Wall-washers are designed to illuminate the walls and other properties of buildings by means of grazing light.

5.5.6 Bollard luminaires

This type of luminaire is designed to guide pedestrians, avoiding both glare and spill-light as a whole.

5.5.7 Light poles

This is the standard type of functional street lighting that is used to provide a combination of ambient and focus light on the street and has the main purpose of increasing social and traffic safety. There is a wide variety of lighting columns, with height, number of light sources, and distribution being some examples of distinctive features. In general it applies that people integrate as much as possible in one mast where possible (lighting for different road users

5.5.8 Pendant luminaires

This type of street lighting is often used when options for mounting on both sides along the entire length of the street are possible. This type is often preferred because the ordinary street lanterns are seen as an obstacle for pedestrians and parked cars.

6. Environmental Psychology

This chapter will explain to what extent light can influence the perceptual atmosphere of our environment. The results of various scientific studies in relation to this influence of light are discussed. The chapter ends with the connection between light and biophilia, in which examples from the light art will be used as an explanation.

6.1 Emotions

Emotions are described as an inner experience that is stimulated by circumstances or that can occur spontaneously (Cheng, 2009). These conditions, formed by the neural system, give rise to affective experiences. Examples of this are tenseness, excitement and joy.
This leads to a response in behavior that can be described as expressive and goal-oriented. (Kleinginna & Kleinginna, 1981). The entire body is used in this process. There is activity in the neural, motor and cognitive system. (Griffiths, 1997)

These emotional feelings can be divided into two groups (Goldie, 2002)
Physical feelings; these are feelings that can be linked to things that can be related to (changes within) the body.
The second group are the "feelings towards". These emotions are directed to a certain object (this can be an event, but also a situation, a person or an object).

6.1.1 Affective Phenomena

Phenomena that can be linked to the formation of emotions can be divided into five categories. These are preferences, attitudes, dispositions, moods and interpersonal stances respectively.

- **Preferences** are assessments of certain stimuli around us. This form of feelings is stable over time. (although having good / bad experiences can change your preferences to certain stimuli)
- **Attitudes** have the same description as preferences, but these feelings are not aimed at a certain stimulus, but at an object or person. These feelings are also stable.
- **Moods** are affective states that are strongly linked to subjective feelings. It has been proven that this form of feelings is fairly stable over time (continuation of these feelings can take a few days). These feelings influence the experiences and behavior of a person (an example of this is a "depressed mood")
- **Affect disposition** is the degree to which you as an individual are accustomed to react with certain emotions in certain circumstances. An example of this is having temperament (Mebrabian, 1996)
- **Interactive stances** is the behavior that we use when it comes to personal contact with specific people or animals (Scherer, 2005). This is partly learned and partly instinctive. (For example, when we pass a friendly-looking man on the street, we will be more inclined to smile to him than when the man doesn't look friendly)

6.1.2 Emotion Models

Many models take the theory that different basic emotions are the basis or building blocks for other emotions (Ortony, 1990). It has been proven that the commonly used basic emotions (anger, fear, disgust, joy, sadness) are recognized by different cultures around the world. (Ekman, 1982)

To eliminate different interpretations of words when it comes to describing emotions, the "pleasure, arousal and dominance model" has been developed (Ruth, 2002). This model contains an XYZ graph that puts the following words on the axis:

DISPLEASURE	PLEASURE
NON-AROUSAL	AROUSAL
SUBMISSIVENESS	DOMINANCE

The latter is described as the extent to which people feel that they are in control of a situation. For example, fear scores low on the "dominance", where anger scores high on this.

6.1.3 Mood

A state of mind, or mood, is an affective mode that someone has for a certain time. This can be based on a single emotion or a combination of several. Logically, the mood can be positive or negative. Mood states are adjusted through external circumstances or events..

6.2 Biological Needs

People's behavior is strongly influenced by the environment that they observe. This observation is seen as having "interacting with".
The well-being of a person depends, amongst others, on the extent to which he / she can fulfill his / her need for information. This information can be strongly linked to the need for "perceptual safety". From our natural instincts, people try to keep a clear picture of their environment at all times and thus avoid potential dangers. This is about orientation as well as recording qualities and shortcomings when it comes to providing protection for the body.
The extent to which this is evaluated determines whether we can feel tense or relaxed in a particular space.

In addition, people have a need to keep an eye on time and other conditions such as the weather. This is one of the reasons that people like to stay in spaces with lots of daylight.
In spaces without daylight, only adaptive lighting systems designed with great care can achieve this awareness to a certain extent.

A final need when it comes to the perception of the environment is the balance between contact with fellow humans (or animals) and the feeling of having their own space. With the correct installation of light sources, the perception of spaces, both inside buildings and public spaces, can offer this balance

6.3 Effect light on mood

Many studies have been done on the influences of a person's immediate environment on his / her state of mind, well-being and behavior. (e.g., Flynn, 1992; Knez, 1995; McColl and Veitch, 2001). . Among other things, research was done into the influence of the heat from the light sources (warm, cold, daylight).

6.4 Atmosphere perception

However, the influence of light on people's state of mind remains difficult to determine. The way in which an environment influences the state of mind of a person varies greatly between different individuals.
The affective evaluation of environments appears to be more consistent than emotions or states of mind. The atmosphere and mood of a person differ from each other. The atmosphere (of a space) is not a feeling, but only an evaluation of the environment. This subjective evaluation has an expected effect on the state of mind of man, but it is highly dependent on many circumstances.
For example, a space can be evaluated as relaxing, but one can still be stressed, depending on other circumstances. It is assumed that the state of mind moves to a certain extent towards the evaluation of the environment in which someone is located. (the stress is supposed to decrease in a relaxing environment). The influence of light on an environment can determine his or her character, according to studies by Vogels (2008).
It is assumed that when establishing the atmosphere of an environment, differences are present between different cultures. For example, Asian people have a more holistic view of their environment, they focus on the environment as a whole and thereby look at the relationships between all objects in this environment. Western people are said to look more at the different objects in an environment and accumulate the assessments of these objects.

6.4.1 Atmosphere metrics

To conduct research into the influences of light on the atmosphere of a room, Vogels has developed a tool with which the atmosphere of a space can be quantified. Her research shows that an environment can be assessed on the basis of four values.

- **Coziness**
- **Liveliness**
- **Detachment**
- **Tenseness**

With the help of Cronbach's alpha, it was demonstrated that the participants in the study interpreted these terms in the same way. Van erp (2008) would add a fifth dimension to this: "calmness"

Interesting conclusions emerge from one of her first studies (Vogels, 2008) into the influences of colored light on the perception of the atmosphere of a room. In the investigations a distinction was made between general lighting (base layer of different tones of white light) and decorative lighting (accent layer of colored light). The relevant results of this study will be briefly explained.

6.4.2 Effect color on atmosphere perception

General Lighting

- Light conditions presented in cool white light are perceived as more bright, less cozy, less tense and less detached when compared to warm white light.

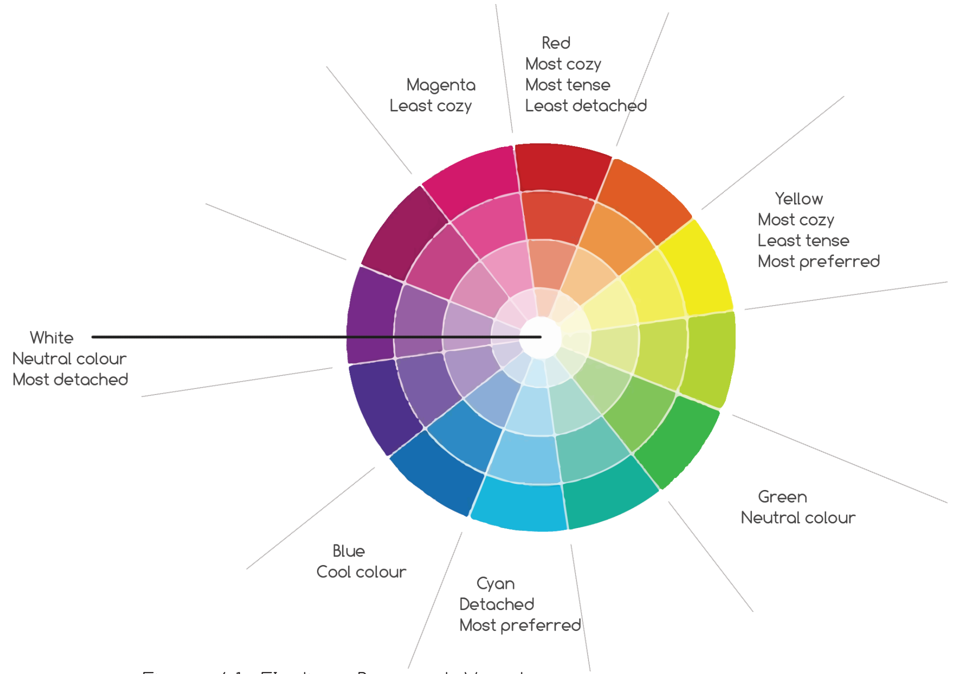


Figure 6.1: FIndings Research Vogels

Decorative Lighting

- High luminance is experienced as brighter, more vivid and is more preferred than low luminance
- Maximum saturation was experienced as less cozy, more tense, less detached and less preferred
- Hue: Red is perceived as less bright, cyan as brighter.

Other color related preferences are shown in the graph above. Vogels concludes the study with the acknowledgment that despite the study shows interesting findings, further research into the influences of spatial distribution, color combinations, daylight and demographic characteristics is desirable.

6.4.3 Relation light characteristics and atmosphere

A follow-up study by Vogels and Seuntjes (2008) investigates, in addition to the effects of color on the perception of the environment, the influences of other light properties. During this research a distinction is made between three types of lighting.

Research

- **White general lighting:** The influence was investigated in the difference in: color temperature, average brightness on the horizontal planes, average brightness on the vertical planes, and the dynamics of brightness and color temperature.
- **White accent lighting:** The influence was investigated in the difference in: brightness, color temperature, beam angle, beam characteristics, and the dynamics of these characteristics.
- **Colored accent lighting**: The influence was investigated in the difference in: color brightness, saturation, beam angle, beam characteristics, and the dynamics of these characteristics

Findings

General lighting

- Bright) White general lighting has the same influence on the perception of spaces as white accent lighting
- "Cozy" and "Relaxing" environments are mainly supported by lower color temperatures (2700K), whereas "Activating" and "Exciting" atmospheres being enhanced by higher color temperatures (3800K)
- An activating atmosphere should have a higher brightness. The brightness in the horizontal plane should be greater than the brightness in the vertical plane.
- An "exciting" atmosphere is supported by a low brightness of basic lighting compared to a high brightness of accent lighting.

Accent lighting

Regarding the accent lighting, amongst other, the influence of the beam angle and the K-factor are researched. K-factors indicate the sharpness of the light sources (K1=sharp, K5=soft).

- Cozy atmosphere - static lighting is preferred
- Activating atmosphere - slow dynamics (minutes, hours) in general lighting is preferred, with accent lighting being static. Slow fluctuations are desirable within the brightness of the accent lighting
- Relaxing atmosphere- static general lighting & slow fluctuations in the brightness of accent lighting
- Exciting atmosphere - static general lighting and strong fluctuations in accent lighting: these translate into changes in brightness, beam angle and beam characteristics (sharpness)

Furthermore, with cozy & relaxing atmospheres, softer beam angles are required (high K-values) and harder beam angles with exciting and activating atmospheres

An overview of findings can be seen in the table below.

Atmosphere	Colors	Saturation level	Beam angles (degrees)	Dynamics
Cozy	orange, blue	medium	50	static
Activating	blue, cyan	medium	50	static
Relaxing	green, blue	medium	50	static
Exciting	all	high	10,60	random (sec)

Table 6.1: Overview Research Vogels & Seuntjes

6.5 Effect daylight on atmospheric perception

Research has been done into the influences of daylight on the perception of atmospheres. (Stokkermans et. Al. 2015). In addition to this, research has been done into the difference between assessments of atmospheres based on real environments and visualizations.

The research shows (small) differences in the perception of atmospheres when adding daylight. (Diffuse daylight was used for this) The relevant results of this study will be briefly explained.
the addition of daylight provides an increase in uniformity and detachment.
The addition of daylight provides a decrease in tenseness

Furthermore, no significant differences are shown between the assessment of visualizations and the assessment of the real environment. While being present in an actual atmosphere undoubtedly increases the influences on your state of mind, it has little or no influence on the visual perception of an environment.

6.6 perceived warmth & positive judgment

Over the years a lot of research has been done into how colors influence the perception of people, objects and environments. The assessment of other people is often strongly influenced by the first impression. This first impression is determined by bipolar properties: Warm against cold. When a person is described as warm, the person is assessed in a different way than other people. (Asch, 1946)
Where research has proven that physical warmth enhances psychological warmth (Williams and Bargh, 2008), other studies show that warmer colors (such as orange and red) can cause a physical feeling of warmth and cold colors (blue and green) a cold feeling (Fenko et al., 2010; Yildirim et al., 2007).

Experiences of warmth can form positive evaluations of people, but also of a certain environment (Choi et. Al. 2016). The correlation between colors and the perception of warmth is strongly linked to cognitive associations. Orange is one of the primary colors for warm objects such as the sun or fire. (Morgan et al., 1975; Xin et al., 2004). Cognitive associations are activated in the brain when something is detected in the sensory system. The group of memories that are activated around the experiences with heat are called "warmth stereotypes".

6.7 Seasonal color preferences

When it comes to clothing, many analyzes have already been done about the preferences for different colors in the different seasons. It can be seen in the image below that when it comes to clothing, people have certain preferences per season when it comes to color temperature, value and chroma. (described in Chapter 2.2)
The Department of Psychology and Wisconsin Institute for Discovery, at the University of Wisconsin – Madison and cognitive science depertment, has investigated general color preferences in relation to the seasons.

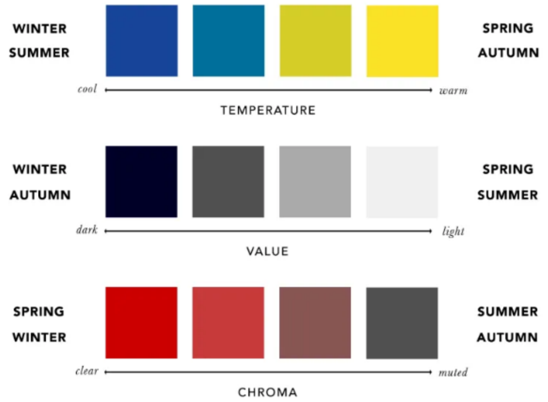


Figure 6.2: Seasonal color preferences

Figure 6.3: An 'Autumn color palette'

The findings of these study (K. B. Schloss et al. /Cognitive Science 41 (2017)) show that only in fall, significant differences where shown when it comes to preferences to certain colors. There is a significant preference for darker colors with an higher saturation in this season. However, this only applies to the colors that are strongly linked to this season. These are mainly warm earthy tones, which can be seen in the color palette below.

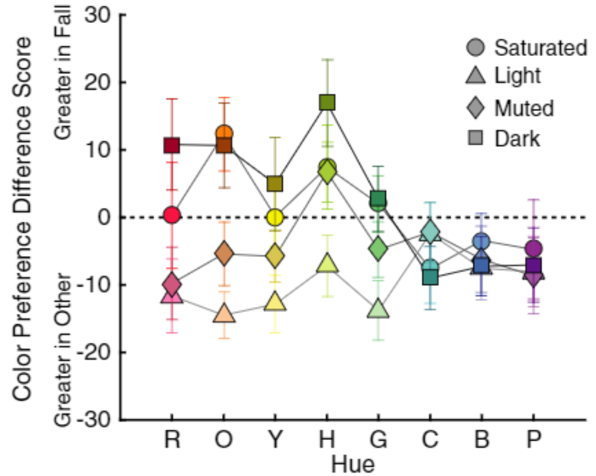


Figure 6.4: color preferences during Autumn

7. Public Lighting

In this chapter all aspects of public lighting will be covered. After a general introduction, all relevant trends within public lighting will be discussed. It concludes with the influence that (street) lighting can have on the behavior of animals, with a brief discussion of how the negative consequences can be limited.

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 public space fulfills two important functions;

- a traffic function (the movement of people from location A to location B)
- And a residency function (spending time in the public space)

7.1 Functions Public Lighting

Public lighting supports the municipality in fulfilling these two functions on the basis of the following three main objectives.

1. Increasing road safety

Road safety describes the extent to which people can move around in public spaces without danger. Each type of road user has its own routing and wishes. For example, the wishes of motorists are different from those of pedestrians. At intersections the emphasis is on the visibility of the most vulnerable road users.

2. Increasing objective and subjective social safety

Objective safety is described as the measurable social safety within an area. Social safety is about protection against human-made threats and crime. (López, Luten, Woldendorp, & van Zwam, 2008). Lighting is very important when it comes to improving objective safety. Good public lighting reduces vandalism, burglaries, theft and violence (CCV, 2013)

Subjective safety describes the degree to which people feel safe in a certain environment; the perception of safety. This is independent of the actual (un-)safety. Light can positively influence subjective safety through face recognition (supervision of potential perpetrators) and by improving the atmospheric perception of an area.

Figure 7.1: A dark alley is often perceived as unsafe

Regulations for the visual conditions are laid down within the Netherlands through the NSVV, an independent knowledge center for light and lighting.

3. Increasing spatial quality

The quality of the public space is assessed on the basis of use and experience. Logically, this experience is different in the dark compared to the daytime. The way in which light can influence the quality of the public space is described on the basis of three functions.

Identity

First, public lighting supports the identity of the city. During the day, the luminaires help determine the figure of the city. During the night, it helps to translate the qualities of the city during the day to the night. It does this by illuminating certain parts of the city or by consciously leaving it dark. The identity of the city is therefore strongly linked to the way in which it is illuminated. This also has to do with the culture of the country. There is, for example, a significant difference between the one-sided business-like lighting of Manhattan and the intensity and diversity of the Tokyo lighting plan. The way inhabitants of a culture view the task of public space in a city is determinative.

Navigation and Orientation

Light in the public space also provides navigation and orientation within the city. The creation of navigation is done by illuminating sign-age and the roads. Lighting also offers routing within a city by highlighting landmarks. Beacons used during the day by people to orientate themselves in a city can fall away during the night. By highlighting geographical features, it is possible to create a so-called 'mental night map'.

Atmosphere and experience

Public lighting has a major influence on the atmosphere of a city, it ensures accessibility and creates an experience. Only with well-placed light sources, where more is looked at than road safety, can residents be tempted to use public space even in the dark. In this way, the public space becomes the living room of the city.

In addition to the three main functions of light, the emphasis is increasingly on the sustainability of municipalities. Energy reductions are necessary to be able to meet Dutch sustainability goals. The light must therefore be as efficient as possible and, where possible, dimmed.

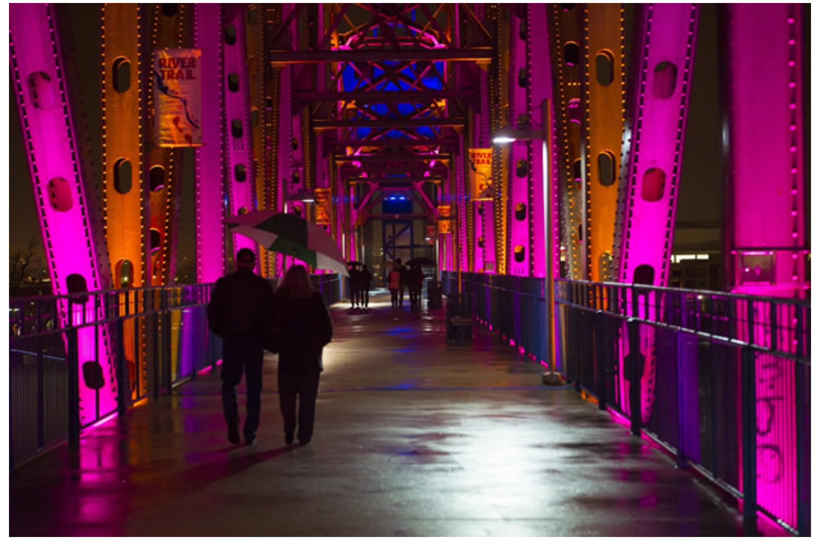


Figure 7.2: An example of modern atmospheric lighting

7.2 Trends within Public Lighting

Where to this day the standard for public lighting is based on the optimization of vehicular safety, whereas pedestrians come in second place, a movement is slowly taking place. The trend to design public lighting based on the perception of humans in growing. To achieve this, the lighting of spaces must be looked at in a more holistic way. Lighting that is adapted to its surrounding and customization will become the new standard. The different layers that are used with indoor lighting, as described in Richard Kelly's theory, can be applied to outdoor lighting.

Integration

Where previously light was only present in the form of street poles, more and more lighting sources are being integrated into the environment (for example in buildings or other architecture). With the advent of LED lighting, size reduction of luminaires is possible, so that the luminaires can be better concealed.

Figure 7.3: Street light integrated in a tram line

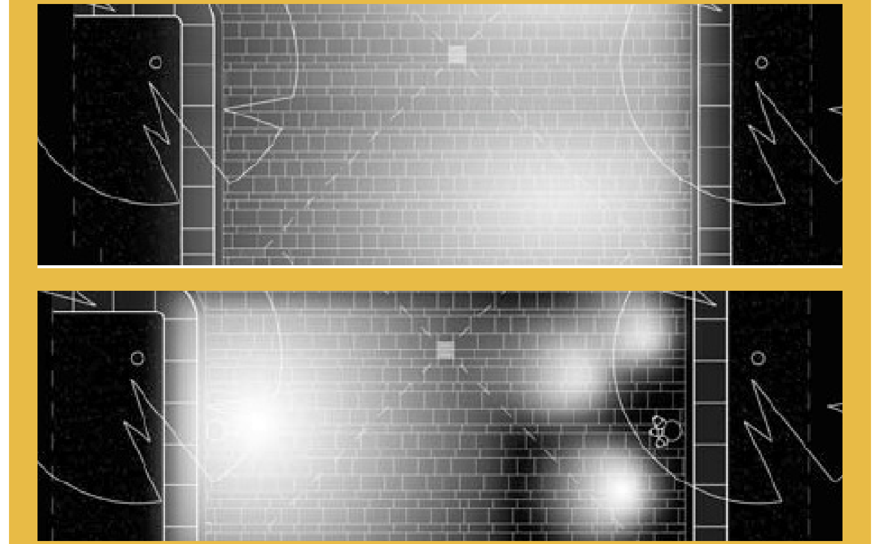


Figure 7.4: Uniform light, multiform light

Multiform lighting

Whereas uniform lighting always was the goal when arranging public spaces, more possibilities for variations when it comes to light distributions are noticeable. In addition to increasing the possibilities for energy reduction, it has aesthetic value. It is a possibility to give areas without motorized vehicles more identity.
Researchers Clanton and Gibbons investigated the implementation of differentiations in light in urban areas. One of the results of the studies is that areas with lower brightness and therefore greater contrasts can actually increase visibility. In addition to appropriate ambient lighting, there is room for focal glow and accents.

Figure 7.5: Bollards

Light for pedestrians

Where lighting within the public space was originally developed for the pedestrian, this changed rapidly with the arrival and further development of the car. Where vehicular safety is still the main focus point, the attention for the pedestrian (and cyclist) is increased. This goes hand in hand with the emergence of "walkable cities". Not only does this increase human health and entail energy reduction, it forms an inclusive environment for both residents and visitors to the city.

User centric design

When designing a lighting plan, more attention is paid to user centric experience. Researching the preferences and wishes of different user groups of the public space becomes the new standard for determining light sources.
One of the many user groups that requires attention is the growing group of elderly people. As mentioned earlier, the elderly become more prone to glare and certain parts of the color spectrum will become less visible. Adaptive lighting is a tool that can meet the differences in wishes between the user groups.

Design for the future

Not only does our current society demand a more holistic way when it comes to designing with light, more attention will have to be paid to future applications of public space. Cities are growing rapidly and as a result to that they change. By taking into account expected changes when installing lights, it can be ensured that the identity of the city remains the same and the lighting becomes more durable.

Reduction of brightness

In cities where the main roads have a very high luminance, the surrounding, somewhat darker, neighborhoods are perceived as less safe. Therefore, it is advisable to reduce the brightness for main roads, which of course will have to comply with the regulations. Another option is the integration of dynamic lighting; by pre-programming or by placing sensors, brightness and contrast can be controlled

Figure 7.6: City before and after dimming

7.3 Intelligence of lighting

The level of interaction between light sources and people around them has different levels. The four different degrees of intelligence of light sources will be briefly discussed.

PRIMARY - DYNAMIC - RESPONSIVE - INTERACTIVE

7.3.1 Primary Lighting

The first layer of lighting is the primary lighting. Without an operating system, it illuminates its surrounding without adapting to the environment. This type of lighting usually only has an on/off function

7.3.2 Dynamic Lighting

With dynamic lighting, sources are linked to small computers that regulate the output of these sources. The settings of these luminaires are pre-programmed (So no sensor equipment is used). This type of lighting can only be applied if the "flow" of the city is known. Depending on the use of different parts of the public space, particular city life can be supported. The pace of changes within the light can vary greatly. Where one installation makes use of rapid variations, the light is adjusted seasonally within other systems.

7.3.3 Responsive Lighting

The light is dependent on input supplied by sensors. It is intended to support patterns and cycles of users of the public space and to create a symbiosis with the metabolism of the city.

7.3.4 Interactive lighting

With interactive lighting the light is determined by direct input from users who use a control system. These users consciously implement changes with the use of the control system. Making it possible for residents of a city to organize the public space itself can be a means to increase the liveliness of the city and one's connection to the city.

It should be mentioned that regardless of the type of lighting, future use of the public space (based on the positioning of the light system) must be analyzed. Site-specific analyzes are desirable. This includes stakeholder interviews and a set-up of so-called user journeys.

7.4 Light distribution dynamic street lighting

To what extent does the implementation of dynamic street lighting effect one's perceived safety?

The (perceptual) security and the brightness of light around someone are two elements that are inextricably linked. Dynamic and responsive lighting, whereby the light is dimmed when there are no or few people in a certain area, could influence this perception of safety.
Research has been done into how much light is needed to support this feeling of safety and which parts of the space around people is preferably illuminated. (Haans et. Al. 2012)

This research is based on a theory that has three characteristics that influence the feeling of safety. (Fischer et. Al. 1992)

- **Prospect**: having an overview
- **Escape:** having a perceived escape
- **Refuge/concealment:** having a hiding place to offenders)

The results of this study indicate that people with light in their immediate surroundings have a good sense of security. Against expectations, the participants in this study best assess the prospect (having an overview) of their environment when the immediate environment is slightly higher illuminated than the environment that is further away.
These results would support the idea of dimming street lighting using sensors.

7.5 Response of fauna to light pollution

The influences of artificial light on behavior are often investigated. The nocturnal animals covered by such studies are bats, birds, moths, mice, and amphibians.
Unfortunately, the wishes of these animals are different when it comes to light. For example, bats (the animals most prone to excessive lighting), like mice, benefit from the application of warm, ideally red, light.
Red lighting however, is known to disorient some type of migratory birds . Birds, on the other hand, ideally see green light, which in turn can be disruptive to bats.

As is now well known, light pollution can also have a negative effect on people. An excess of light has an effect on the human biological clock; the sleep rhythm is disturbed. This is because less melatonin is produced. This can even lead to an increased risk of cancer (Haim, 2010). Blue light is the most harmful to humans when considering the melatonin level (Molenaar, 2003). Cold colors and especially blue light should therefore be avoided.
But also the plants that are in the immediate vicinity of light sources are disturbed. For example, trees are susceptible to delayed leaf fall and an (too) early sprout of branches

The conclusion is that the dimming of light, provided it does not impede social and traffic safety, can have a positive influence on the welfare of fauna and flora. Where dimming is not possible, the use of warm (not red) light sources is desirable. At specific locations, where one type of nocturnal animal is present in particular (such as on the drilling platform), colored lighting can be experimented with.

Figure 7.7: A drilling platform with green lighting to prevent disturbance of birds

8. City Branding & Identity

This chapter briefly describes city branding and identity. It explains how social representation can improve the city figure.

8.1 Introduction

the well-being of citizens and visitors to a city go hand in hand with the figure that people have with a city. Iconic buildings and monuments play a major role in this. Technological developments and the increase in globalization have increased the desire and necessity of cities to distinguish themselves. The focus is on tourism, employment, culture and places of residence (Kotler, 2002).

Research indicates three important facets that municipalities can use to promote their city. (Hankinson, 2006, Kavaratzis, 2005)

- **Cultural mega events,**
- **Restoration and promoting heritage**
- **The construction of iconic buildings**

The ultimate goal (Andrews, 2001) is to form so-called "quality of life", often abbreviated by QOL. This includes the sense of satisfaction and well-being in relation to the city by either residents or visitors.

The identity of a city is assessed by the degree to which a city is distinctive compared to other cities. (Lync, 1960). The identity encompasses the differences that immediately come to mind when thinking about a city. (This even applies to people who have never been to the city). This is considered as a non-copyable property of a city.

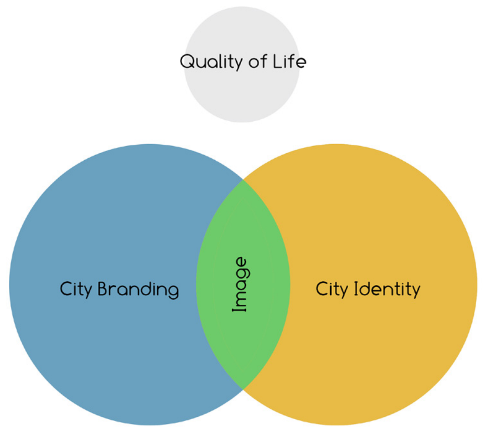


Figure 8.1:City Branding and Identity

This illustration shows that usually only the part of city branding is considered that corresponds to the identity in the person's mind. This overlapping part forms the figure that people have of the city. This 'figure' is the list of ideas, beliefs and impressions that someone has about a city. (Kotler, Haider and Rein, 1993)

8.2 Social representation

Besides the forming of an figure of the city and thereby increasing tourism (and the income along with it), city branding is very important in forming a common identity and preventing social exclusion. (Kavaratzis, 2004)

Blichfeldt emphasizes the fact that people form the figure of a city through associations. Therefore, it is not possible to impose an figure of a city on someone, one can merely try to offer a consistent figure to the perceiver. (Blichfeldt, 2005)

The city sends an figure to the receiver, whereby the receiver chooses to what extent he accepts the figure as a reference. This figure is then converted into an figure of the city through cognitive associations.
This makes it necessary to burn as a city from their own identity; do not try to present yourself differently than you are; there will then be a lack of acceptance.

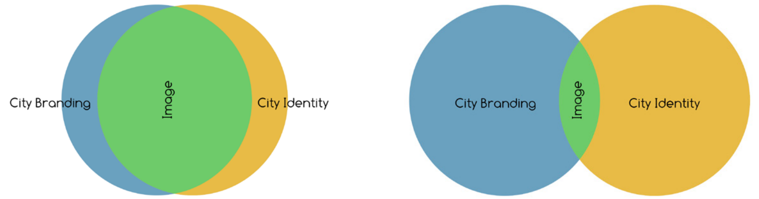


Figure 8.2:City Branding and Identity (2)

Although everyone experiences the city in their own way, there is nevertheless a general picture, shared by a large part of its inhabitants. (Neacsu and Negut, 2012

8.3 Figure management

When a city tries to change the figure of the city through branding, the inhabitants must always be given the highest priority. After all, the inhabitants are the most affected by any changes. (Reiser and Crispin, 2009). This also applies when the city undergoes new "flagship" developments, the main purpose of which is to develop a new area or building to strengthen the local identity.

When a city does not develop itself based on its own (local) identity, residents of this city will feel alienated from this development.

Although the environment of a city is an element where the city can adjust its figure, it should primarily serve as a way to strengthen the local identity of the city.

9. Master Plans Municipalities

To see how different cities use lighting in public spaces to enhance their city branding, a number of lighting plans have been analyzed. These will first be briefly discussed one by one, after which the similarities and differences will be concluded.

Hereby, the role that mood lighting can play in strengthening the city branding of the municipalities concerned will be described. It must be said that the extent to which cities have worked out their lighting plans differs greatly from each other. This will lead to a difference in the degree to which the various municipalities are discussed.
Also, the lighting plans were not all issued in the same decades, which means that differences in digital transition can be seen.

The light plans are discussed on the basis of the following criteria;

- City Branding/identity
- Goals/vision
- Division area's/streets
- Light layering
- Atmospheric lighting
- Technical aspects (general, light colors, dimming, luminaires)
- Digital transition
- Sustainability (Reduction light (-pollution), fauna)

Depending on the design of the lighting plans and the visions of the lighting designers who have set up the lighting plans, the above-mentioned topics will be discussed to varying degrees (or not at all).
Where according to the municipalities there are possibilities for the development of atmospheric lighting, a * will be shown

9.1 The Hague

Brand identity

The most important features of The Hague

- Green city by the sea *
- International city of security

Furthermore, The Hague likes to identify itself as hospitable and modest.

Figure 9.1: Hospitable look city center The Hague: Combinations of Warm white and white light

Goals/Vision

Safety, atmosphere and experience are the most important goals. This concerns both traffic and social safety and the livability, identity and atmosphere within the city. The city branding is enhanced by the figure quality and structure that is visible in the city.
Within the coastal areas there is a place for tourism, where fauna is spared artificial light. Man must always be taken as a starting point; human size and color recognition are important

'WE BRING THE LIGHT WHERE IT IS NEEDED, IN THE RIGHT FORM AND AT THE RIGHT TIME'

Division area's/streets

Four areas are divided in the light plan of The Hague. Each of these areas gets its own light specifications.

- Typical Streets
- Various streets
- Objects (e.g. art)
- Special areas (e.g. squares, parks)

Figure 9.2: An example of 'city light' of The Hague

Light layering

Four different light types are subdivided for the different areas

- Living light (living room of the city, comfortable light with safety, readability and a human scale at the forefront)
- City light* (excitement, liveliness, court city quality (hofstadkwaliteit))
- Road light (technical fixtures: focused on way-finding)
- eco light (limited light emission in green areas)

Atmospheric lighting

Atmospheric lighting is an important point when it comes to creating an atmosphere and experience. However, only project-based realization *. Investments and money management must be arranged per project)

Technical aspects

Light color

3 ranges of color temperature are applied

- Neutral white light: applied for visibility of traffic; focused on movement of people.
- Warm white light: combination of atmosphere and visibility
- warm light: applied in residential areas for a homely atmosphere. focus is on color rendering and face recognition

Figure 9.3-5: From top to bottom: examples of a technical fixture, historical lighting and customization within The Hague

Luminaires

Four types of lighting are possible within the luminaires. Standardization (of management) is desirable for each of these

- Customization *
- Historical lighting
- Residence: archetypal residential lighting
- Technical fixtures

Digital transition

in the future, lighting poles would like to be seen as carriers of technology to support the "smart city".

Reduction light (-pollution)

The Hague wants to become a climate neutral city. The aim is a light reduction of 50% by 2030. Without financial assistance, it will come to a reduction of 40% in 2038, with assistance to 58%. Telemanagement can play a role in this.

9.2 Rotterdam

City Branding/identity

Rotterdam is

- City of waterfront*
- Green city*
- City of architecture

Furthermore, Rotterdam is characterized by the contrast between tradition and change.

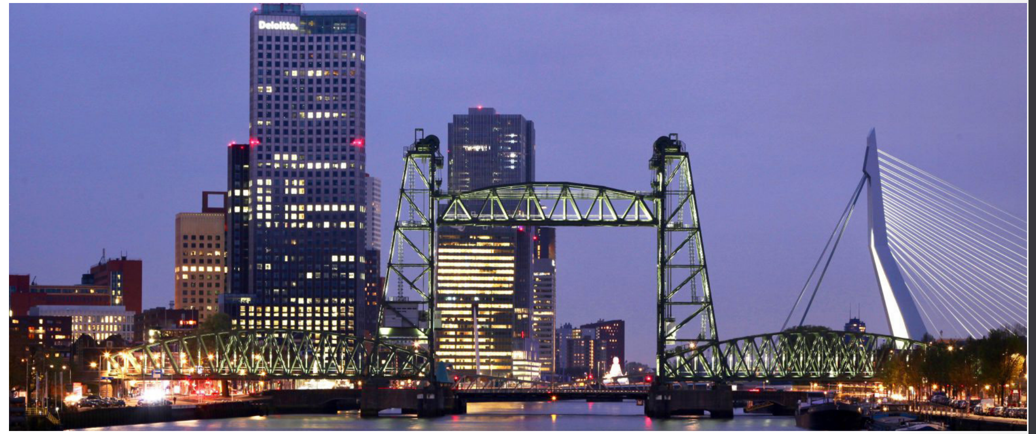


Figure 9.6: Rotterdam, City of Waterfront

The main goal is to optimize traffic- en community safety, furthermore to;

- Design a equal day and night-scape, whereas the public domain should have a leisure function*
- Standardize maintenance
- Reduce overall energy levels.

The center of the city should be accessible and focus on experience; creating atmosphere is the most important here.

Daylight is a metaphor for the city of Rotterdam; it is constantly changing.

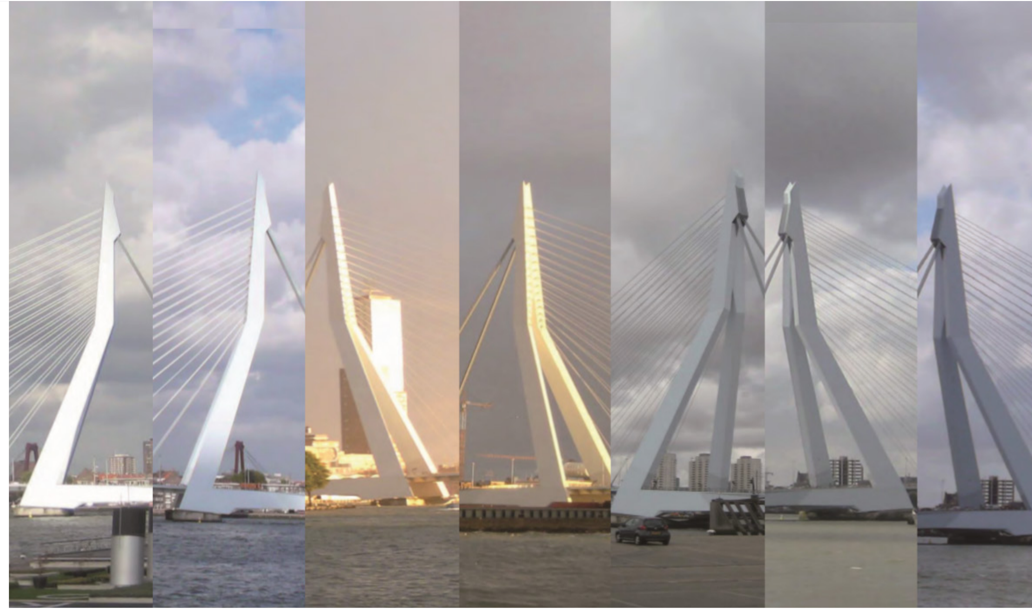
Light in the city must have the following function:

- Strengthening urban morphology
- Creating coherence and recognizability
- Reducing CO2 and taking care of standardization
- Translating the day scene from Rotterdam to the night scene; to also show the character of Rotterdam at night. *

Division area's/streets

- The division of the city by the municipality of Rotterdam is as follows:
- City streets; characterized by many different traffic forms. These streets are often arranged by tree structures. Face recognition is necessary, this is supported by light between 2700 and 3300 Kelvin. Pendant luminaires are preferred in this area.
- Cycle paths and footpaths: face recognition is important, active dimming where possible is desired
- City center: "The city lounge" feeling should dominate *. Ambience and orientation get the focus here
- Squares: Enlightenment extends to the contours of the squares; Facade lighting has priority here. Accent lighting through new lighting concepts is desired *. Extra switching options are being provided for this.
- Waterfront; this typical Rotterdam appearance is characterized by white light without light distribution to the water (waterfront should be visible, not the water in front of it)
- Traffic plazas, parks, artworks: Extra focus should be given here, customization is required *

Figure 9.7: daylight as a metaphor for constantly changing city
Figure 9.8: Creation of urban morphology in Rotterdam
Figure 9.9: a typical residential area in Rotterdam,focused on recognizability



Light layering

Light consists of basic lighting and possibly (colored) accent layers

Atmospheric lighting

- Accent layers with mood lighting are possible in some places, simplicity and sophistication are two values that must be taken into account.
- Corresponding basic lighting makes accents expressive *
- Glow is possible by showing the lamp itself
- Accents are possible in city centers and high-rise buildings. Pastel tones are preferred here

Technical aspects

General

Direct light with a high G-Class is preferred

Light colors

- 2800 - 3200 K
- Warm white is the new standard. It ensures good color recognition, safety and spatial structure
- Hard colors such as red and green must be avoided
- Pastel tints are allowed with accent layerS.

Digital transition

In the future, Rotterdam will focus on controlling with light sensors (telemanagement)

Sustainability

Wildlife will be spared from light as much as possible.

Figure 9.10: A square in Rottedam, focused on the plinth around the square
Figure 9.11: City streets, light focused on face recognition. Combination of pendant and upright luminaires
Figure 9.12: A typical waterfront where light is focused on the buildings without light distributions to the water

Dimming

- Between 11 p.m. and 5 p.m., where possible, lights are dimmed by 50% (always taking the catwalk effect into account; one feels when viewed in the only illuminated area)
- Dimming options are determined per street
- Passive dimming is the standard. tests with active dimming are possible
- All new installations will receive a management system with dimming function

Luminaires

A reducTion in the number of luminaires is desirable. There are currently too many masts (tram lines, signaling, etc.); They must be made multi-functional. Where possible, pendant luminaires are used

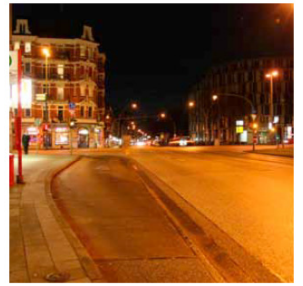


Figure 9.13: An example of an initiative for atmospheric seasonal lighting
Figure 9.14: A site-specific artwork consisting of atmospheric lighting
Figure 9.15-17: The trend of increasingly whiter light, which has been set in motion by the rise of LED
Figure 9.18: Where possible, pendant luminaires are used

9.3 Amsterdam

Goals/vision
The inner city of Amsterdam must be a safe space
Encounters, outdoor playing and the earning of money must be encouraged
Road safety, social safety, experience and atmosphere are the most important points for attention

The three pillars of the above are
- Light to size
- Durability
- Innovation

Installation of light sources must support the current cityscape, but also the future. It must support dynamics and be sustainable.
Light is not needed everywhere and always, but where it is necessary, integrated customization is required. All stakeholders must be involved.

Atmospheric lighting
Depending on the location is possible:
- Special lighting
- City illumination
- Decorative lighting *
- Light art

Decorative lighting and light art contribute to the experience of the city. seasonal lighting is always arranged on own initiative and falls under the costs of business associations.

Figure 9.19: Typical Amsterdam atmospheric lighting
Figure 9.20: A more basic atmospheric seasonal lighting.

Technical aspects

General
Light with the highest possible RA value will be chosen

Light colors
2700-3000K, other color temperatures are also possible from an artistic point of view

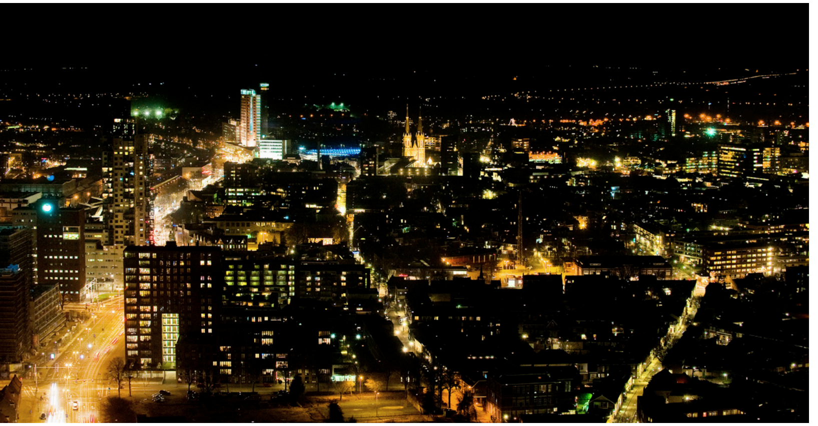
Dimming
- Dimming is possible depending on the locations. A lower limit of 3 Lux with a uniformity of 0.2 is the standard.
- Dimming mainly adds something to the live-ability of the city, the energy reduction is negligible.
- In the event of an emergency, sources can return to full lighting.

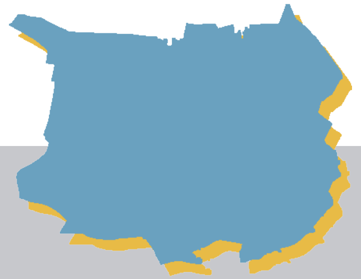
Luminaires
- Luminaires should be selected per area using the puccin method.
- Where possible, pendant luminaires are used. (because these are more expensive than masts, this depends on the neighborhood)

Digital transition
Light poles are more than just carriers of light.
Technology pilots are possible concerning the development of "smart cities"

Sustainability
- In 2035 all public lighting will be LED
- in 2025, 45% less CO_2 will be emitted compared to 2012
- Animal welfare is very important, therefore restraint in lighting in green structures is necessary

Figure 9.21: Historical light poles: Light that optimizes facial recognition: Because of monumental buildings, pendant luminaires are often not possible
Figure 9.22-23: Two examples of site-specific customized luminaires, designed to match the district





9.4 Tilburg

City Branding/identity

Tilburg can be described with the following terms:

- Social
- Experimental and contrary
- Decisive
- Humorous
- Raw
- It builds on urban ambitions and small-scale cohesion. Originated from agricultural settlements where many textile factories were later placed

Goals/vision

- Neighborhood-oriented lighting must be installed
- The focus is on the use scenario of the city, (for example, different lighting is required when the stores are closed)
- Neighborhoods should support the feeling of "coming home in the evening."
- Experience value is becoming increasingly important compared to road safety
- Basis of white light for light experience on a human scale.

Division area's/streets

Tilburg was formed by merging different villages, where each part has its own atmosphere. This atmosphere must be determined on the basis of experience and usage scenario.

Figure 9.25: The sky-line of Tilburg: Colored light is used in high-rise to support the mental night map
Figure 9.26: modest lighting in a residential area
Figure 9.27: A catering street with seasonal lighting in Tilburg

"LIGHT IS NOT A GOAL, BUT A MEANS TO CREATE AN EXPERIENCE'

Modest lighting is appropriate for residential areas.
Per neighborhood there is room for specialization to enhance the atmosphere, identity and orientation.

Squares have various functions, depending on usage scenario, light should support these functions.

- Living room
- Theater
- Stage

There are two atmospheric areas in the city center: The kernwinkelgebied and the Dwaalgebied.
City Streets in the city ring are low-traffic *.
The core shopping area is a pedestrian area; here is room for contrast within the lighting.

Light layering

- Basis of white light
- Accent layers (potentially colored), determined per neighborhood

Atmospheric lighting

The "rigging" of the Christmas lights in the winter months has emotional value and added value to the story of the city.*

"WITHOUT A SIMPLE BASIS THERE IS NO ROOM FOR SPECIALIZATION"

Figure 9.28,29: differences in atmosphere regarding shopping hours:
After closing, the plinth is dimmed to 50%
Figure 9.30: A shopping street with pendant luminaires

Figure 9.31: ' City Circle' , a luminaire designed for Tilburg

Technical aspects
Dimming
After closing times, the facades of shops must be dimmed to 50%. The light is "from the city" again. However, a sense of security remains guaranteed and window shopping remains possible.

Luminaires
- High light-points are preferred
- Luminaires are vandal-proof
- Facade lighting and pendant luminaires are preferred (due to space saving)
- Movable masts will be installed for squares
- The "city circle" designed for Tilburg is a recurring principle

Digital transition
- Light masts will become data carriers and will have special settings for lighting around calamities
- In addition, there will be a permanent connection for atmospheric lighting.*
- Lighting will become dynamic or even interactive through sensors.

Sustainability
- Sky light and residual light will always be limited when possible
- Warm light (<3000K) has the least impact on fauna.

9.5 Conclusions
Where can atmospheric lighting play a role in municipal lighting plans?

Brand Identity
The identity of a city is often directly linked to the history of the city and how this city has influenced the personality of the people who live there. A thorough analysis must be made of whether the City branding is based on identity or whether the municipality wants to control the figure of the city. For example, The Hague claims to be hospitable and modest by nature, but whether this matches the identity of the city is questionable.

Goals/Vision
What is common to all lighting plans is that traffic and social safety are paramount. Furthermore, the aim is to standardize when it comes to maintenance and municipalities want to use light to strengthen the identity of the city.
Furthermore, all cities try to translate the quality of their city that is visible during the day into the night. Where basic lighting does this to a certain extent, atmospheric lighting could play a role here.
The difference between some lighting plans is the degree of diversity that it wants to radiate using the lighting plan. For example, Rotterdam is clearly looking for a coherent base layer, in which Tilburg has room to make the different neighborhoods differ in terms of light properties. This too is something where atmospheric lighting could play a role.

Divide areas / streets
Where all municipalities divide urban districts into other segments (one based on street type, the other based on neighborhood or use of urban district), it is clear that in certain areas road safety is a priority. In such areas there are no chances for placing atmospheric lighting. Pedestrian areas and squares within the city center however, seem suitable for this.

Layers of light
What the light layers are called differs per light plan, the implementation is always the same. (Mostly warm) White light forms the base layer, which creates clarity and enables the wayfinding and reading of the environment. Color rendering plays an important role in this.
There is room for specialization in the accent layers and here there are possibilities for applying atmospheric lighting. The extent to which color can be used here depends on the lighting plan. All municipalities agree on one thing; these accent layers must be determined on a project and location-specific basis.

Atmospheric lighting
Atmospheric lighting contributes to the experience of the city. Precisely because of the unity in basic lighting, mood lighting can really come into its own. Municipalities make a distinction between seasonal lighting and decorative lighting. The first is in all cases done on one's own initiative, whereby (the majority of) the costs are for the business associations. There is, however, the possibility to link the lighting to the municipal grid and special dimmable connections are often installed. For general decorative lighting, project-specific discussion with the municipality is desirable.

Light colors
Neutral and warm white are the standards for the basic lighting. The degree to which variation can be made in this spectrum (2700-3300) is different. In The Hague's master plan, for example, residential areas are lit up more warmly to create a more homely atmosphere.

Dimming
All municipalities support the dimming of lighting if the situation requires it. Not always for saving energy, but especially to prevent light pollution. Tilburg takes a more interesting position, in which it dims the plinth (instead of turning it off) to increase the quality of life at night. atmospheric lighting could use this dimming. With low illumination, smaller contrasts and color differences are needed to stand out. Atmospheric lighting can thus be added whereby light pollution is limited.

Luminaires
Although every municipality has different regulations on the diversity of luminaires, there are a number of similarities. For example, all municipalities seem to use hanging luminaires or façade lighting in the city center whenever possible to reduce the use of posts. Furthermore, attempts are being made to further reduce the number of posts by making the ones there multifunctional; (multiple luminaires are attached to one mast or lighting is combined with tram lines.) When atmospheric lighting must be designed integrally, this will have to be anticipated.

Digital Transition.
Everyone agrees; Light poles will play a different role in the future. The extent to which municipalities are willing to be a forerunner in this area is different.

Sustainability
Although the figures differ, there are many similarities here: Avoid unnecessary lighting to save energy and prevent light pollution. Hereby also fauna is considered. (However, good color rendering appears to be more important than increasing the life of nocturnal animals.)
Ambient lighting will have to limit light pollution and, where possible, adopt warm colors in order to prevent disturbance of nocturnal animals

10. Aims and Objectives

In this chapter the aims and objectives for designing an atmospheric light-based luminaire for the public space will be discussed. Firstly, the process of designing and placing a light (for the public space) is described to explain the role of all stakeholders. Subsequently, an overview of all stakeholders and their interests is presented. These interests and all the literature described in this report are the building blocks for the wishes and demands, explained in the list of requirements. Based on this, a design vision has been developed, which will form the basis for further ideas generation and concept development.

10.1 An initial design framework

Designing city-specific atmospheric lighting

Based on interviews with various lighting designers, landscape architects, municipal employees and business associations, an initial design framework has been set-up, describing who should play what role in the development of atmospheric lighting.

Set-up
(finances)

Involvement:
Municipality, Business Association

The initial idea for placing atmospheric lighting is in the hands of a business association, residents group or from the municipality itself. The latter will in any case take a leadership role in any cooperation. After the reasoning behind the ideas are discussed, it is necessary to discuss financial matters. If the idea is not developed internally, the municipality will never pay the entire amount, since there is little to no money available for such projects in their budgets. Often, the municipality will engage in a financial collaboration with business associations, because they are willing to invest capital for realization.

Analysis
(Identity, location)

Involvement:
Municipality, Designer, Local Residents

To analyze what the area (and the city itself) needs in terms of light, a (lighting-) designer should be appointed. In consultation between the parties, the identity of the city will be discussed and the (light) designer will have to analyze what the ultimate wishes of all parties are. To gain support for such projects, local residents should be stimulated to participate in a co-creation process. This will ensure social representation and therefor enlarge the viability

Development
(Luminaire, system)

Involvement:
Designer

Based on the analysis of the area and the wishes of all parties, the (lighting-) designer will develop a city-specific luminaire and the associated control system. With the exception of approval during interim meetings, the project will be in the hands of the designer. This designer will develop a system that fits the usage scenarios of the environment.

Installation
(Circuit, programming)

Involvement:
Designer, Installer, Municipality

Lighting installers and lighting designers will be responsible for the installation of the luminaires. The municipality will assist with the logistical matters (space for mounting and power supply). Light designers are responsible for adjusting the lighting in relation to the environment (illuminance, spatial distribution, glare prevention, etc)

Control
(Maintenance, update)

Involvement:
Municipality, Designer

Once installed, the municipality will be responsible for the control and maintenance of the lighting. Possible collaboration with lighting designers may be desirable if the programming needs to be adjusted based on changed usage scenarios of the environment (or events). Depending on agreements, the costs for this will mainly be for the municipalities.

10.2 Overview Stakeholders

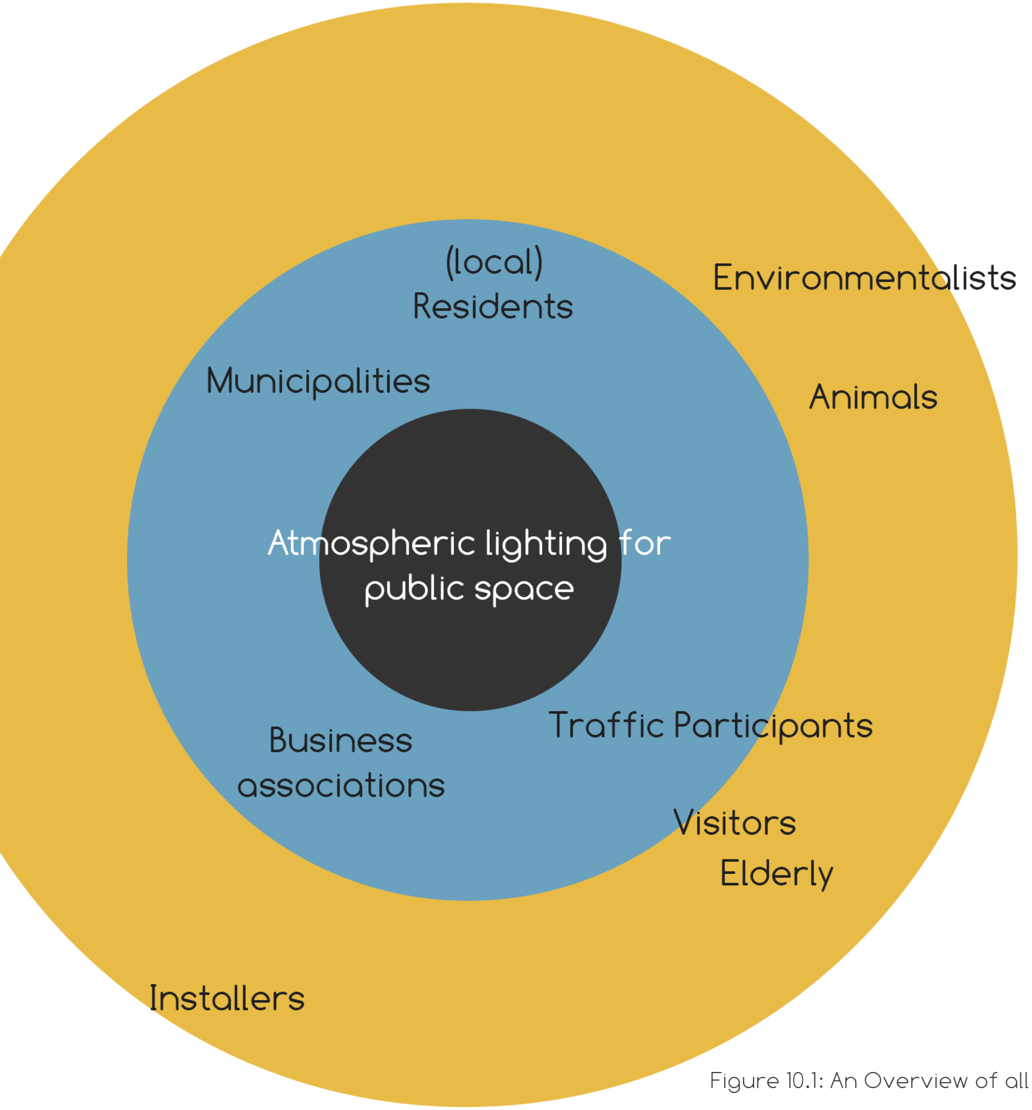


Figure 10.1: An Overview of all Stakeholders

Direct Stakeholders

Municipalities

- Increase QOL through improvement of city branding
- Making the city center attractive
- Improve well-being residents
- Limit energy costs
- Limit light pollution
- Easy of maintenance
- Install future visioned lighting
- Support events
- Good distribution of costs with companies

Local Residents

- Minimize light pollution
- Making their neighborhood attractive (feeling proud)
- Ambiance during winter months

Business Associations

- Increase visitor's residence-time
- Increase Profit
- Involvement of urban planning
- Good distribution of costs with municipalities
-

Traffic Participants

- Traffic Safety Guarantee

Indirect Stakeholders

Traffic Participants

- Traffic Safety Guarantee

Visitors

- Relaxation/Activation
- Atmosphere (shopping, catering)

Elderly

- Social security guarantee
- Optimal view

Installers

- Good electricity connection
- Ease of installation and maintenance

Animals & Environmentalists

- Minimize light pollution

10.3 List of Requirements

A program of requirements has been drawn up based on all stakeholders and their specific interest or objections with regard to the installation of atmospheric lighting. A division has been made between the wishes and demands. Concepts will only be considered viable if they meet all demands. Furthermore, the wishes are arranged by importance/ significance, which is linked to the numbering behind the wish in question. The wishes are categorized from A to D, A having the highest priority. This categorization will influence the assessment of concepts.

10.3.1 Effect/Application

Demands

- 1. The atmospheric lighting must be based on the (local) identity and the user scenarios of the city where it is placed, in order to increase social representation.
- 2. The luminaire should allow for the creation of brilliance, focus and ambient light (according to Richard Keller's theory).
- 3. The luminaire should allow for the change of light colors (based on the results of Vogels) in order to adjust the atmospheric perception of the surroundings. Thereby, the colors of the atmospheric lighting should be in harmony with colors indicated in the lighting plans.

Wishes

- The luminaire should be capable of meeting the standards that belong to certain light classes (suitable to certain pavement classifications), in order to replace existing lighting and prevent the increase in the number of light sources. (A1)
- The luminaire should allow for the creation of light dynamics, which should be adaptive (according to the Vogels & Seuntjes studies), in order to influence the atmospheric perception of the environment. (A2)
- The atmospheric lighting should improve the identity of the city by helping to convert the day image into the night image (B1)
- The atmospheric lighting should allow for the application of bio-mimics. (B2)
- Depending on the user scenario, the atmospheric lighting should allow for the support of warmth-or cold stereotypes by using cognitive association. (C1)
- The atmospheric light should be capable of matching the atmosphere that comes with the arrival of the winter season. (Similar to decorating a Christmas tree. (C2)
- The configuration of atmospheric lighting should support the principles of gestalt in order to create orderly chaos (C3)

10.3.2 Technical/Light Specs

Demands

- 4. The luminaire should limit the radiation in the spectrum of Ultra-Violet and Infrared
- 5. The luminaire should be operational between -10 and 40 degrees Celsius
- 6. The luminaire should have a maximum weight of 25 [kg] so that the luminaire can be carried by one person according to the Working Conditions Act
- 7. Heat distribution of electronic components must be supported to prevent overheating
- 8. The electronics of the luminaire must be optimized for standardization of maintenance.

- 9. The housing of the luminaire should allow for personalization, in order to fit their surroundings.
- 10. The luminous efficacy of the luminaire should be at least 50 [Lm / Watt]

Wishes

- The luminaire must prevent light diffusion into the air to limit light pollution (A3)
- The atmospheric lighting must be dimmable (A4)
- The atmospheric lighting should not increase the average illumination of its area by more than 5[lux] (B3)
- Atmospheric lighting must minimize the reduction in facial recognition. The color rendering index (CRI) may not fall by more than 10. (B4)
- The luminaire should not have moving parts (to allow for dynamic lighting) (B5)
- Depending on the location, the luminaire should allow for both pendant and upright installation. (B6)
- The luminaire should allow for adaptations in spatial distribution of the light, appropriate to the location (B7)
- The use of bright cool colors must be avoided to minimize the impact on the life of nocturnal animals (D1)

10.3.4 Material

Demands

- 11. The luminaire must be vandalism proof or should allow for installation on an unreachable location.
- 12. The housing of the luminaire should prevent rainwater from entering and should be resistant to other weather conditions
- 13. The luminaire should prevent the installation of an extra mast, unless this can be combined with other functionalities

Wishes

- The luminaire must be made from durable (in relation to its life span) materials. (A5)
- The material of the housing must be available in several colors or it should allow for (spray-) painting to match the environment. (B8)

10.3.5 Safety

Demands

- 14. The atmospheric lighting must not adversely affect vehicle road safety
- 15. The luminaire must prevent annoying glare (The atmospheric lighting must not negatively affect the safety of the visually impaired (the elderly))
- 16. Electronic components must be covered In order to prevent shock hazards.

Wishes

- The atmospheric lighting should not affect the brightness in the occurrence of calamities (C4)

10.4 Design Vision

"DEVELOP A PROGRAMMABLE LUMINAIRE WHICH HAS THE MAIN FUNCTION OF POSITIVELY INFLUENCING THE STATE OF MIND OF BYSTANDERS BY USING ITS ADAPTIVE LIGHT PROPERTIES TO CREATE DESIRED ATMOSPHERES"

Customizability is central to the design of the luminaire:

- The luminaire should be **adaptable** during installation to ensure that the quality of the light is optimized for its environment.
- In contrast to the electronic components, which are optimized for standardization or maintenance, the housing offers a certain **design freedom** to match the identity of the city.
- **Programmable** light properties enable the luminaire to vary between layers of light and by means of light scenarios improve the residential quality of cities.

The luminaire will be installed in areas where pedestrians are the main or only traffic participants

10.5 Assumptions & Design Choices

When converting the literature findings into a design vision, a number of choices have been made. Partly, these choices have been made based upon assumptions. How these assumptions have influenced the design vision and how this vision will mark the continuation of the design process will be discussed.

Assumptions

- The atmosphere metrics model will be used for the evaluation of public space (ch. 6.4). It is assumed that the model used in the research for assessing interior spaces is applicable to public spaces.
- Hereby, it is assumed that the difference in light properties have the same influence on the atmospheric perception of the public space as is described for interior spaces. (ch. 6.5, ch. 6.6)

Design Choices

- All concepts will be developed with applications of LED light in mind. LED lighting is one of the most economical light sources and very suitable for applications with different color tones.
- Concepts will be developed for applications in low-traffic areas. This means uniformity and color rendering is less important than standard street lighting. The concepts will be developed with the main objective of increasing the spatial quality of the public space. Whereas the aim will be to increase the identity and improve the atmosphere of a city center. (ch.7.1, 7.2, 8.1, 10)
- Concepts will be based on dynamic lighting, considering the intelligence of the light sources (ch.7.3). By avoiding the use of sensors and Apps (and thus focus on pre-programming scenario's), the idea's will be better applicable for various environments.
- When developing concepts and making light scenarios, the possibilities of dimming and the application of warm shades of light will be examined to limit influences on the behavior of nocturnal animals. The influences of specific color hues (green and red) will not be included in determining designing lighting scenarios. (ch. 7.5)

11. Concepts

11.1 In the Spotlight

The first concept 'In the spotlight' is based on illuminating the street surface by means of multiple (overlapping) light beams. These light beams differ in brightness and sharpness in order to create a dynamic playful whole. The concept responds to multiple use scenarios of the public space. Visualizations of both scenarios (A & B) can be seen on the right

11.1.1 Layers of Light

Different types of light are created depending on the usage scenario. In the one scenario there is a combination of ambient light, focus light and brilliance. The latter is created by reflections and the overlapping light beams.
In the second scenario, there is a high degree of ambient lighting and a moderate amount of brilliance.

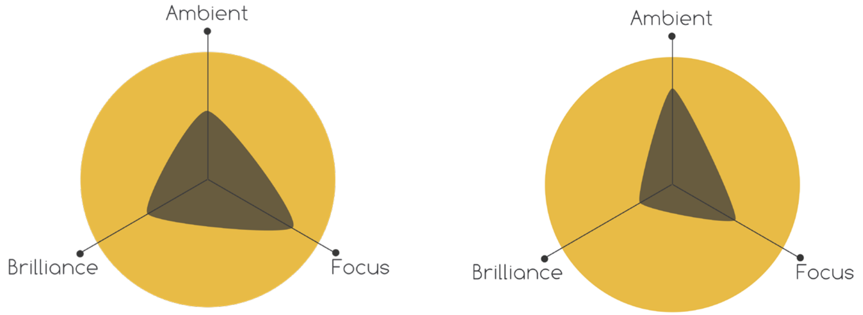


Figure 11.1,2: Visualization of different light layers of scenario A (left) and scenario B (right)

11.1.2 Adaptability

By positioning the light sources closer or farther from the lens, as can be seen in figure 11.7, variations in width and sharpness of the light beams can be made. Furthermore, by rotating the light sources, certain parts of the public space can be illuminated.
Dynamic light can be created by allowing the different LEDs to pre-programmed fluctuate in brightness.

If there is a need for uniform light (and high color rendering) within the use scenario of the public space, a choice can be made to switch light sources and illuminate the street with ambient light.
This can be done by turning off the spot lights and turning the light sources which create ambient light by grazing material to full brightness. This scenario is shown in the right-hand visualization (figure 11.6)

11.1.3 Spatial Distribution

Depending on the usage scenario, several light distributions of the luminaire are conceivable. In scenario A it can be seen that the distribution of the light is uneven and asymmetrical. In scenario B a wide uniform light distribution is created.

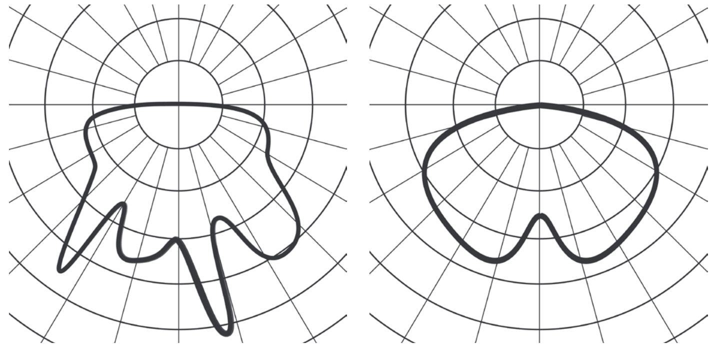


Figure 11.3, 4: Visualization of the spatial distribution of scenario A (left) and scenario B (right)

Figure 11.5: visual presentation of Scenario A.
The luminaire producing a play of brilliance

A

B

Figure 11.6: visual presentation of Scenario B.
The luminaire producing ambient light

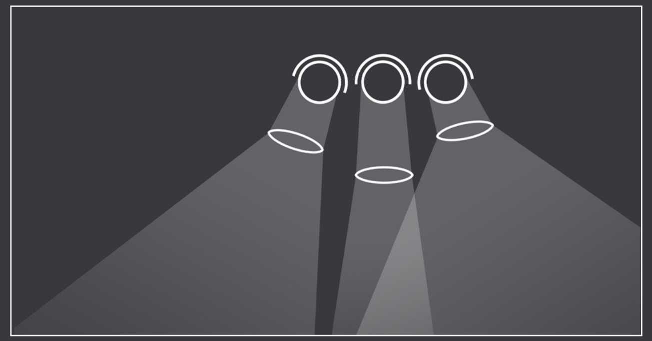


Figure 11.7: Schematic overview of the creation of multiple overlapping spotlights; distance to lens determine sharpness of the beam

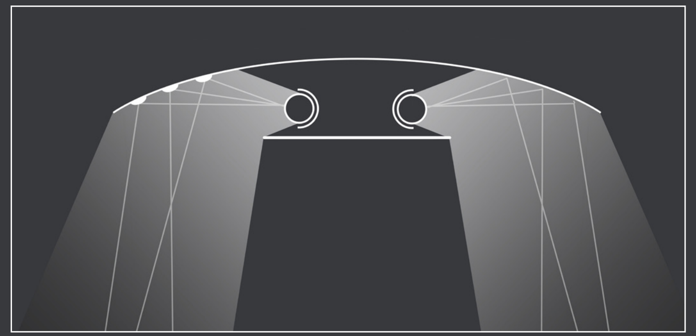


Figure 11.8: Schematic overview of the creation of ambient light

11.2 Refracted Reflections

The second concept is based on a light source that is refracted and reflected through a number of panels. These panels, which are part of the luminaire differences in material properties. A playful 'sphere' of light is created by difference in mirroring and transmittance. The panels of the luminaire are rotatable, so that the different light beams can be influenced.

11.2.1 Layers of Light

This concept will create ambient, focus and brilliance lighting, where the emphasis will be on the latter. This 'play of brilliance' will be created by illuminating the luminaire itself (illuminated panels) and by the playful patterns that the luminaire will project onto the ground surface of the public space.
By rotating the panels, certain surfaces can get higher illuminance values relative to the immediate environment, creating focus lighting.

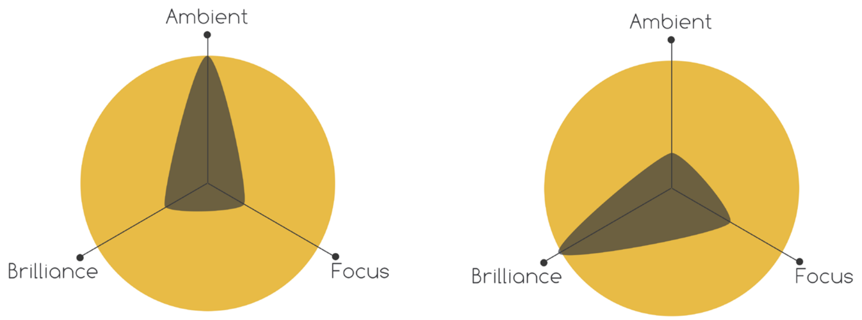


Figure 11.9, 10: Visualization of different light layers

11.2.2 Adaptability

Dynamics within the lighting is created by programming fluctuations in brightness and color of the light sources. These will of course be adjusted to the possible use scenarios of the public space.
Furthermore, it is possible to rotate the panels when installing the luminaire, in order to influence the spatial distribution. This way the distribution can be optimized for the location of the light source.

11.2.3 Spatial Distribution

In the figure on the right you can see an example of the spatial distribution of a luminaire creating this kind of lighting. An asymmetrical application can be seen in the example. The spatial distribution can be influenced by the adaptability discussed above, depending on the application of a luminaire. For example, a higher uniformity or axial symmetry can also be desirable in certain applications.

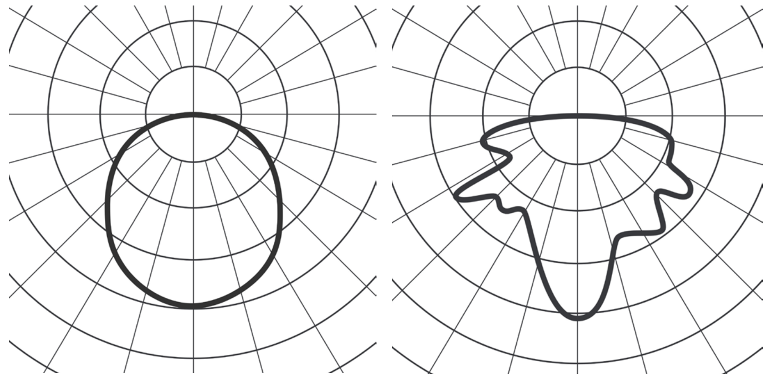


Figure 11.11, 12: Visualization of the spatial distribution

Figure 11.13: visual presentation of Scenario A.

Figure 11.14: visual presentation of Scenario B

A

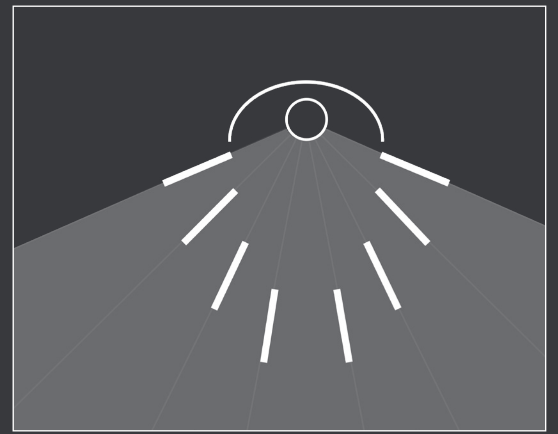


Figure 11.15: Schematic overview of the luminaire producing ambient light. All panels are rotaded parallel to the beam direction

B

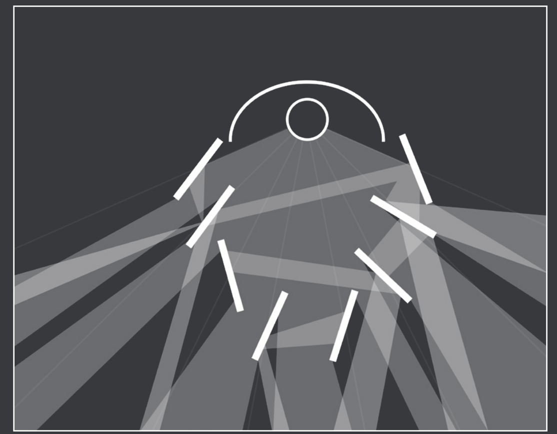


Figure 11.16: Schematic overview of the luminaire creating brilliance through reflections on the rotated panels.

11.3 Shaped Reflections

This concept is based on a light source which illuminates an (asymmetric) surface around itself via a reflective surface. (This concept is ideally applied in luminaires that are placed below eye level to prevent direct glare.)By creating a repetition of such luminaires in a street, a playful pattern of different shapes can be formed.
To create this, it is necessary to use different asymmetrically reflective surfaces to get a varied whole.

11.3.1 Layers of Light

A luminaire that distributes such light will create ambient, focus and brilliance light. The difference in illuminance between the illuminated areas and the immediate environment provides a certain amount of focus lighting. Brilliance is created by overlapping the illuminated surfaces in a playful way.

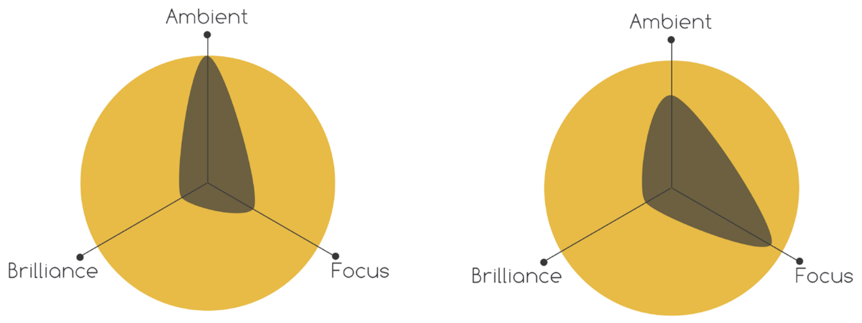


Figure 11.17, 18: Visualization of different light layers

11.3.2 Adaptability

Dynamics within the lighting is created by programming fluctuations in brightness and color of the light sources. These will of course be adjusted to the possible use scenarios of the public space.
Furthermore, the design freedom of the reflective surfaces will ensure a degree of adaptability; By designing these surfaces site-specific, the light can be adjusted to the public space.

11.3.3 Spatial Distribution

In the figure on the right you can see an example of the spatial distribution of a luminaire creating this kind of lighting. It can be seen that the distribution of the light in this example is uneven and asymmetrical. Depending on the immediate surroundings of the luminaire, certain areas are more illuminated or left dark. For example, the focus in the street can remain entirely on the plinth, while enough brightness is created to optimize visibility.

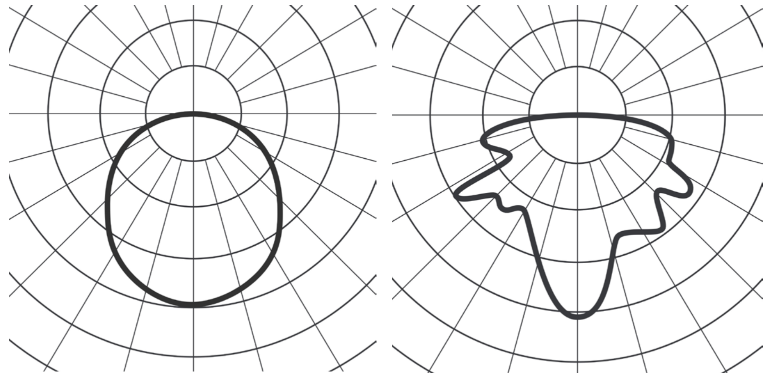


Figure 11.19, 20: Visualization of the spatial distribution

Figure 11.21: visual presentation of Scenario A.

A

B

Figure 11.22: visual presentation of Scenario B

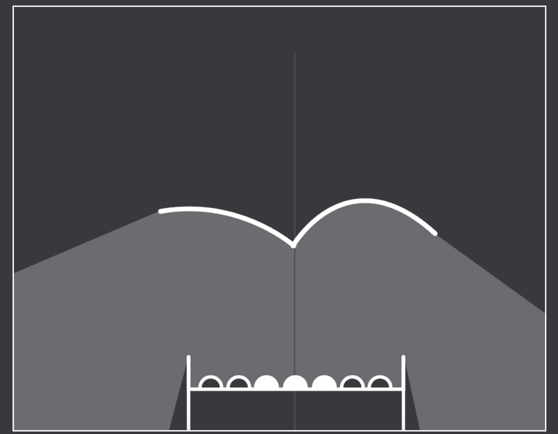


Figure 11.23: Schematic representation of the section view of the light distribution focused on producing ambient light

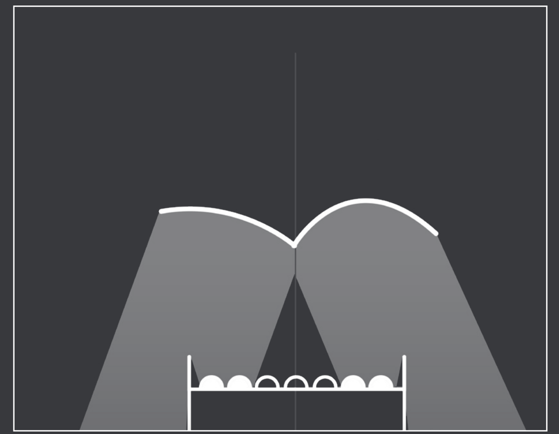


Figure 11.24: Schematic representation of the section view of the light distribution of 'Shaped Reflections' By turning on the LED units on the side, more focused light will be produced.

11.4 Rippling Projections

This concept is based on multiple light sources that create a rippling, water-like, light projection. This is created by means of a glass dome that deviates from the sphere shape due to differences in thickness and a variety of dents

11.1.1 Layers of Light

Different types of light are created depending on the usage scenario. In scenario A, ambient and brilliance light will be created, with a strong emphasis on the latter. Due to the deviations in the spherical shape of the glass dome, a playful pattern on the ground surface of the public space will arise through refraction. In the second scenario, there is a high degree of ambient lighting and a moderate amount of brilliance.

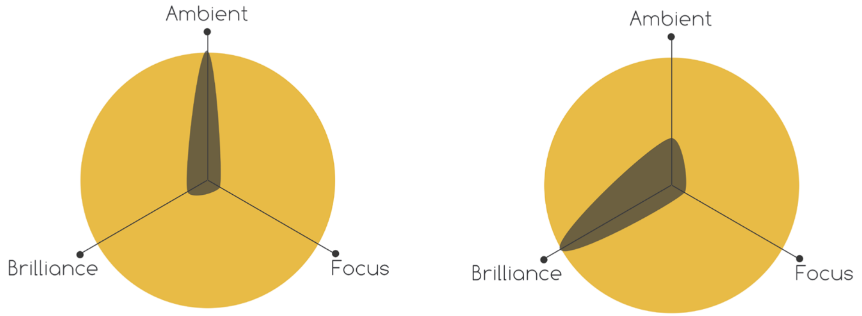


Figure 11.25, 26: Visualization of different light layers of scenario A (left) and scenario B (right)

11.1.2 Adaptability

Dynamics within the lighting is created by programming fluctuations in brightness and color of the light sources. Through these fluctuations, the illusion will be created that the light moves across the ground surface.
If there is a need for uniform light (and high color rendering) within the use scenario of the public space, a choice can be made to switch light sources and illuminate the street with ambient light.
This can be done by turning off the spot lights and turning the light sources which create ambient light by grazing material to full brightness. This scenario is shown in the right-hand visualization.

11.1.3 Spatial Distribution

Depending on the usage scenario, several light distributions of the luminaire are conceivable. In scenario A it can be seen that the distribution of the light is uneven and asymmetrical. In scenario B a wide uniform light distribution is created.

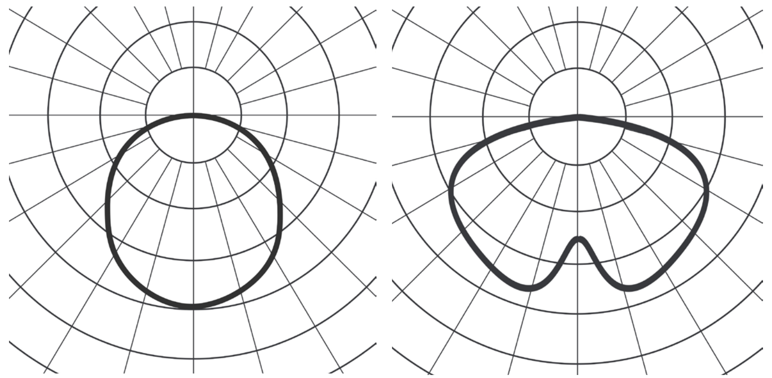


Figure 11.27, 28: Visualization of the spatial distribution of scenario A (left) and scenario B (right)

Figure 11.29: visual presentation of Scenario A.

A

Figure 11.30: visual presentation of Scenario B.

B

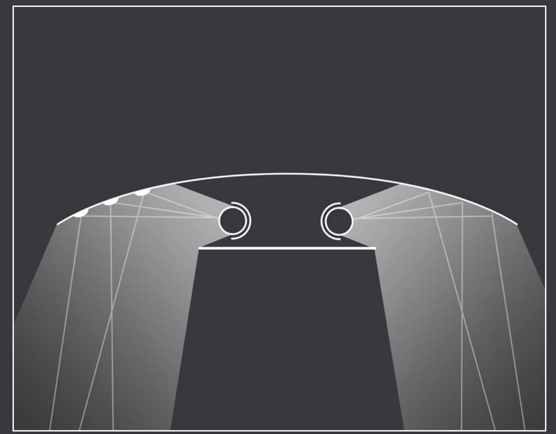


Figure 11.30: Schematic overview of the creation of ambient light through the grazing of materials.

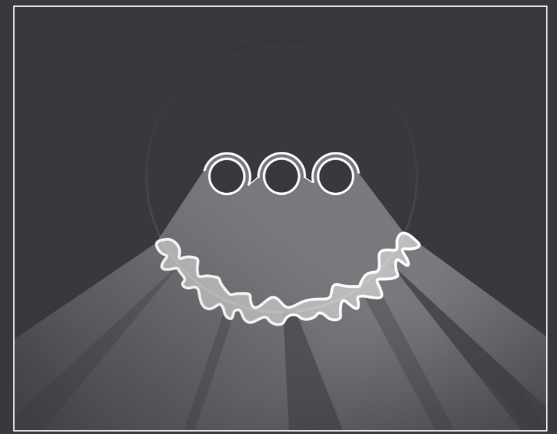
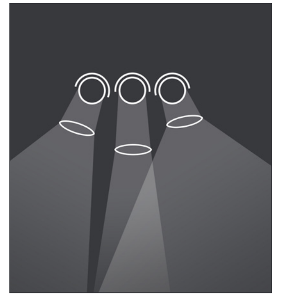


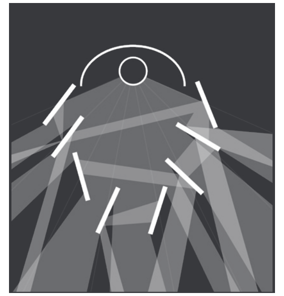
Figure 11.31: Schematic overview of the creation rippling projections through a glass dome that deviates in thickness

12. Assessment of Concepts

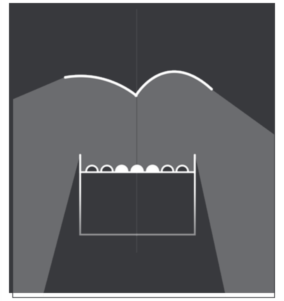
The four discussed concepts will be assessed in this chapter. After all pros and cons points of each concept are discussed, the concepts will be evaluated with the program of requirements as a benchmark. The weighted objectives method will be used for this evaluation. Because the concepts are based on the creation of light with certain methods (and not on the design of a specific luminaire), the concepts will be judged purely on their overall potential. Requirements that concern the quality of a luminaire will therefore not be included in the assessment.



In the Spotlight



Refracted Reflections



Shaped Reflections

Rippling Projections

12.1 Pros and Cons

12.1.1 In the Spotlight

- The concept can respond to multiple use scenarios of the public space. This makes it suitable for use in areas that are car-free for only part of the day; Because of the uniformity of the light distribution, the luminaire supports road safety and face recognition.
- All light layers described by Kelly are present in this concept. This allows for the use of all the beneficial properties of the three light layers.

- To get the playful character on the ground surface, multiple light sources are needed. This makes potential luminaires more complicated and more expensive.

12.1.2 Refracted Reflections

- In addition to lighting the surroundings, the luminaire itself is also part of the atmospheric experience.

- Due to the many components that are needed to make the experience of this light possible, it is a complex application. This makes potential luminaires more complicated and more expensive.
- The application of the light reduces the design freedom of the luminaire itself. This makes it more difficult to design the luminaire for a specific municipality and thereby respond to the local identity
- Due to the low uniformity, the concept can only be applied in pedestrian areas

12.1.3 Shaped Reflections

- One light source is required for this application. Possible luminaires will therefore be more electronically minimalistic than the other concepts.
- Because this lighting concept supports application in a Bollard, its light distribution makes it very suitable for areas where the plinth is ideally lit from the inside. (Shopping area)
- When used as a bollard, it is very suitable in areas where light pollution should be prevented, such as parks.

- Due to the low uniformity, the concept can only be applied in pedestrian areas
- The concept contains little to no dynamics. This makes it less suitable to serve as atmospheric lighting.
- Because the light is reflected downwards by materials with high reflection values, the concept is less suitable as a pendant luminaire due to the increased risk of glare.
- Because ideally the reflective parts are designed site-specific, it is a relatively complex application.

12.1.4 Rippling Projections

- The concept can respond to multiple use scenarios of the public space. This makes it suitable for use in areas that are car-free for only part of the day; Because of the uniformity of the light distribution, the luminaire supports road safety and face recognition.
- The concept has the potential to create the illusion of moving light, without needing moving parts.
- Due to the moving light and the water-like projections on the ground surface, the concept is suitable for applying biomimicry.
- The concept creates a lot of 'play of brilliance'. According to Richard Kelly, this type of light has the potential to create atmosphere and liveliness.

- To get the playful character on the ground surface, multiple light sources are needed. This makes potential luminaires more complicated and more expensive.

12.3 Weighted Objectives

	Rel. demands	Rel. Wishes	Weight	Spotl.	Refr. Refl.	Sh. Refl.	Rippl. Pro.
Quality of light, Use of all light layers (Brilliance, Focal, Ambient)	D2		16	9	7	8	8
Customizability light emission			*(30 tot.)*				
Adaptations in spatial distribution, Dimmable		A4	11	9	6	6	9
Change of colours & colour combinations	D3	C1	10	8	7	6	8
Light dynamics, Biomimicry		A2, B2, B5	9	7	6	5	9
Limitation glare & light pollution		D5, A3	12	8	6	9	8
Facial recognition & traffic safety (brightness, elderly)		B4	7	7	5	8	6
Ability to create winter season decorations with light		C2	5	6	5	5	5
Integration, Diversity of application (less masts)		A1	10	6	6	4	6
Innovation		A2, B7, D3, A1	13	6	5	6	8
Simplicity		B5	7	6	3	7	6
		Total	100	741	580	655	757
		Grade		**7,4**	**5,8**	**6,6**	**7,6**

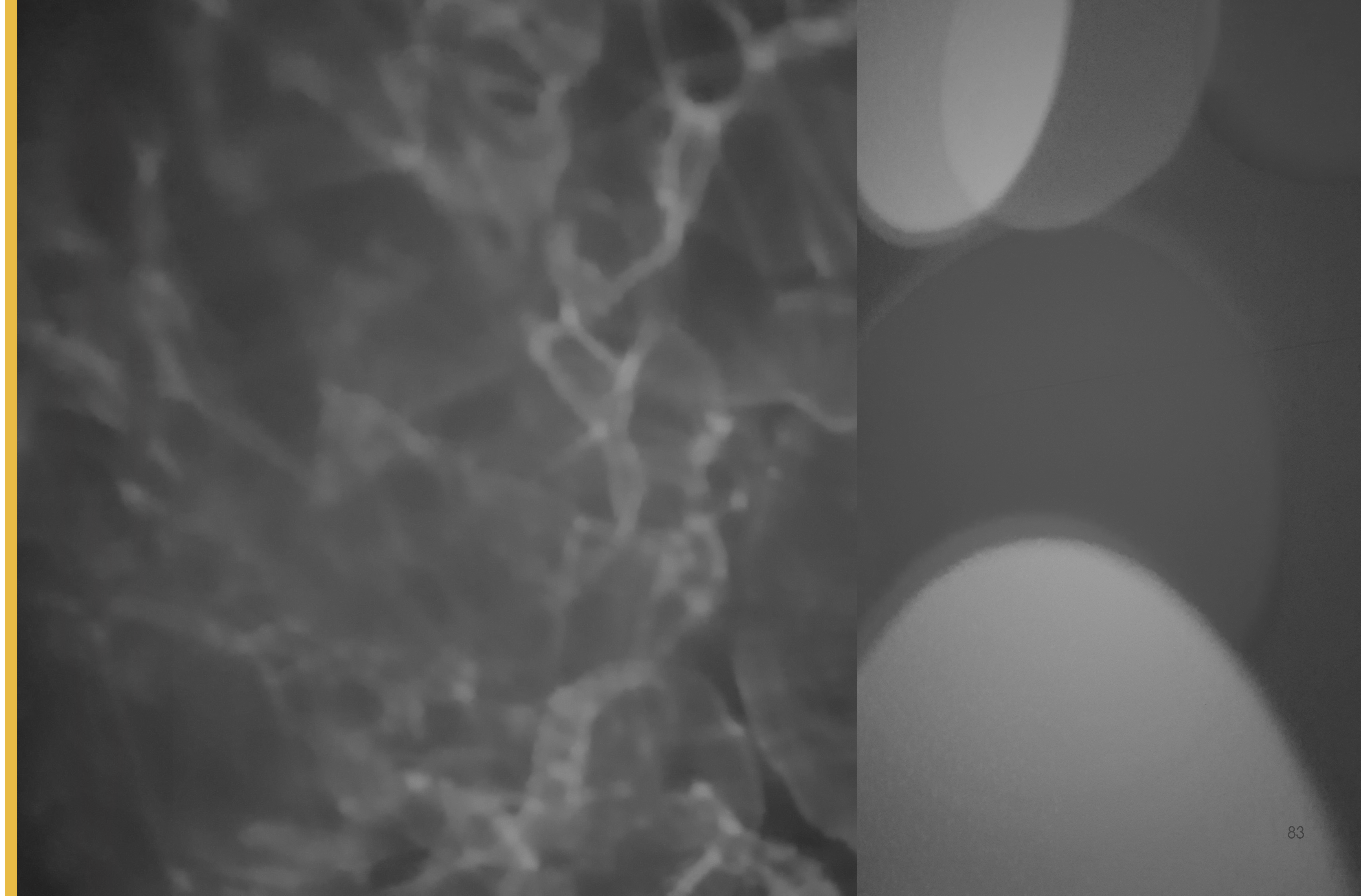
Table 12.1: Weighted Objectives Model

To be able to make a choice between the four concepts, a weighted objectives model has been set up. The concepts were assessed on the basis of their light emission. This concerns demands 2 and 3 and wish A1, A2, A4, B2, B4, B5, B7, C1, C2, D3 and D5. (The precise requirements and wishes can be found in chapter 11.3)

On the left in the table the objectives can be seen, which in some cases consist of merging multiple demands and wishes. The priority of these requirements and wishes is linked to the so-called 'weight' factor of the composed objectives.

12.3.1 Conclusion

It can be seen that the first and last concepts ('In the spotlight' and 'Rippled projections' respectively) score the best, with a slight preference for the last concept.
Because the biggest difference between the two concepts is the glass-shaped dome, which in 'Rippled projections' provides the water-like effect, it was decided to merge the two concepts. In this way, based on the location in the public space, a choice can be made for an application within the biomimicry or for an application of playful spotlights.



13. Tilburg; A case study

To further develop the chosen concept, a choice was made for the application of a case study; The city of Tilburg. Tilburg is a city where the city center is currently developing strongly and for which a master plan for lighting is being drawn up by lighting agency based in Rotterdam. Therefor, there is room in the city center for the application of atmospheric lighting in the nearby future.

In this chapter, Tilburg will be introduced, after which an analysis will be made of the city center and its use

13.1 Introduction

Tilburg is a city located in Noord-Brabant (A dutch province). With over 200,000 inhabitants, it can call itself the 7th largest municipality in the Netherlands. Tilburg was formed by a number of neighborhoods that started working together and thus formed an administrative unity. This can be seen in the contemporary structure of the city; the city has a number of different neighborhoods, many of which still have their original 'center'.

Figure 13.1: The Location of Tilburg

Tilburg has grown because of the extensive sheep breeding that the area around the city knew. This made it the largest wool city in Brabant (1600). Due to this large supply of wool, the city has developed into a major player in the Dutch textile industry (18th century).This textile industry settled between the herd walks. At its 'top', the city knew 123 woolen mills around 1871. The construction of the Wilhelmina canal (1916-1923) and the priushaven (1921) anticipated the export of textile goods.After

Figure 13.2: A herd of sheep in Tilburg (20th century)

the second world war, the city began the reconstruction, including the construction of the east-west boulevard, to the south of the railway line.

During the 60s of the twentieth century, the textile industry disappeared from the city and gave way to the establishment of modern industry, created in various industrial areas. The city now has more than 10 large industrial sites, with the largest (Crows, Loven and Vossenberg) offering space for 7,600 companies and more than 100,000 employees.

From 1975 the 'city ring' was built in the city, with the aim of promoting the flow of traffic. Unfortunately, a lot of historical heritage was demolished during this construction under the supervision of the mayor, who was nicknamed 'Cees de Sloper' (Cees the demolisher). Despite that, the city still has many monumental buildings: In the second half of the 19th century and the beginning of the 20th century, Tilburg was very prosperous due to, among other things, the cloth industry. Due to the architectural wealth of the styles of this time, parts of the city have been given a protected cityscape

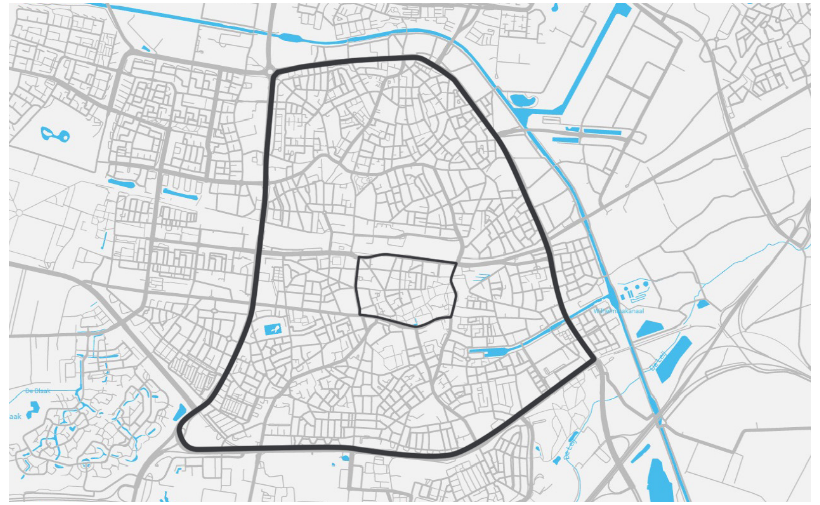


Figure 13.3: The City ring of Tilburg

In addition to these buildings, the city also has a lot of industrial heritage. In the form of old cotton spinning mills, textile factories, factory chimneys and other factory buildings, remnants of the industrial past are visible throughout the city.

Figure 13.4: The remarking factory chimneys found throughout Tilburg

13.1.1 Kruikenzeikers

The people of Tilburg are commonly referred to as 'kruikenzeikers' ('Jar pissers'). This is because from the 17th century until the late 19th century, residents collected their urine in jars to sell to the textile factories. These factories needed the ammonia present in the urine to process wool. The carnival name (every brabant city in the Netherlands has a special name during carnival, a folk festival within the Christian tradition) of Tilburg is therefore 'Kruikenstad' ('jarcity')

Figure 13.5: 'Kruikenzeikers', Tilburg during Carnaval.

13.1.2 Coat of arms & Flag

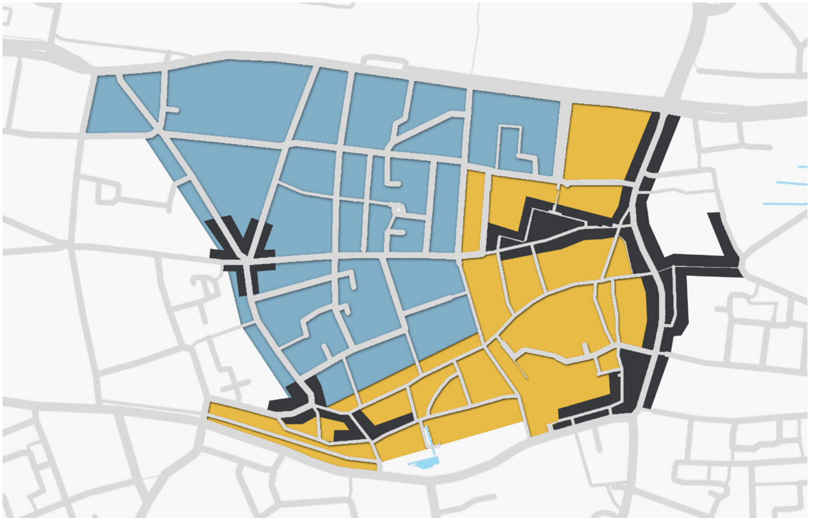
The coat of arms of Tilburg consists of three golden towers, with the middle one being just a little higher than the next two. The three towers are shown in front of a blue area. The heraldic colors gold / yellow and blue represent wisdom / wealth and science respectively.

The flag of Tilburg, consisting of blue and yellow planes, symbolizes the merging of the three municipalities of Tilburg, Berkel-enschot and Udenhout into one new municipality; Tilburg (1997)

Figure 13.6: Tilburg's Coat of Arms
Figure 13.7: The Flag of Tilburg

13.2 The City Centre

Within this project, the city center of Tilburg will be used as a case study, with the emphasis on the 'dwaalgebied' ('wander area'), the core-shopping-area and the associated and surrounding squares and streets with catering establishments. The areas are shown in Figure X.



Wander Area
Core shopping Area
Catering Area

Figure 13.8: A devision of Tilburg's city centre

13.2.1 Wander area

The wander area is the area that connects the shopping area and busy squares with the station. Besides that it offers a place to live for many people, it therefor is an area where many people walk or cycle through (on their way to the station or shopping area). It is a quiet part of the city and feels a bit village-like. In addition to many (old) houses, the area has many small scaled businesses. From business associations and the municipality there is a desire to turn it into an area that people like to stroll through; a true 'wander area'.

Figure 13.9: A typical street in the Wander area

13.2.2 Core shopping area

The core shopping area of Tilburg, indicated in yellow, lies against the wander area and is focused on promoting the purchasing power of the city. This area is currently under development, with the municipality hoping to encourage businesses to settle here. The aim is to combine large international retailers and small local businesses. Where the shopping area mainly consisted of the Heuvelstraat, efforts are now being made to create a routing with businesses; a 'shopping circle'.

Figure 13.10: A typical street in the Shopping area

13.2.3 Catering area

There are a number of squares and streets in and around the two aforementioned areas with the focus on catering. In addition to making events possible, the areas offer space for many small-scale businesses. 'De Heuvel' is seen as the most central square in Tilburg and therefore also has the greatest density when it comes to catering businesses.

Figure 13.11: A typical street in the Catering Area

13.3 Streets in City Centre

Figure 13.12: Relevant streets in the city centre

Pedestrian Area

Nieuwlandstraat

Figure 13.12 shows the streets of Tilburg, subdivided into car-free streets and streets that allow motorized vehicles. The Nieuwlandstraat will be partly car-free in the near future. For this street this means that traffic is allowed to pass between 06:00 and 11:00, after which the street is only available to pedestrians and cyclists for the rest of the day.After this will be tested by the municipality, it will be examined whether other areas in Tilburg will also become car-free in order to improve the residential climate of the city.

With the current concept, the greatest potential will lie in (partly) car-free streets. the use of atmospheric lighting in Smaller streets where little motorized traffic runs through it becomes feasible if dynamic street lighting is used.

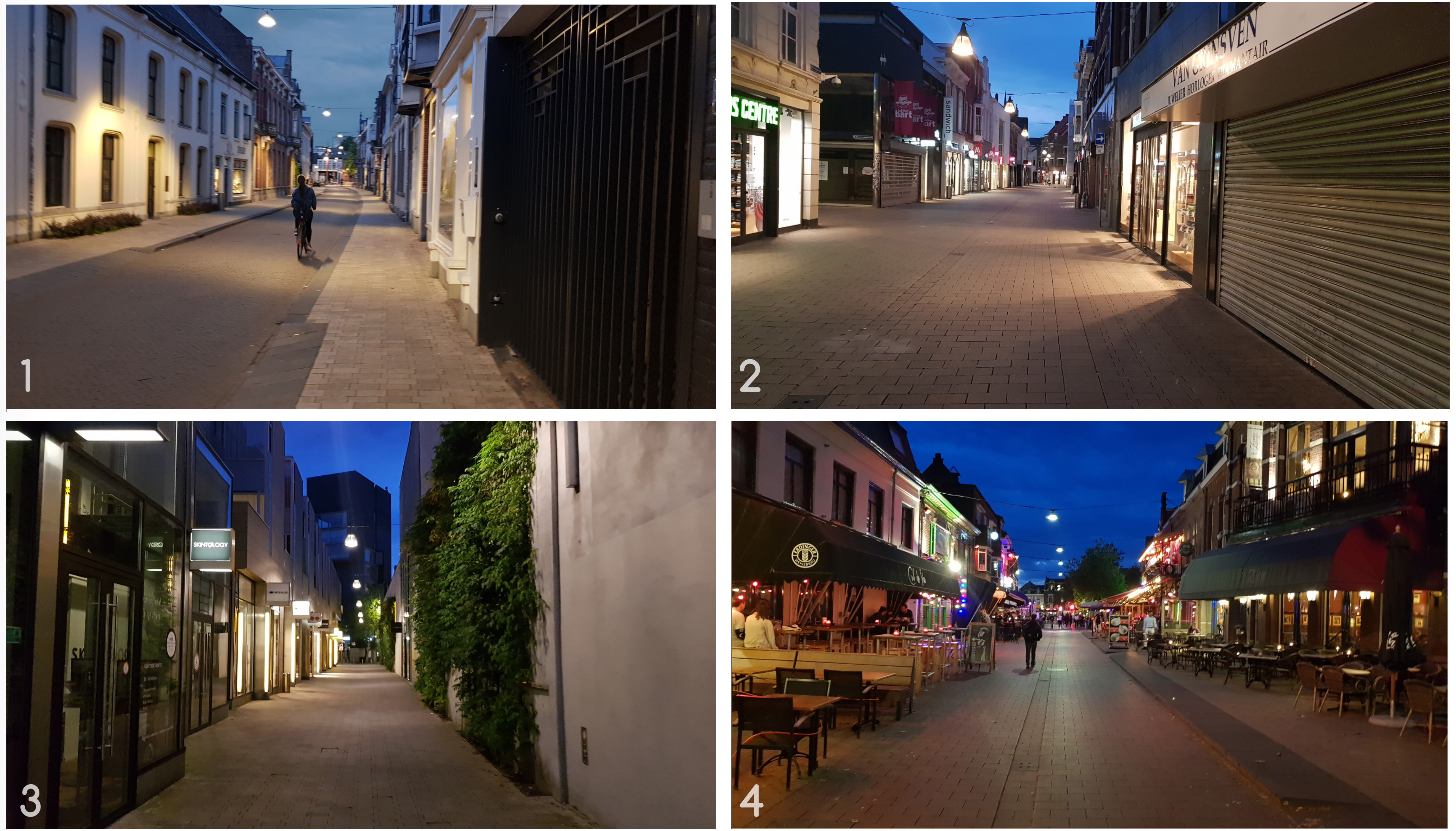


Figure 13-16: A number of night scenes of the streets where mood lighting can be applied are shown above. The numbers refer to the numbers on the map on the left.

13.4 Events in Tilburg

To get a further picture of what is going on in the public space of Tilburg, an overview has been made showing all the annual events that are held in Tilburg. The events are then briefly discussed.

Because dates change annually, the 2019 calendar year is used here as a reference

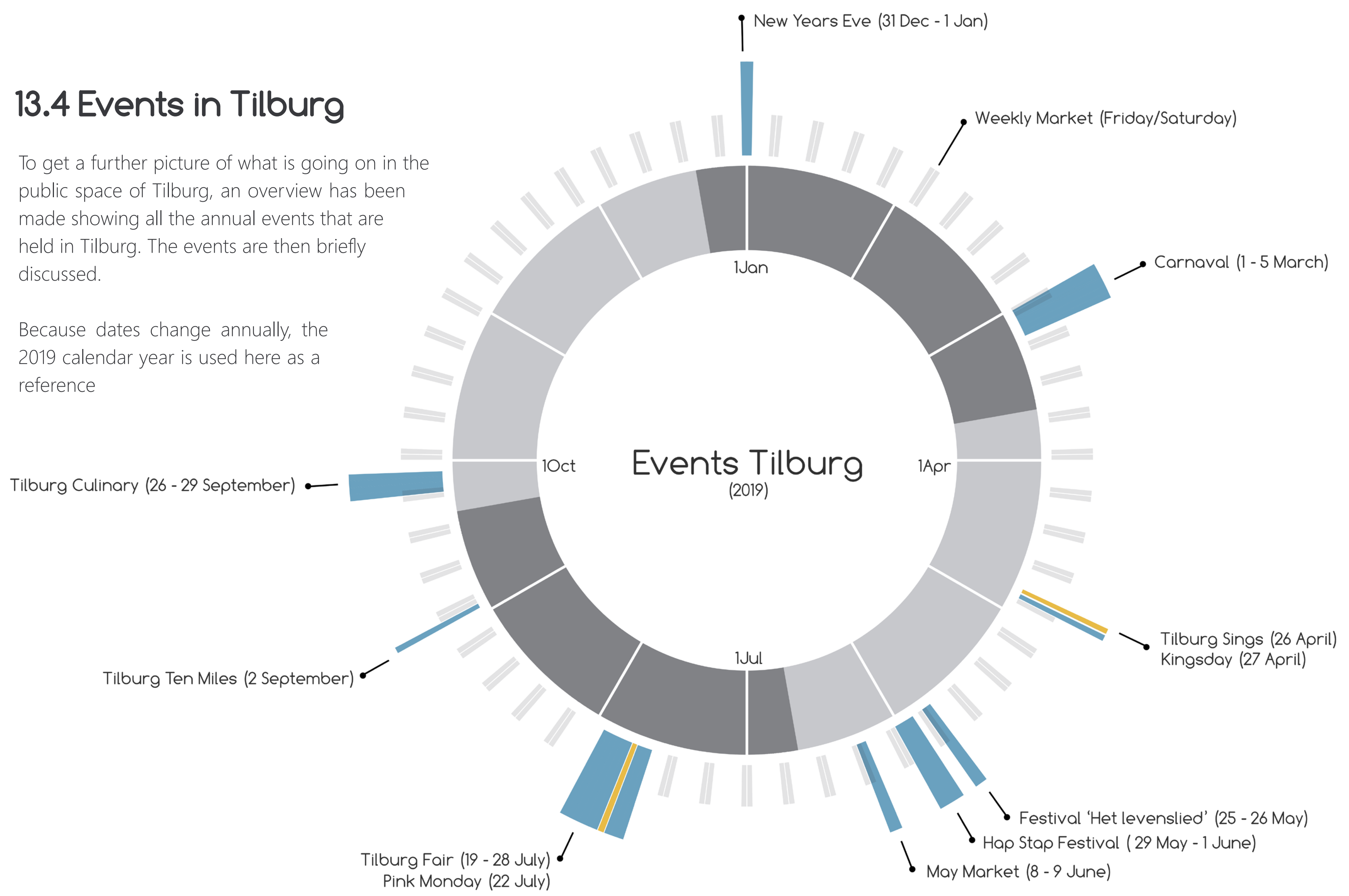


Figure 13.17 :An overview of all events in Tilburg

Weekly market
A cozy market with 230 stalls. Mainly (local) fresh products are sold here. The market is held weekly on Friday and Saturday.

Carnaval
An event within the Christian tradition focused on craziness, ridicule and exuberance. People go dressed up in the streets, which are full of bars, parades and music.

150.000

Tilburg sings
An event in which there is mass singing along with well-known songs.

15.000

Kingsday
Celebrating the birthday of the Dutch King Willem-Alexander.

150.000

Festival het levenslied (the song of life)
An event in which there is mass singing along with well-known songs.

18.000

Hap stap festival
A food festival, located in the city center of Tilburg

40.000

May market
The city center is changing into one large marketplace for second-hand items. The market lasts from 10 p.m. to 5 p.m. and will therefore remain open at night.

120.000

Tilburg Fair
The largest fair in the Benelux. The event is more than 400 years old and is held annually. There are around 250 attractions throughout the city.

1.3 - 1.4 Million

Pink Monday
An event to celebrate the equality of LGBT people. The largest gay event outside of Amsterdam. The city turns pink and offers many activities, including a 'pink caravan'.

250 - 300.000

Tilburg ten miles
Large massive (running) tour through the center of Tilburg.

10.000

Tilburg Culinary
All catering establishments open their doors to hold tastings of their cuisine

13.000

14. Creating Social Representation

To make a better analysis of Tilburg, it was decided to set up an online questionnaire for its residents. It was decided to use a combination of open and closed (multiple choice) questions to obtain a combination of quantitative and qualitative data. The questionnaire was set up with the aim of gaining a better picture of the preferences of the inhabitants of Tilburg in order to create atmospheric lighting using social representation. Furthermore, the purpose of the questionnaire was to create a better picture of activities being undertaken in the center of Tilburg in order to find out how atmospheric lighting can improve the experience of these activities.

The questionnaire was completed by 21 people. Of these people, 52% (11/21) are female. The age of the respondents varies between 25 and 64 years. Of the 21 respondents, 14 people live in the center of Tilburg, the remaining 7 people live in neighborhoods around the city center.

14.1 Tilburg and its inhabitants

If Tilburg is to be compared with other cities, it is mentioned that the city is growing and developing at a very rapid pace. This would be due to the close community and the 'we-feeling' of the inhabitants, who together initiate and take on projects. That the city has grown because of the textile industry can also be clearly seen, according to the residents; it gives Tilburg a unique raw and industrial look. An asset of the city center is that it is relatively compact for the population of the city and therefore easy to visit by foot.

14.1.1 Tilburgers

The inhabitants of Tilburg are sober people, to their own opinion. Although they are proud of the city, they are modest and don't want to be seen as show-offs. Furthermore, it is repeatedly mentioned that people are stubborn/contradictory and use very direct cynical humor.

14.1.2 Tilburg

With regard to the question of attributing character traits to Tilburg, it is mainly mentioned that there is a major contradiction in decisiveness and modesty. It is a proud, enterprising city, but at the same time it is reserved. Furthermore, the city is fairly contemporary, innovative and surprising. The city is stubborn and undertakes things that have not been done anywhere else. This makes Tilburg a unique city in the eyes of its inhabitants.

14.1.3 Pride

When asked about what Tilburgers are proud of, it is noticeable that they are relatively satisfied with how things are going in the city. They are proud of the developments that the city has made over the past 5 to 10 years. These developments have contributed to the increasing popularity of the city and the many events that are being organized for residents and visitors. According to the Tilburgers, these developments have been made possible by the good cooperation of entrepreneurs and the involvement of all residents. The municipality's large investments for improving the city center can count on a lot of support.
Finally, it should be mentioned that the inhabitants are proud of the history of the city and the culture that this has brought with it. The nickname 'kruikenzeikers' is proudly awarded.

14.2 The inner city of Tilburg

The respondents indicated that it was important to create a certain unity within the areas of Tilburg for the purpose of city branding. However, what they find even more important is the possibility to create an emphasis on the diversity of the city. It has also been mentioned several times that the respondents hope that all areas of Tilburg are brought to the attention, without letting financial interests (of entrepreneurs) take the lead.

14.2.1 Wander Area

Opinions about the wander area are generally positive. It is considered an authentic and quiet part of Tilburg that feels like a village. The monumental character makes it a unique and cozy area full of history. Although there is already a lot of greenery to be seen in most streets, the residents of Tilburg like to see even more greenery in this neighborhood to make it less gray.
Although the residents of Tilburg welcome the arise of small businesses in the wander area, they hope that the area does not become too busy and that it retains its modesty.

14.2.2 Core shopping area

The opinions about the core shopping area are purely negative. The area is very gray and lacks all forms of personality. The area is sometimes too busy (e.g. shopping evening) and other times completely empty. This negative character is reinforced by the vacancy in the shopping streets.
When the stores are closed, the area feels unsafe. Respondents (mainly women) do not feel safe when they have to walk through the area during late hours. More atmosphere and liveliness in the areas would offer a solution according to the residents.

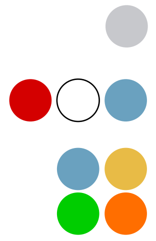
14.2.3 Catering areas and squares

The residents of Tilburg are enthusiastic about the catering areas and squares. The diversity of catering establishments is great. They are also pleased with the atmosphere in the establishments, partly due to the generally friendly character of the people of Tilburg. It is again emphasized by the respondents that the environment of the catering establishments often has great contradictions with the catering areas themselves. (e.g. the dark and 'unsafe' shopping street)

14.3 Color and light

14.3.1 The color of Tilburg

When asked about colors that match Tilburg's identity, these are the three answers that came up a lot.



Gray: The color gray refers to the rawness of the city and the modesty of its inhabitants.
Red-White-Blue: The colors of Willem 2, the soccer club of Tilburg.
Blue-Yellow: The colors of the flag and coat of arms of the city.
Green-Orange: These are the colors that the city bears during Carnival, when Tilburg takes the name of 'kruikenstad' (jarcity).

14.3.2 Light

Respondents indicate that they are open to the use of color when it comes to illuminating the public space. It is indicated here that the color itself must depend on the season, the situation, circumstances and the area that needs to be illuminated. For example, it is stated that warmer colors would be better in the wander area, whereas brighter colors would not look out of place in the core shopping area, because this is an area with more activity.

To get an idea of the preferences of the respondents, twenty types of luminaires were shown. Each image was asked to assess the lighting on the basis of two statements. The first statement asks to what extent the participants think the lighting is only suitable for the winter season or whether it is suitable for all seasons. The second statement asks to what extent the respondent believes that the lighting fits in with Tilburg's identity.

	1	2	3	4	5	
only suitable for winter season	○	○	○	○	○	suitable for all seasons
does not fit in with Tilburg	○	○	○	○	○	fully fits in with Tilburg

With the first statement an attempt has been made to get an idea of which characteristics of lighting are directly linked to the winter season (In an interview with the business association, it emerged that many residents of Tilburg felt that certain type lighting was out of place outside the December month, because in their eyes it was Christmas lighting, while the intention of the business association was to install general atmospheric lighting).
With the second statement, an attempt was made to find out whether the people of Tilburg have a similar taste and whether it is possible to link certain types of lighting to the identity of a city.

14.3.3 Conclusions

Because the study consisted of only 21 people, the conclusions of this study will not be based on scientifically proven correlations, but on own interpretation of the results.

It can be seen that brilliance created by scattered small bright lights in white / blue tones only seem to be suitable for the winter months in the eyes of the respondents. Furthermore, all span-lighting with objects that can be referred to as Christmas (garlands, balls, stars, etc.) is considered unsuitable outside the winter months.


Figure 14.1-3: Lighting suitable in winter months only

Lighting that makes use of illuminating its immediate environment (whether or not by means of projection) is considered suitable for use throughout the year. This may be due to the fact that these lights illuminate parts of the public space that are present throughout the entire year, and therefore not only during the winter months. It is remarkable that the color of the light seems to influence the assessment of the lighting on the basis of the first statement. It can be concluded that the use of color makes the lighting more suitable to use throughout the whole year.


Figure 14.4-5: Lighting suitable thoughout the whole year

When the lighting is assessed on the extent to which it fits with Tilburg's identity, there seem to be slightly more divided opinions. Many images are rated as "average" (Average ratings between 2.5 and 3.5), with this number being created by a combination of high and low ratings. However, there are 4 images that stand out in terms of ratings; the following four images have scores of 4 and higher. It is striking that these are the only four images (out of 20) of lighting in which different colors of light are mixed.

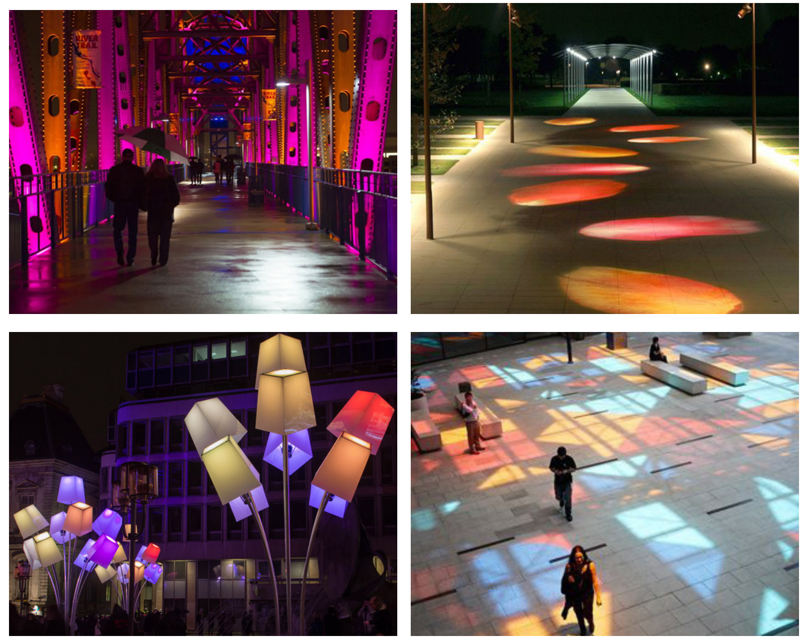


Figure 14.6-9: Lighting thats suits the identity of Tilburg

The three images that score the lowest in the second statement are all three images that show span-lighting. It is stated here that this type of lighting is considered as passé and has a lack of personality since a lot of Dutch cities use similar luminaires.


Figure 14.10-11: Lighting thats does not suit the identity of Tilburg

15. Iterative Prototyping

This chapter will briefly discuss the conclusions of all tests. The tests carried out by mock-ups and prototypes are intended to optimize the parameters of atmospheric lighting and, considering these parameters, to develop a luminaire that can provide this atmospheric lighting.

15.1 First tests

These research questions were attempted to answer with the first test setup:

- Can tube-shaped parts be used as a replacement for a collecting / fresnel lens when it comes to adjusting the sharpness of the light beam?
- How does the sharpness of the light beam relate to the distance to the illuminated surfaces?
- What is the minimum number of light sources with which dynamic "projections" can be generated without moving parts?
- What characteristics must the fluctuations have to simulate natural dynamics? (Such as wave movements, wind through trees)
- Which speed of color transitions is desirable when it comes to generating "fast dynamics" (see source Vogels and Seuntjes)?
- Up to what speeds are the color transitions 'invisible'?

The following materials were used for the first tests:

Three High-Power RGB led's

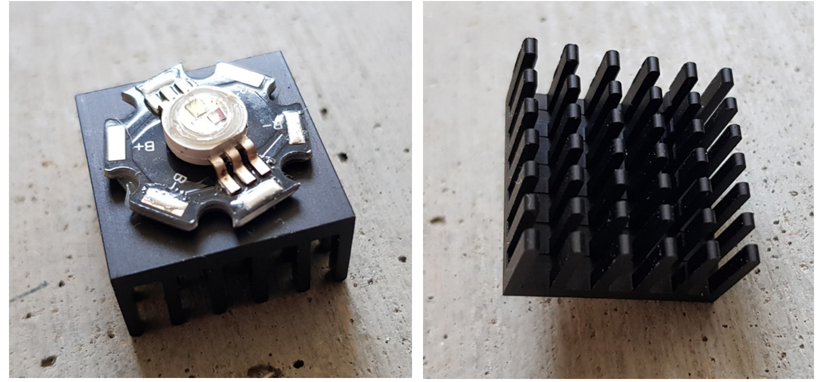


Figure 15.1: A High-power RGB LEd mounted onto a aluminium heat sink

As usual with LED lighting, this lights obtains all colors through additive color mixes. It contains three (high-power) LED units, in the colors green red and blue. (brightness red = 50 lm, green = 70 lm, blue = 15 lm). They each have a power of 3 watts and work with voltages between 2 and 3.8. To increase the heat conductivity of the components, these LEDs are mounted on aluminum heat sinks

(Although these lights are unlikely to provide enough light to function as street lighting, they have been chosen for integration into the prototypes because they can be easily controlled with 9V batteries.)

Tubes

Tubes with the same diameter (4 cm) and length (10 cm) were used for the first tests. With these tubes, the sharpness of the light beams will be created in this test setup and take over the function of the lens.

Plastic cover

Figure 15.2: A plastic dome shaped cover, used to create dynamic visualizations

This plastic cover has a number of thickenings and is used to create dynamic light. Due to the thickness differences in the cover, the light is refracted differently from other angles. Dynamic patterns can be created by allowing the lamps to fluctuate in light intensity.

15.1.1 Findings

Sharpness without lenses

When it comes to monochrome colors, it is possible to use tube-shaped objects to adjust the sharpness of the light beams (without a substantial difference with the use of lenses). When it comes to applications where colored light is created by additive color mixes, the use of tubes is less suitable.

Figure 15.3 Color mixing at edge of light beam

As can be seen in the figure above, the distances between the three color LEDs provide a rainbow representation at the edges of the light beam. Unless this is a desired visual effect, lenses will have to be used. (Due to the limited financial resources, this project will nevertheless use tubes when it comes to designing test setups.

Sharpness light beam in relation to the “projection distance”

In this test set-up, the LEDs were positioned with a maximum distance of 2.5 meters (ceiling height). As can be seen in the figure below, differences in beam sharpness between distances of 1 meter and 2.5 meters are relatively small. It should be mentioned that the environment in which the test was performed was very dark and the effects always remained clearly visible. In new test set-ups, greater distances and lower brightness values must be tested.

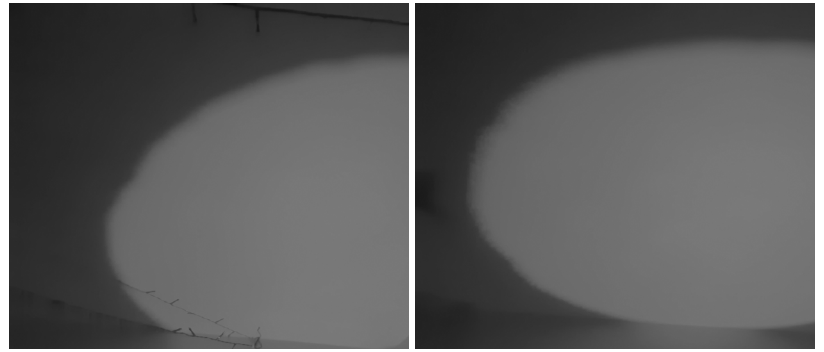


Figure 15.5:Sharpness of light beams; a comparison between 1 and 2.5 meter projections

Dynamic Fluctuations

To test the effect of different fluctuations, three light sources of the same monochrome light were used. Dynamic visualizations were created by using the refraction in the plastic cover.

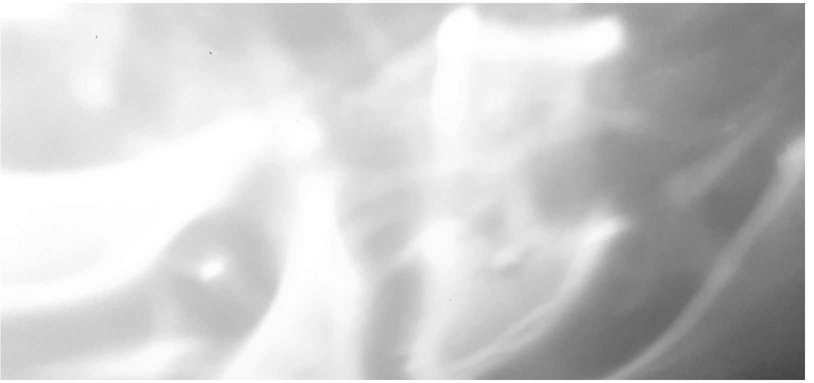


Figure 15.6: Dynamic Visualizations with first prootype

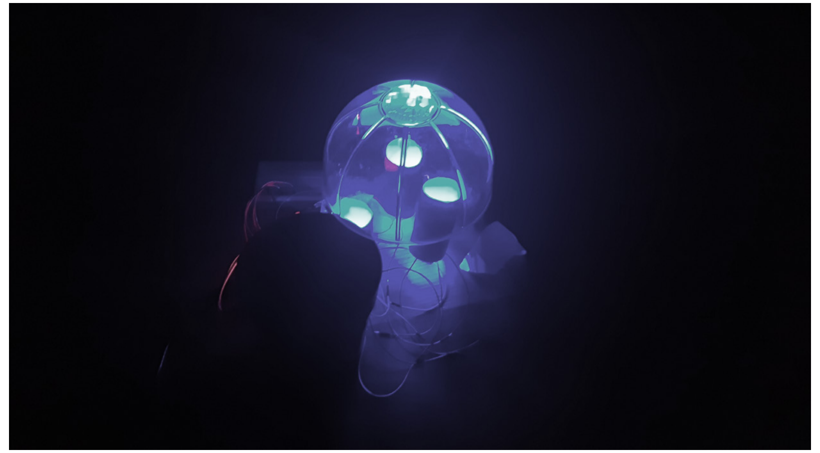


Figure 15.7:The test set-up

First of all, it was investigated at which speeds the light sources could fluctuate to create an activating atmosphere without the environment being experienced as stressful. It has been tested with cycles between 1 and 10 seconds (from 0% brightness to 100% and again to 0%). It was concluded that all cycles with jumps greater than 33.3% per second (1% per 30 ms) are experienced as unpleasant. Fluctuations of around 33.3% per second therefore seem suitable for use where an activating atmosphere is desired.

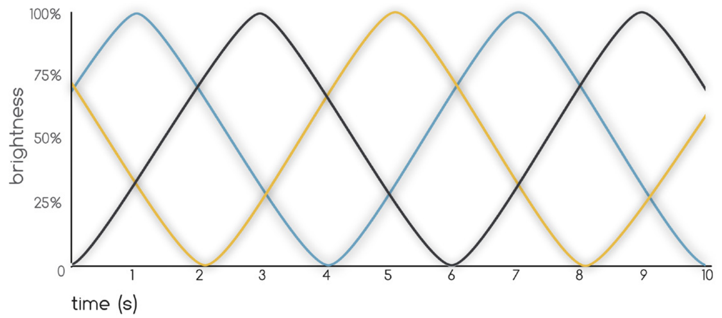
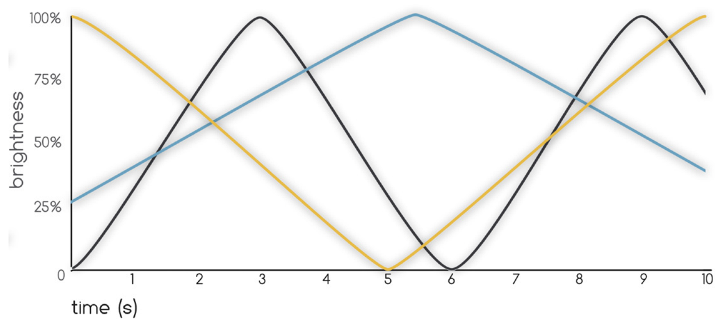
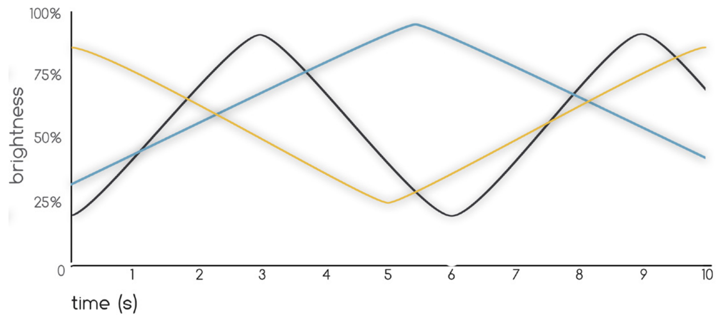


Figure 15.8-10: Dynamic Fluctuations

However, the regularity of the fluctuations was clearly recognizable in the test set-up mentioned. To obtain a more biomimetic dynamic, the frequencies of the cycles are set to different numbers. A combination of 1% brightness fluctuations per 30ms, 50ms and 75ms (2/255, 3/255 and 5/255) proved to be a good combination: With these values, the lighting seemed to fluctuate randomly.



Because in the aforementioned test every 20 seconds is a moment where the values of all three light sources are at their minimum, it was decided to adjust the coding and not let the lighting fluctuate between 0 and 100% but between 20% -90%, 15% -95% and 25% and 85%. This dynamic light came more justice and moments of darkness were prevented.



Furthermore, it can be concluded that three light sources are too little to create good light dynamics (without using moving parts): Sharpening the light beam ensures better visualisations, however, this also ensures that only a relatively small area can be illuminated. Putting the sources further apart can offer the solution here, but this is at the expense of the quality of the patterns.

Color transitions

To see which transitions of light colors are possible without the steps themselves being visible, several small tests have been done. Hereby, transitions between adjacent colors in the color wheel (analogous) and opposite colors (complementary) are used.
As expected, big differences can be seen here.

Figure 15.11: 10 -step color transitions

- When a transition between two adjacent colors is made in the near 10 seconds, the steps are not visible. (It is noticeable that the light is changing, because your memory notices that the color was different a few seconds ago, but the transition itself is not visible)

- Transitions between complementary colors can (logically) be recognized faster. This transition must therefore take twice as long (20 seconds) to be “invisible”

The above results apply to transitions of light in a relatively dark environment and for color transitions between colors with full saturation. As a result, these findings cannot be used as a concrete guidelines; The perception of light is highly dependent on the environment.

15.2 Design Iterations

15.2.1 Prototype Building

Based on the initial concept and the results from the first tests, a first prototype was built. Based on the available electronics and the associated dimensions, it was decided to opt for a 1: 1 scale model.

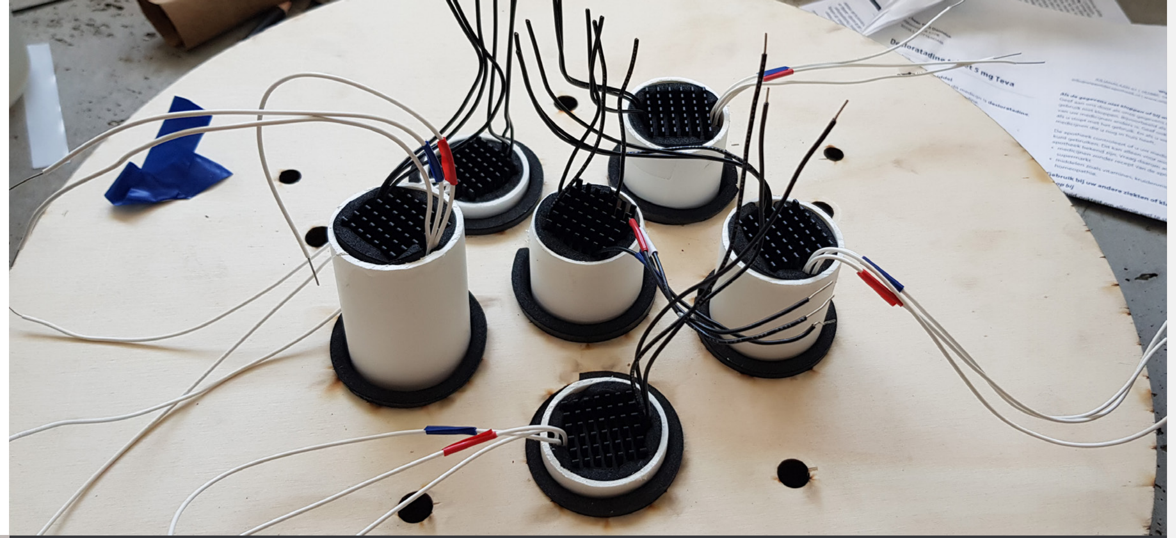


Figure 15.13: wiring electrical components

Figure 15.12: A first complete prototype

With this prototype, the floodlight will be made by a programmable LED strip mounted on the outside of the electronics compartment. The light from this strip will provide ambient light by covering the white plates.

Two covers were made for the prototype. A transparent dome-shaped cover and the same cover with pits and bumps. The last cover will provide the watery projections on the street.

Figure 15.14: Two Covers; without and with relief

Because one of the conclusions from the first tests was that three light sources are not enough to make biomimic dynamics, 6 LEDs (3W, RGB) are built in here.

After being mounted on a heat sink, the leds are integrated in tubes (40 mm) of different lengths. In this way a variety of bundle sharpnesses has been created. As mentioned earlier, lenses are more desirable, but this option has been chosen due to a lack of financial resources.

15.2.2 Findings

- Although there is a clear difference between the covers with and without relief, it can be concluded that the hood should ideally have a larger wall thickness. The thicker the hood, the more the light will be refracted and the clearer the projections on the ground surface will be.
- The dynamic effect that is created by the fluctuations in brightness of the light sources are best appreciated with the use of monochrome color. Therefore, when this effect is desired within certain light scenarios, it is best to use monochrome light.
- The reflection of the inside of the spot lights has an adverse effect on the sharpness of the light beams. When sharp light beams are required (for applications with a smooth cover), these tubes are therefore ideally sprayed with matte black lacquer.
- The reflective cover is fairly large in this prototype, making it appear out of proportion with the rest of the fixture. Where this is technically possible, this ratio will be corrected in the final design.

15.3 Creating a Visual Model

Based on previous findings and the light calculations (Appendix B), the final design has been worked out (Ch. 16). To be able to validate the design and all lighting scenarios, a final prototype was made.

This is built with a 1: 2 scale compared to the final design. Although this scale is quite unusual, it is applied here based on the dimensions of all available electronics.
The conclusions of earlier studies have been included in the design.
For example, the sharpness of the light beam is optimized by attaching an absorbent material to the inside of the spots.

Figure 15.18: Six spotlights, with absorbent material

Figure 15.17: the finilized scale model

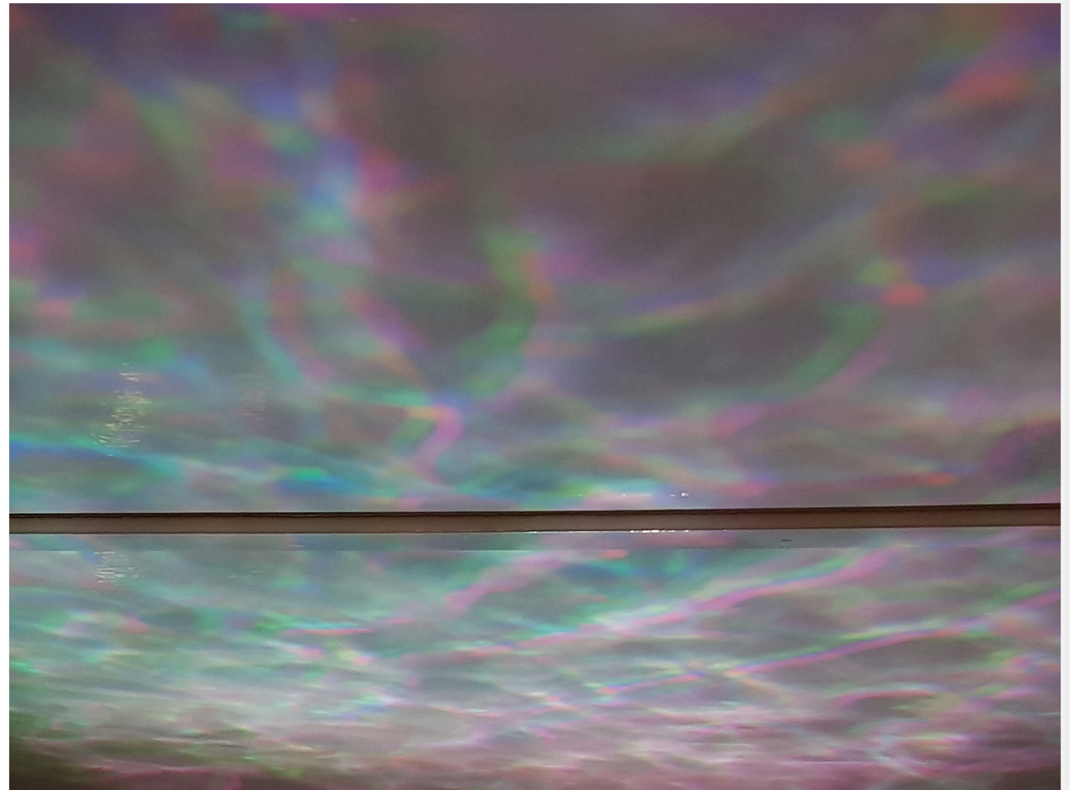


Figure 15.19: A play of Brilliance, created with the model

Furthermore, a new cover has been made. This is made by vacuum forming over a clay mold. This has a thickness of 3 [mm], which appears to be more than sufficient for creating biophilic projections.

The dimensions of the design have also changed. These are optimized for integrating all electronic components. Furthermore, the design has been adjusted, so that glare is prevented as much as possible.

Figure 15.20: A Vacuum formed cover with relief

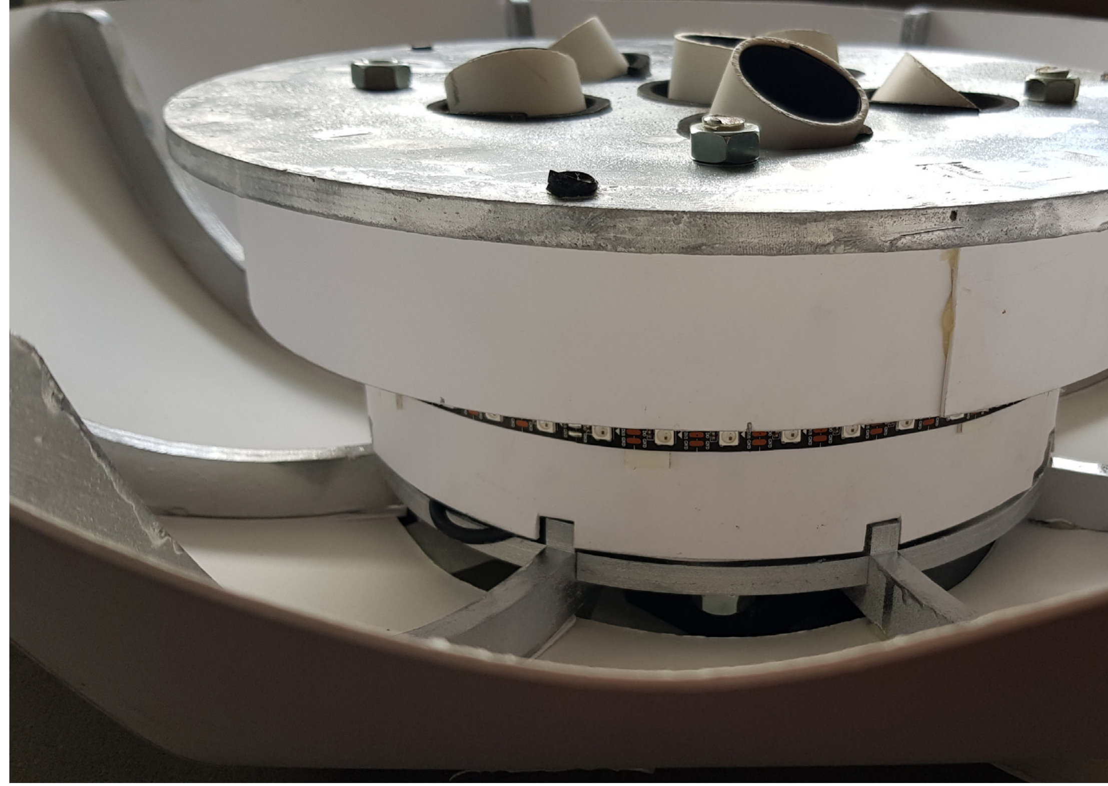


Figure 15.21: A close-up of the model

- It can be see that the projections with this cover are very intense. The fixture would normally be suspended at a height of 6 meters, which would mean a height of 4 meters when translated to the scale of the prototype. However, the electronic components used do not have the capacity to illuminate the room from that height. therefore it has been tested with heights up to 2.5 meters.
- Apart from the direct light from the spots, there is no more glare
- The parts seem visually more proportional to each other

All conclusions based on the light effects and applied light scenarios are discussed in chapter 21

16. Final Design

The final design of the luminaire will be discussed in this chapter. All parts will be named on the basis of an exploded view, after which they will be exemplified based on their function and assembly.

Figure 16.1: A render of the final design

The whole consists of 54 high-power RGB LEDs that are controlled by one driver. The fixture has 6 adjustable spots and a ring with 12 mounted modules, each with 4 LEDs. The luminaire is designed as a hanging fixture, but can also be mounted as a mast due to the universal connection. As a reference to the rawness and industrialism of Tilburg, it was decided to use mainly unprocessed aluminum for the manufacture of the parts. Furthermore, the fixture is designed in such a way that all parts can be easily replaced without having to dismantle or take down the fixture.

16.1 Exploded view

On the page on the right you see an exploded view of all parts. It can be seen that, where possible, the use of Aluminum has been chosen. The parts will be manufactured by laser cutting, sheet metal machining and CNC milling and will usually be mounted by means of welding connections or mechanical connections. In the following sections will be explained for each component.

16.1.2. Weight

All parts of the fixture together weigh 19,645 [kg], with 3 [kg] laid for the internal driver and the cabling. This complies with the previously established requirement of a maximum weight of 25 [kg].

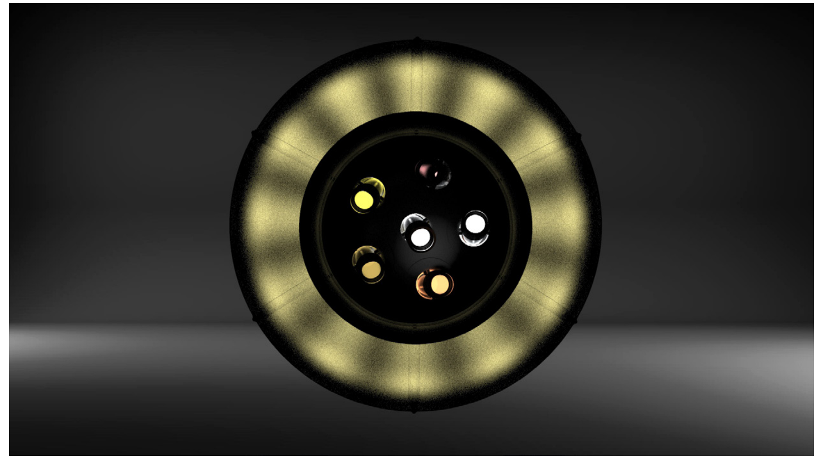


Figure 16.2: A visual representation of the light effect

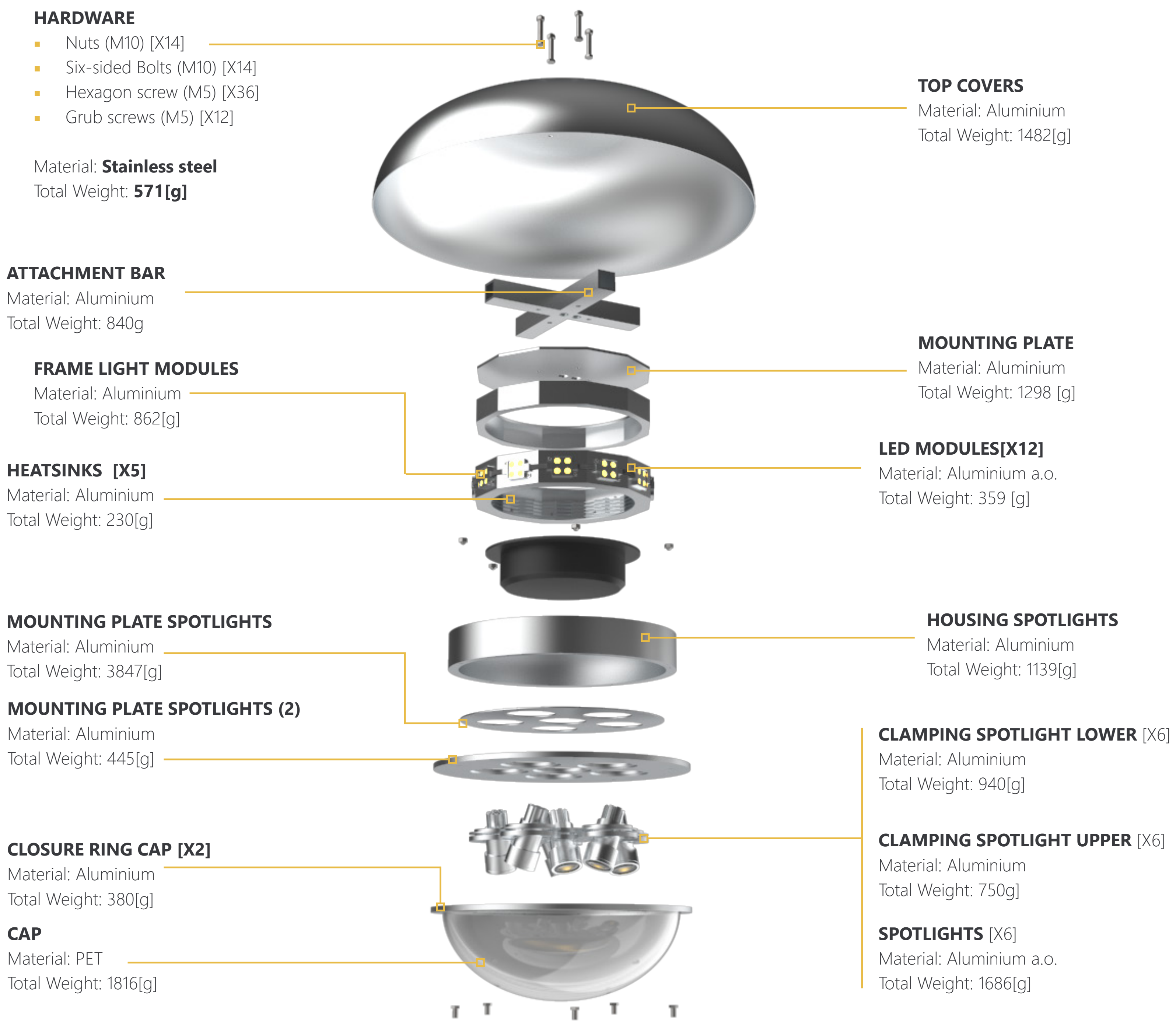


Figure 16.3: an exploded view of the final design

Figure 16.4: A close-up of the six adaptable spotlights

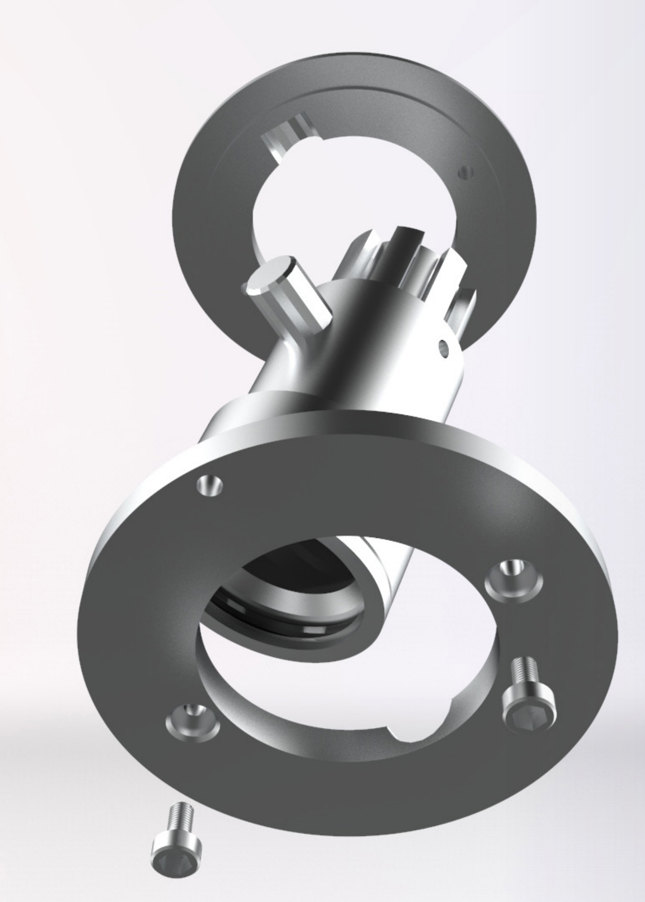


Figure 16.5: An exploded view of the spotlight

16.2 Spotlights

The fixture has a total of 6 spot lights, each of which can rotate over an axis of 360 degrees and have a vertical freedom of movement of approximately 40 degrees. During assembly, the 18-sided legs of the spotlight are fixed between two clamping discs with the help of hexagon socket screws. The disks are fixed with the help of a grubscrew, so that the assembly cannot rotate anymore. The installation of these components will be prepared for installation, but will mainly be carried out on site.

A lens is built into the spotlights, with which the sharpness of the light beam can be adjusted. depending on the application (the type of cover) and the location, a sharp bundle or a softer one can be chosen. This can be done by rotating the cap with the lens by means of threads closer to or further away from the light source.

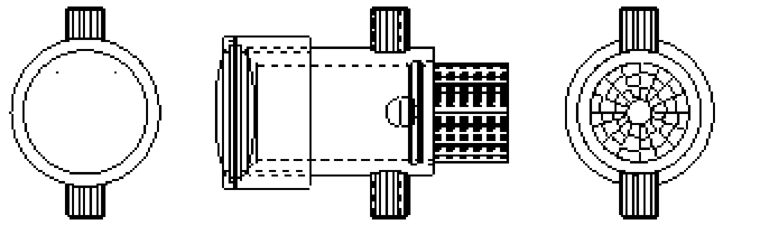


Figure 16.6: Technical drawing of the spotlight

16.3 LED Modules

As mentioned earlier, the ambient lighting of the fixture is created by 12 LED Modules. In Appendix X, a light calculation has shown that these modules are powerful enough to meet the light requirements of the areas in which the luminaire is placed.

The modules are fixed to an aluminum plate by means of screws and are connected in series by means of wiring. In this way the modules are easy to replace if one fails;
The upper cover parts are unscrewed, after which access to the underlying electronics is obtained. After this, the wiring of the relevant module is disconnected, after which it can be unscrewed and replaced.

On the inside of the frame, five aluminum rings are attached to the modules and function as heat sinks. These will prevent the modules from overheating.

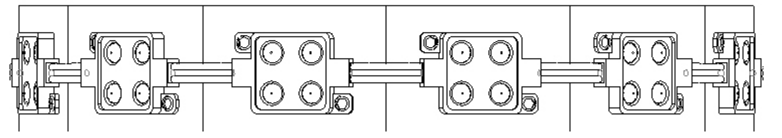


Figure 15.29: Side view Ring LED modules

Figure 16.7: A top view on the internal electrical components and it's heatsinks

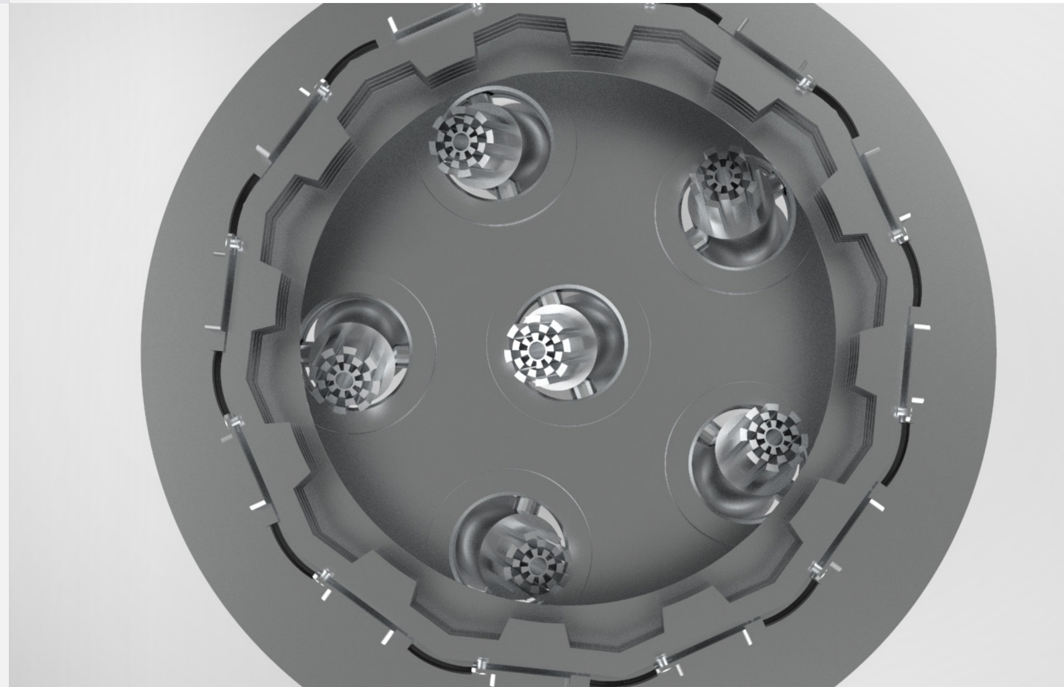


Figure 16.8: The ring with LED modules, linked in serie

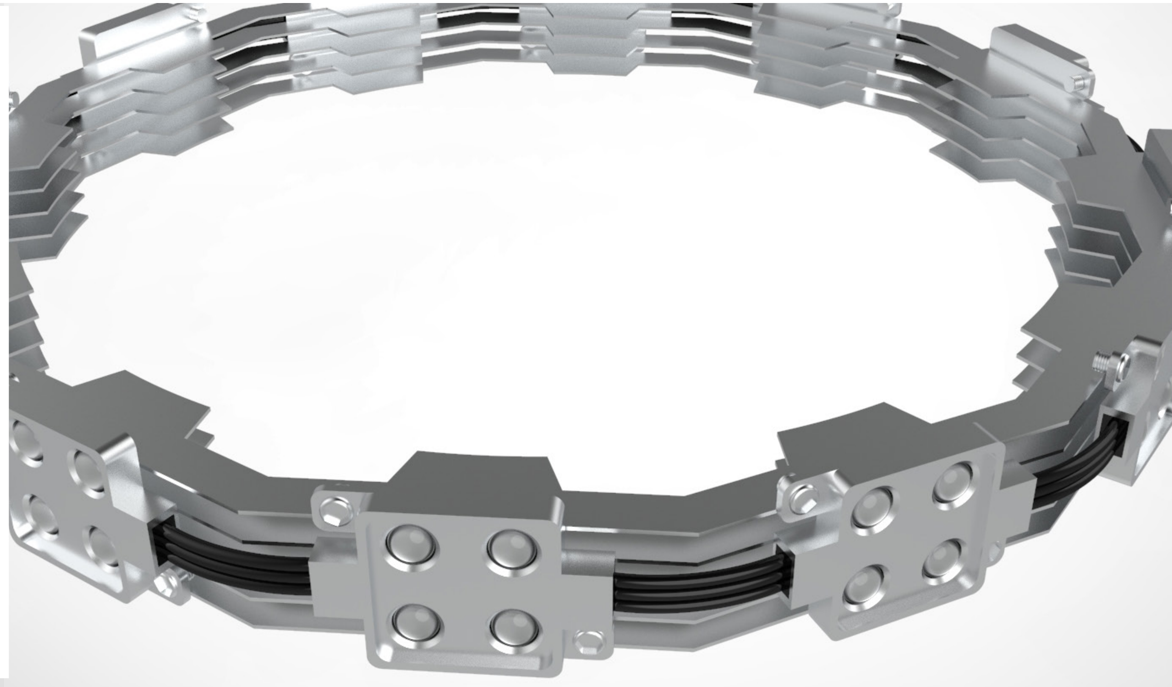


Figure 16.9: The transparant cover

16.4 Transparent Cover

The transparent cover, with a thickness of 6 [mm], will be manufactured by thermoforming. After this, the cap will be clamped in by two aluminum ring parts. This assembly is mechanically secured to the mounting plate of the spotlights.

As discussed in Chapter 12 and Appendix C, there is the option of mounting a completely even transparent cover or opting for a cover with relief. The latter will create biophilic patterns on the street surface.

16.5 Suspension System

Space has been created in the upper part of the luminaire for the suspension of components and the luminaire as a whole. Three rods are welded between two thick aluminum plates, on which the weight of the entire fixture is attached. This is mechanically connected to the cabling.

A number of bolts are fastened to the same mounting plate by means of pin welding. These will be used to make the connection to the top cover The use of pin welding merely requires tightening the outside.
In this way the plates can be removed separately to replace the underlying electronics.

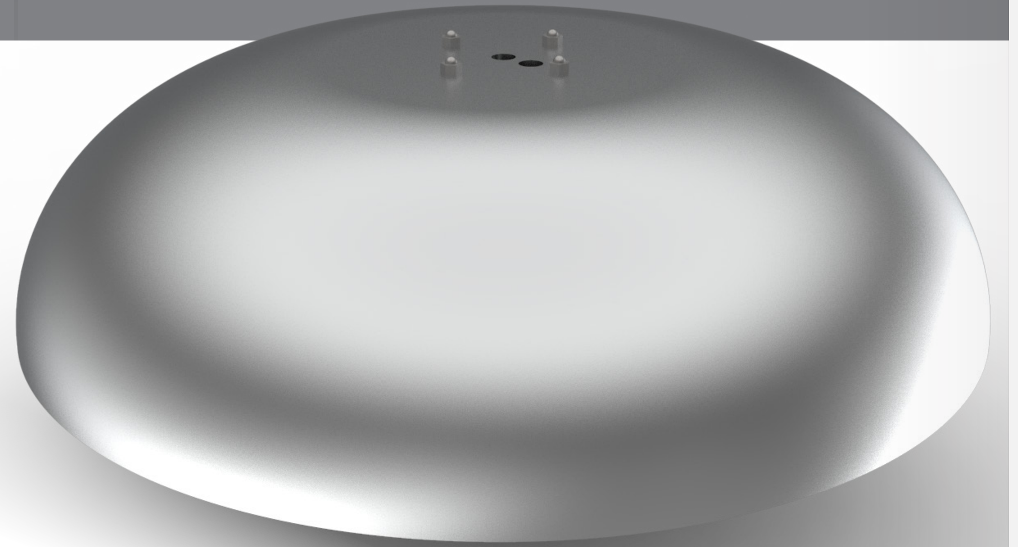


Figure 16.11: The top cover, mounted by four bolts.

16.6 Top Cover

The top covers, shaped as a hemisphere, has a thickness of 2 [mm]. This part will be manufactured by means of deepdrawing (similar to the process of making metal pans). n addition to stopping rain, this top cover has the main function to reflect the light from the LED modules.

Figure 16.10: The suspension system

Figure 16.12: Downview of final design in working

16.7 Installation and Maintenance

16.7.1 Installation

Although the calculations for the light levels are based on installation at a height of 6 meters, the degree of customizability (physically setting the spotlights to the environment and the adaptive, programmable light properties) ensures that the luminaire can be installed at different heights.

Because the luminaire has an internal driver, only one cable has to be laid, a 230V power cable (as is common with street lighting).

16.7.2 Pressure and heat management

Because it can get hot inside the fixture, pressure differences can arise between the interior spaces and the (much colder) outside air. To eliminate these pressure differences, waterproof ventilation membranes have been integrated into the luminaire. These membranes allow air to pass through in two directions, whereby water particles are filtered.

if these channels do not provide adequate ventilation, the components may overheat in extreme cases (all electronic components at full capacity in outdoor temperatures of 40 degrees). It is therefore necessary to integrate a thermal emergency switch in the driver.

17. Parameters

To be able to create certain atmospheres with lighting, a certain degree of adaptability is required. Certain lighting scenarios can be created by setting the properties of light dynamically or responsively.
In this chapter the adjustable parameters of the lighting will be explained. This will act as an introduction to the next chapter: 'creating a lighting script'.

17.1 Introduction

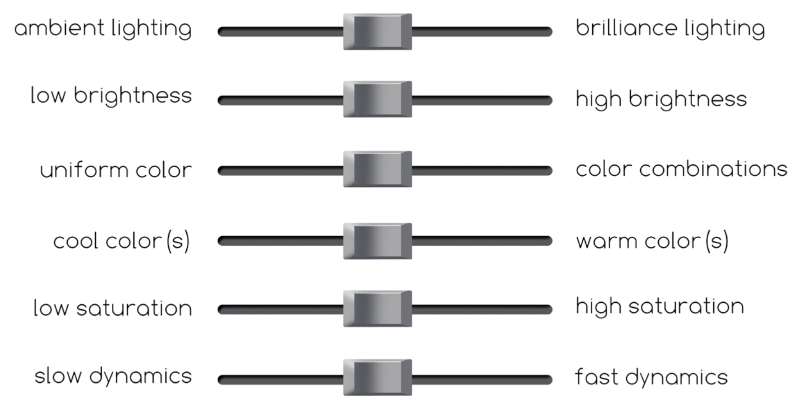
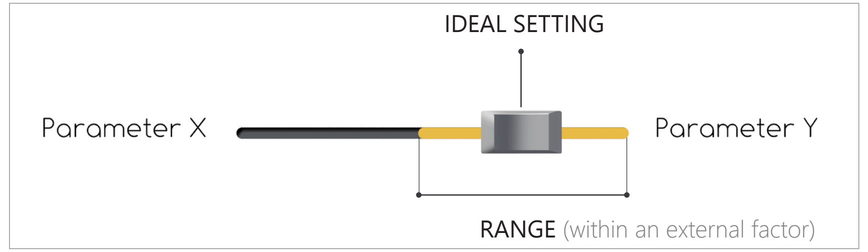


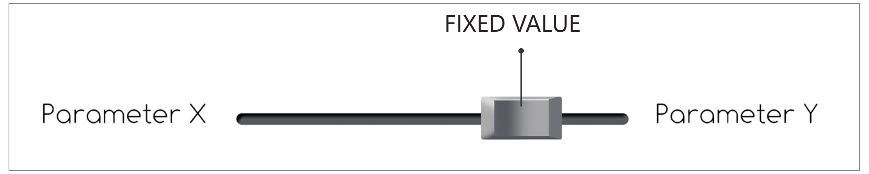
Figure 17.1: A visual overview of all adaptive parameters

Because the parameters of lighting can be quite complex, it has been decided to make the visualization as simplistic as possible.For each slider an explanation will be given on how this parameter can be set and what values fall within the spectrum of this slider.
In this chapter, an explanation of the extreme parameters (slider fully to the left or right) will be given. Nevertheless, all values between these two extremes are possible!

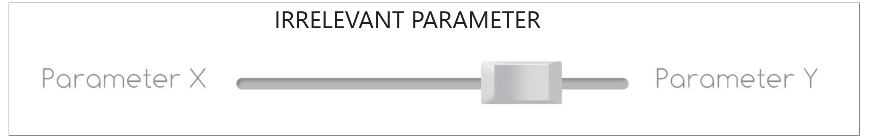
In Chapter 18, these sliders will be used to indicate what the ideal parameters are for a particular external factor.



The range in which the slider is located can be seen in yellow when a certain factor applies. Within this range, the parameters can shift if multiple factors apply. (Examples of this will be shown in Chapters 17 and 18) The position at which the slider is positioned is defined as the ideal setting.

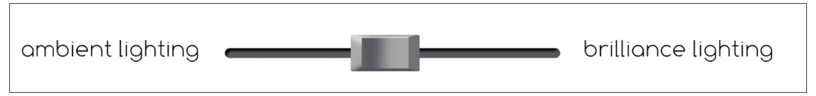


If the slider is indicated without a colored part, that means that when these factors apply, these settings are fixed.



When a certain factor has an influence on certain parameters and has no influence on certain parameters, the latter is indicated by a semi-transparent slider.

17.2 Ambient lighting - Brilliance



The first and perhaps the most determining parameter for the atmosphere is that of the type of light. Although there is a certain degree of focus lighting due to the narrower light beams (see ch. 5.1), a mere distinction will be made here between ambient light and a play of brilliance.

100% ambient lighting

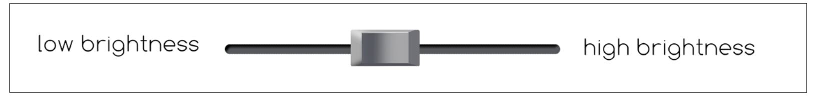
Fully ambient lighting can be generated by merely using the grazing light of the luminaire.
Moving the slider all the way to the left will ensure uniform illumination, whereby a high degree of face recognition is created by the high level of vertical illuminance. This uniformity will therefore ensure good perceptual / subjective safety (ch. 7.1).

100% brilliance lighting

By shifting the slider all the way to the right and thus mainly creating a 'play of brilliance', the evenness of the light will decrease considerably. The luminaires will completely dim the grazing lights and generate patterns on the street with the targeted lamps. The dynamics of the many light surfaces will positively contribute to the liveliness of the environment.

The slider as it can be seen in the image above refers to a scenario in which the light types are combined equally.

17.3 Low brightness - High brightness



The next discussed adaptive parameter is the brightness of the light. To be in the right order of magnitude in terms of brightness, the regulations of the NSVV have been applied.

Within the Netherlands, NSVV (The Dutch Foundation for Lighting Engineering), an independent knowledge center, provides guidelines on public lighting. Although these are guidelines, and municipalities are not legally required to adhere to these guidelines, the aim is always to comply with them.

17.3.1 Lightingclass Table

The NSVV has drawn up quality criteria for public lighting and offer guidelines when it comes to illuminance levels and face recognition.
First, a distinction is made between three classes:

- M-Classes (motor vehicles)
- C-Classes (Conflict zones)
- P-Classes (Pedestrians and slow traffic)

These three classes are subdivided into M1-M6, C0-C5 and P1-P6, each with its own values. By filling in tables with various weighting factors, these classes can be determined for different areas. This lighting class is determined by a number of parameters. These parameters are assessed with a weighting factor with values between -1 and 1. Six minus the sum of all weighting factors results in the lighting class. (examples of this can be found in Appendix C)

Within the case study of this design process, only the P-class will apply. The remaining two classes will therefore not be further discussed.
The following areas apply within the P-class:

- Roads with a permitted speed of up to 50 km / hour with a residence function
- Allowed speed up to 30 km / hour, including (moped) cycle paths and footpaths.

The fully completed tables for the area's within Tilburg and further explanation of the weighting factors can be found in Appendix C.

The following lighting classes and associated minimum values apply to the intended areas in Tilburg.

- The wandering area with vehicles: P5
- The wandering area without vehicles: P6
- The core shopping area: P5 (with additional quality criteria with regard to face recognition)
- Catering streets and squares: P5 (with additional quality criteria compared to face recognition)

The minimum values for these classes, also the minimum values used by the adaptive luminaires, can be found in the table below: (the values are measured on steet level

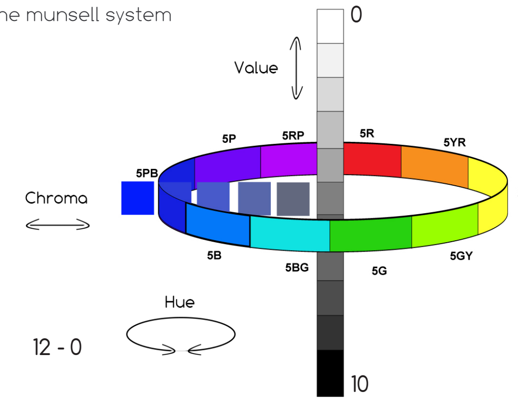
Class	horizontal illuminance		Additional	(in case of facial recognition)
	Egem in lx	Emin in lx	Ev.min	Esc.min
P1	15,0	3,00	5,0	3,0
P2	10,0	2,00	3,0	2,0
P3	7,50	1,50	2,5	1,5
P4	5,00	1,00	1,5	1,0
P5	3,00	0,60	1,0	0,6
P6	2,00	0,40	0,6	0,4

Table 17.1: The lighting classes and their requirements

17.4 Uniform Color - Color Combinations

In the following chapters (H17, 18, 19) we will discuss the colors of the light on the basis of the Munsell color system, discussed in H2.2.1.

Figure 17.2: The munsell system



Because the value of the colors is determined by the brightness of the light source (dimming a light source will decrease the value), a 2D representation of the system will be used here. Hereby, Value 10 is used as a reference. Although all colors are possible, the colors are for simplification divided into 20 Hue's.

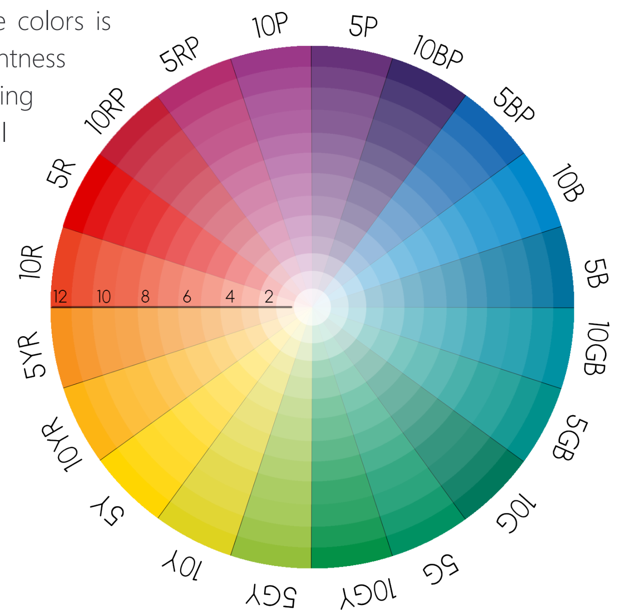


Figure 17.3: A 2D representation of the munsell system with value 10

The third parameter to be set is the quantity of color.

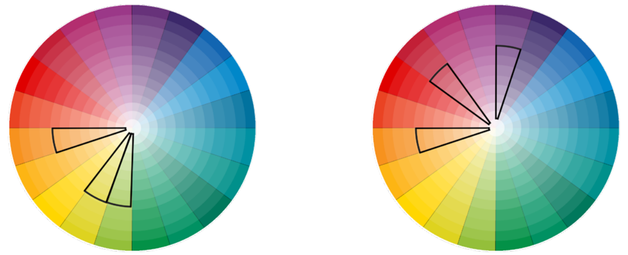
When the slider will be moved completely to the left, the luminaire will radiate completely monochrome light. Regardless of the extent to which the luminaire will create ambient or brilliance lighting, only one color will be used. Within this color, saturation can be varied. (The color wheel shown on the right shows 20 colors. In practice, all colors can be selected)

For aesthetic reasons it was decided not to combine more than three different colors. Because the different spot lights overlap, the colors are mixed. The use of more than three colors will make public lighting too busy, while the desire is to keep the lighting modest.
Because interviews with residents of Tilburg showed that they would like to see subdued colors in the residential areas, it was decided to use as many adjacent colors as possible. The theory behind this is explained below.

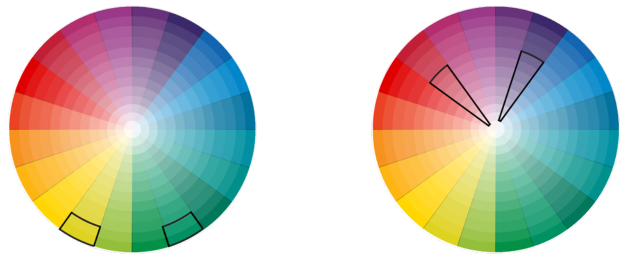
Figure 17.4: additive color mixing

When three colors of full saturation are combined, three analog colors will be chosen (the colors will therefore be contiguous in the color wheel) or three colors with a maximum of 1 hue in between.

When within a lighting scenario the choice is made to use less saturated colors (with a tendency towards partel shades), colors may be chosen with two intermediate hues. The use of complementary colors will be avoided for aesthetic reasons.Examples of possible color combinations can be seen below.



For a combination of two colors, there is a maximum of two hue's in between the case of full saturation and a maximum of three hue's in between the case of low saturation.



(warm) white light may be used at all times, possibly as an addition to the aforementioned color combinations.
When a more exiting atmosphere is desired in areas outside residential areas, one can deviate from the above theory. **The restrictions on the proximity of the possible color combinations are therefor not applicable.**

17.4.1 Color Transitions

To adjust the desired atmosphere, it is desirable to adjust the color of the light. Based on the tests, it has been decided that the transition between colors should ideally remain invisible. When testing (Appendix X), the following was concluded about this:

- When a transition between two adjacent colors is made in the near 10 seconds, the steps are not visible. (It is noticeable that the light is changing, because your memory notices that the color was different a few seconds ago, but the transition itself is not visible)

- Transitions between complementary colors can (logically) be recognized faster. This transition must therefore take twice as long (20 seconds) to be "invisible"

The above results apply to transitions of light in a relatively dark environment and for color transitions between colors with full saturation. As a result, these findings cannot be used as a concrete guidelines; The perception of light is highly dependent on the environment.

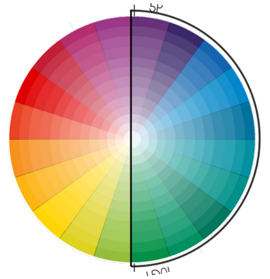
17.5 Cool Color (s) - Warm Color (s)

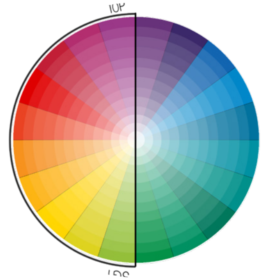
cool color (s) — warm color (s)

As discussed in chapter 2, a distinction can be made between colors that are perceived as "warm" and colors that are perceived as "cold". It has also been proven that different color tones have a different influence on the atmospheric experience of a space (ch. 6.3, 6.4, 6.6). To be able to influence this experience, the luminaire can be pre-programmed to produce cold colors, warm colors or a combination of both.

cool color (s) — warm color (s)

To distinguish between cold and warm, the color wheel can be divided into two parts. Although the Hue's GY and P are discussable, the right-hand side is generally considered cold colors. When the slider is completely to the left, the luminaire will therefore only make use of this set of colors.





Naturally, the other half of the color wheel is considered to be warm colors. When the slider is fully to the right, the luminaire will only use these colors.

cool color (s) — warm color (s)

17.6 low saturation - high saturation

As discussed in 17.3, when colored light is used, a distinction can be made between high and low saturated colors. The expressiveness of the light source and the extent to which a specific color influences the atmospheric experience of a space can be influenced by this;

low saturation — high saturation

The slider all the way to the right means using colors with full saturation. The slider all the way to the left means using colors with low saturation, where colors take on pastel shades.

Figure 17.5: a color palette in pastel shades

17.7 Slow dynamics - fast dynamics

slow dynamics — fast dynamics

The last discussed parameter and the associated range is the dynamics of light. Within the design, dynamics are created by allowing different light sources to fluctuate in brightness, whereby the projections of these light sources create a dynamic pattern on the street surface.

slow dynamics — fast dynamics

static light

The slowest dynamic is no dynamic at all. When desired (because this is desirable in a certain atmosphere (ch. 6.6.2) or because traffic safety has the biggest priority (ch. 7.1), it will be decided to move the slider all the way to the left and therefore to opt for full static light.

slow dynamics — fast dynamics

fluctuations of 33,3%/sec.

During testing (ch. 15.1, 15.2), it has been concluded that fluctuations within brightness higher than 33,3%/second was perceived as unpleasant to look at. (It created more restlessness than it was activating).
Therefor, the maximum dynamic the luminaire can be set to is 33,3%/sec brightness fluctuations of all 6 lights and grazing LED-strip.

18. Setting the Parameters

In this chapter all factors that influence the lighting parameters will be discussed. For each factor, it is described which parameters are influenced and approximately to what extent. Furthermore, recommendations will be made regarding the use of colored light. An example of a color palette and its RGB values will be given per scenario.
The chapter will form the basis for writing a light script.

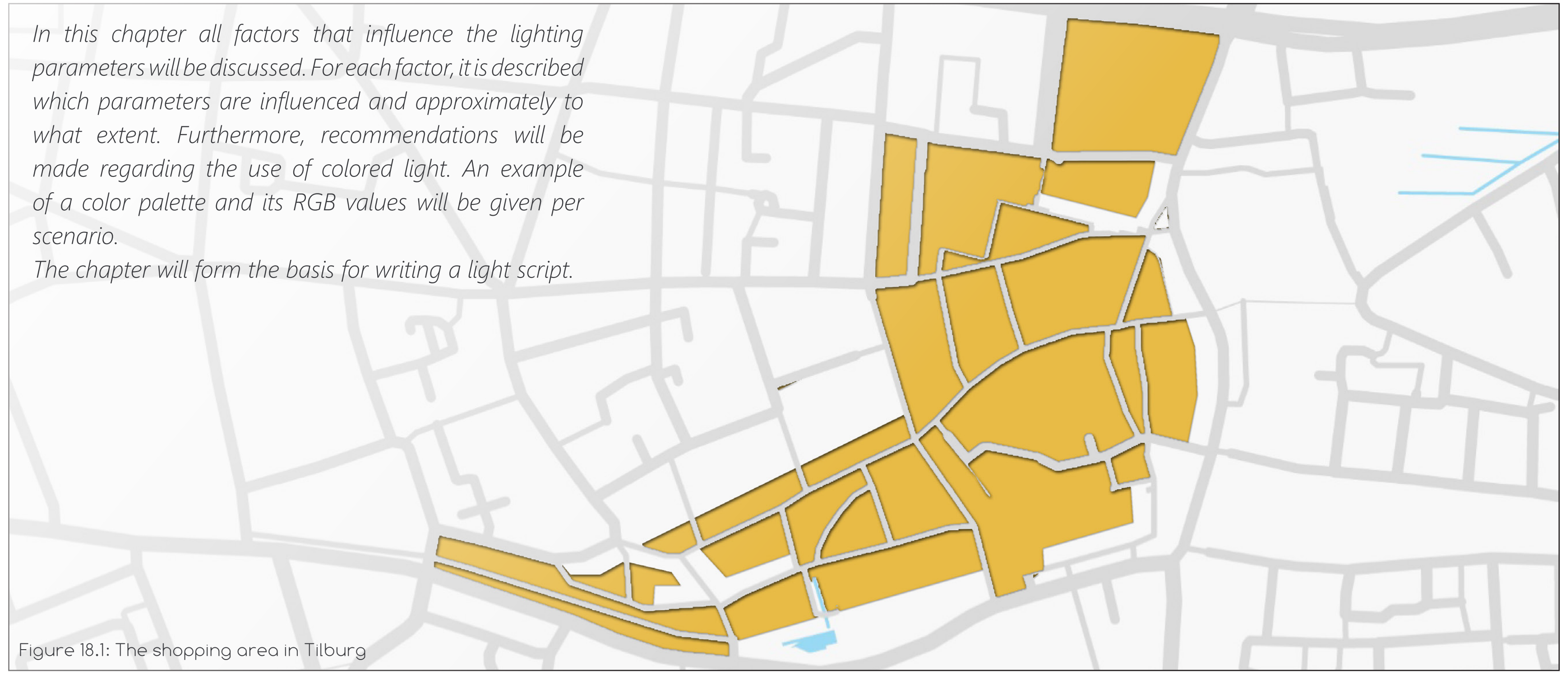


Figure 18.1: The shopping area in Tilburg

18.1 Activities

First of all, analyzes have been made for the three different areas regarding the pedestrian activity.These analyzes are based on input from respondents, observations and an interpretation of data collected by tracking the location of electronic devices.

For future references, all elaborated light scenarios are numbered in this chapter, indicated by the number after the '#' character.

18.1.1 Shopping Area

The graphs, based on the above information, show the number of visitors to the area in blue and the (pedestrian) activity on the street in yellow.

The time is displayed on the X-axis and the number of visitors on the Y-axis. Because the exact number of visitors varies per street in the area and the time, depending on the season, the weather, holidays, the economy and certain (micro) trends, it has been decided not to link values to the Y-axis. The graphs therefore serve as comparison material with respect to each other.

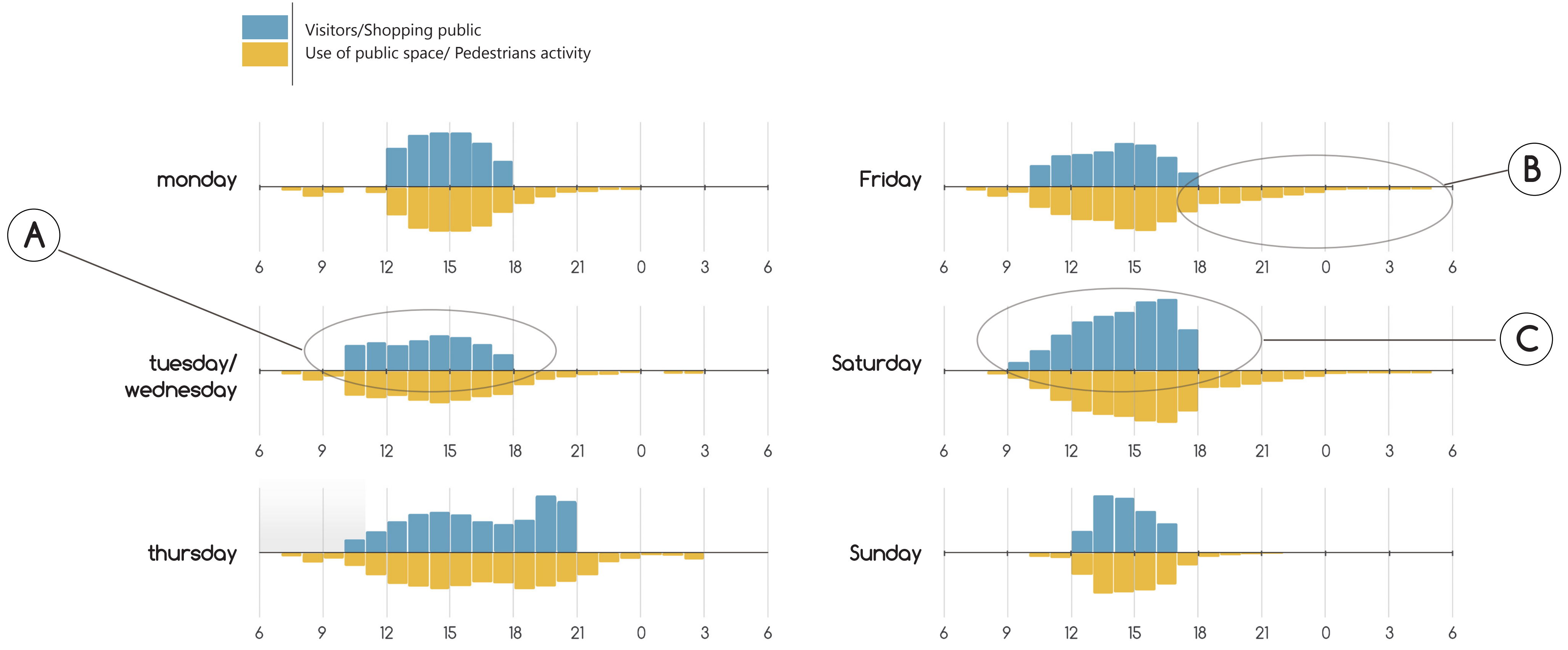


Figure 18.2: An overview of the pedestrian activity in the shopping area

(Average) Store opening times:

Mon	12:00-18:00
Tue	10:00-18:00
Wed	10:00-18:00
Thr	10:00-21:00
Fri	10:00-18:00
Sat	10:00-18:00
Sun	12:00-17:00

The graphs show that the number of visitors to the core shopping area varies per day. conclusions that can be drawn from the above graphs are discussed:

Visitors

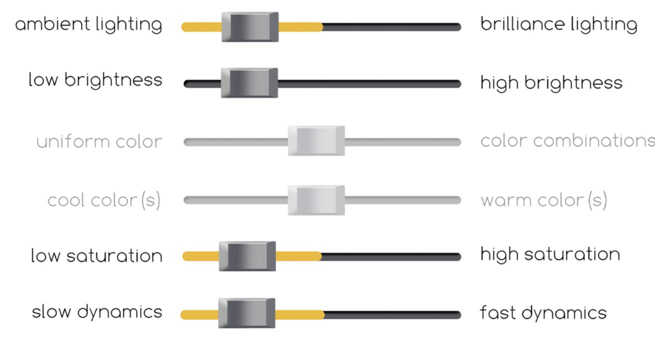
- Monday afternoon it is a bit busier than Tuesday to Friday, because the shops are only open in the afternoon.
- The stores close at 6 pm. After this, the area has no visitors and the area is used as a passage. Thursday is an exception to this.

Pedestrians

- Although the shops only open at 10 a.m., there is street activity in the morning. This mainly consists of people who use the area as a passage to go to work. The peak here is between 8 a.m. and 9 a.m.
- After closing time, the area is still used by many people for routing. Mainly on Thursdays, Fridays and Saturdays, the times when the catering establishments are the busiest, the core shopping area is widely used in the evenings.

Below we will discuss how the conclusions from the graphs influence the parameters of atmospheric lighting.

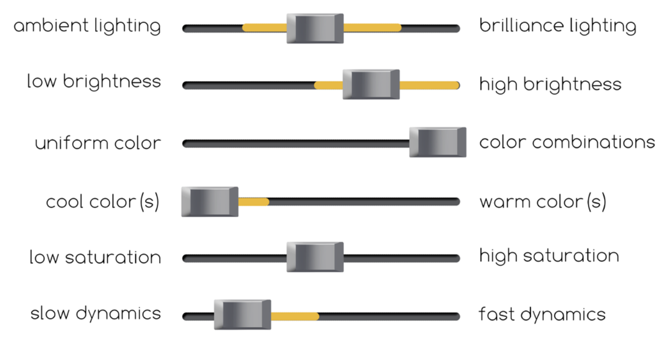
Opening hours (#1)
Because the stores try to excite people with objects, lights and colors through their shop windows, the light will be more subdued during opening hours than outside. This will be done to prevent over-stimulation. This has the following effect on the parameters of atmospheric lighting;



During the opening times, the atmosphere is therefore partly created by the shop windows themselves. However, the stores only open at 10 a.m. The street lighting is therefore only on during shopping evenings, in the afternoon during the winter period and during specific weather conditions (more about this in 18.2)

The questionnaire held with the residents of Tilburg (H14) shows that the shopping area is often experienced as either too busy or too empty. To eliminate this feeling, the light will respond to these moments.

(Too) Quiet shopping hours (#2)
During the moments that it is very quiet in the city center (for example, to be seen in figure 18.2, indicated by annotation A), a more activating/ lively lighting scenario will be created. This will be done through the creation of slow fluctuations in both general lighting and accent lighting, the use of higher color temperatures and higher brightness.
Furthermore, according to Dr. Vogels (ch. 6.6) the use of cyan can be desirable to support an activating atmosphere. All possible colors within this scenario are shown in the color circle on the right; the hue's 5P to 10GY with chroma 7 to 8.



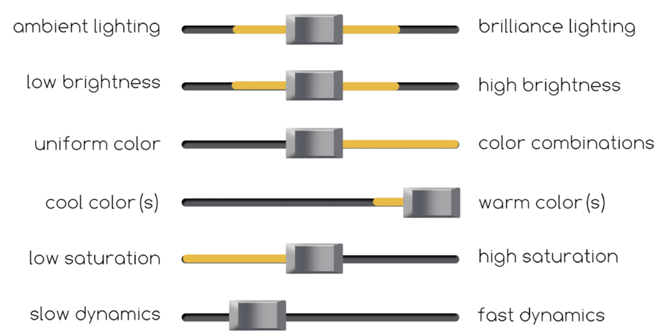
Example

R	87	93	92
G	145	165	169
B	199	193	151

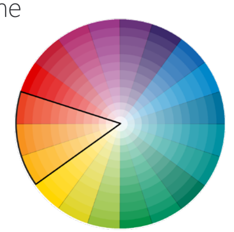
(Too) Busy shopping hours (#3)
A more relaxing atmosphere will be created during the busier shopping hours (indicated in figure 18.2 with the annotation C). This will be done by generating static ambient light and creating slow fluctuations in brightness in accent lighting. Also, light with low color temperatures willbe used here.
Furthermore, the use of green can be desirable to support a relaxing atmosphere (ch. 6.6). All possible colors within this scenario are shown in the color circle on the right; the hue's 5RP to 10GY with chroma 7 to 8.

Example

R	241	253
G	122	199
B	99	88



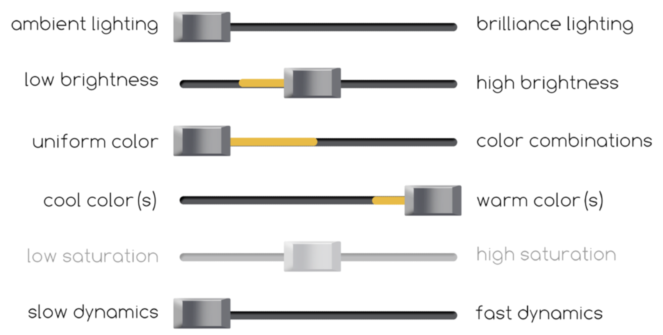
Nightly hours (#4)
Figure 18.2, indicated by annotation B, shows that there is often still street activity in the core shopping area until late in the night. It is stated from the questionnaire (H15) that this area has a low perceptional safety during night during this period.
Creating a suitable lighting scenario can offer a solution here. During these hours, the area will get a more cozy atmosphere, whereby facial recognition will also be improved; Static monochrome ambient light will be used. This light will get a low color temperature. The warmer colors will ensure an increased positive judgment of one's surroundings ((ch. 6.8) Choi et. Al. 2016). This will increase the perceptual safety of this environment.



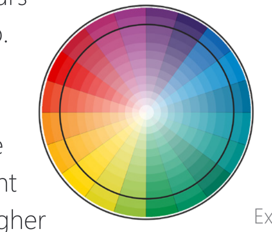
possible colors within this scenario are shown in the color circle on the right; 10YR to 10R with chroma 12 to 7.

Example

R	247
G	146
B	30

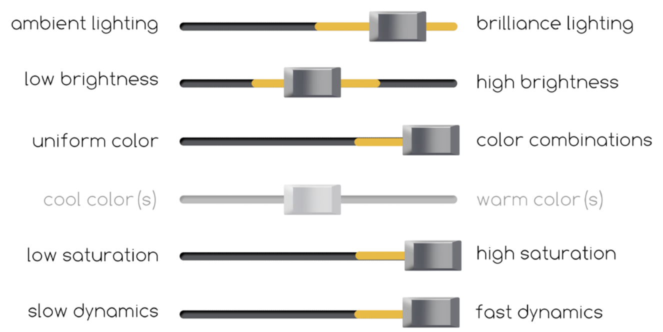


Remaining (#5)
In the remaining time outside of business hours there is room for a more exciting light scenario. Despite the fact that the shops are closed, this increases the residential quality of this area. During this period there is room for more brilliance, a more playful use of different color combinations, where colors have higher saturations, and the use of more dynamics. This is shown in the image below.



Example

R	228	24	247
G	44	127	154
B	44	167	51



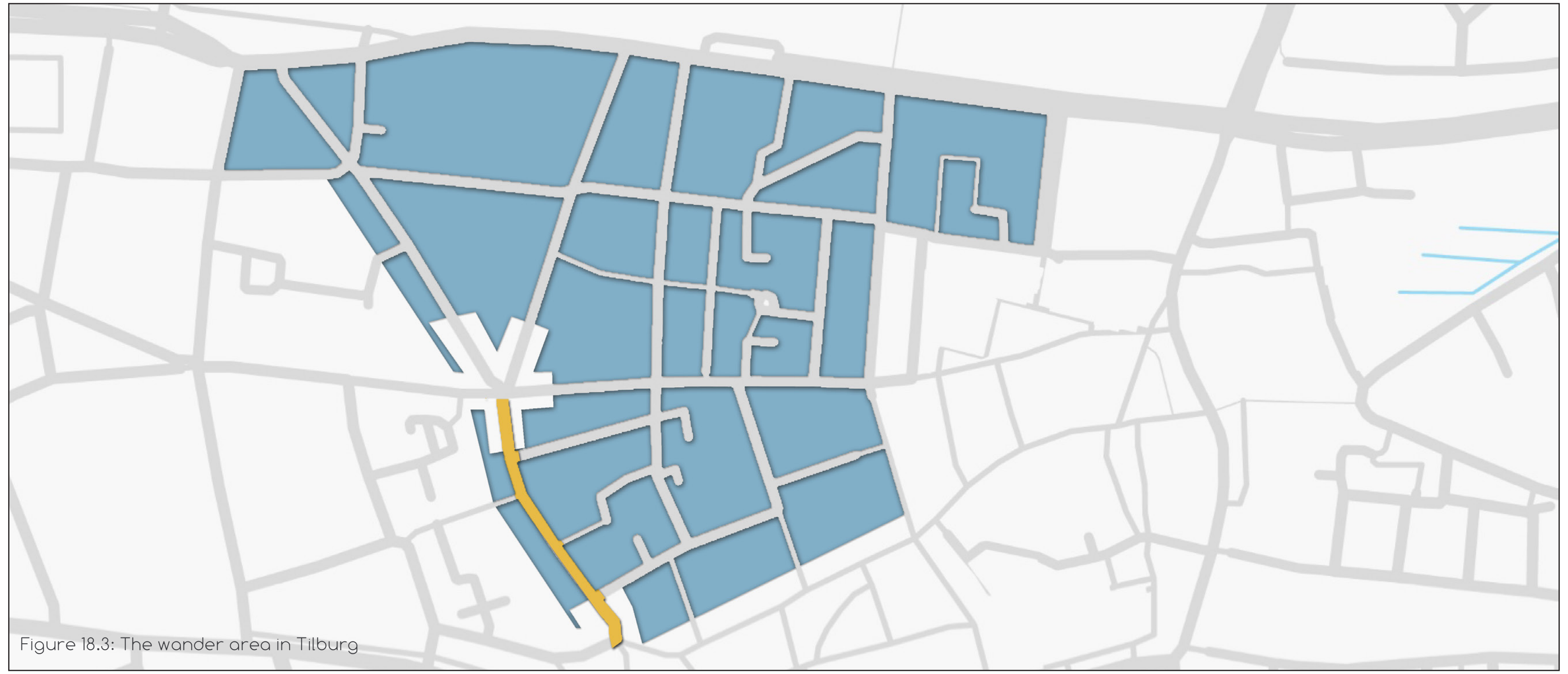


Figure 18.3: The wander area in Tilburg

18.1.2 Wander Area

Because the wander area consists mainly of residential buildings, it is hard to distinguish the 'visitors' of the area from the passers-by.

This area, in contrast to the core shopping area, does allow for traffic in the form of cyclists and motorized vehicles, these are shown in the graphs on the page on the right.

From 2019, motorized vehicles will only be allowed on Nieuwlandstraat (indicated in yellow on the map) between 06:00 and 11:00. The expectation is that more car-free streets will be created in this area in the near future.

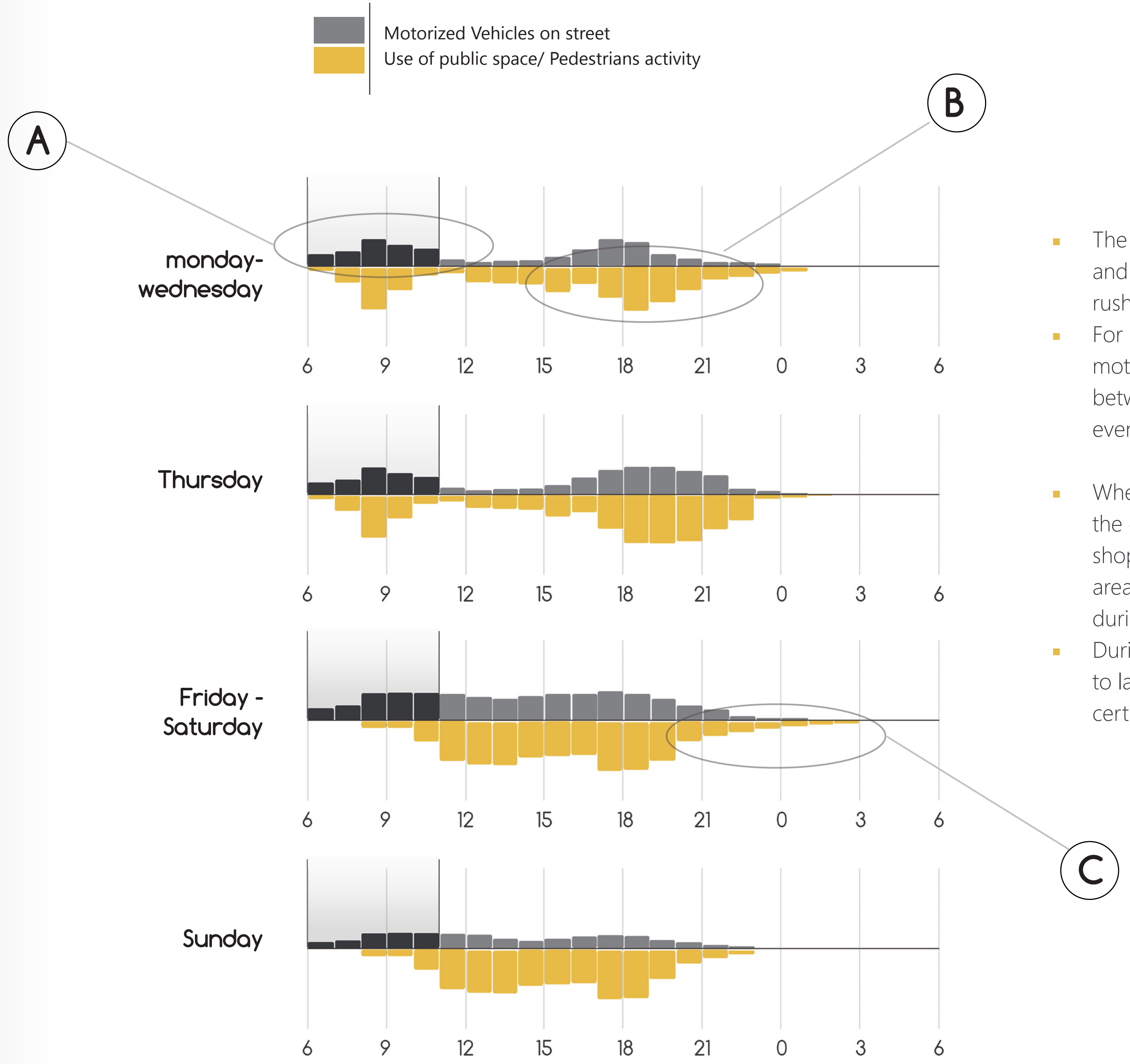


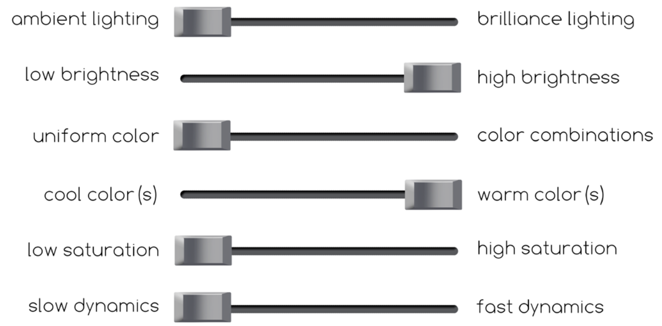
Figure 18.4: An overview of the pedestrian activity in the wander area

- The graphs show that, because the area serves as a passage to and from the station, the traffic on the street is very dependent on rush hours.
- For example, from Monday to Friday, an increased intensity of motorized vehicles as well as cyclists and pedestrians can be seen between 8:00 am and 10:00 am and 5:00 pm to 8:00 pm. (The evening rush hour is longer than the morning rush hour.)

- When the graphs of the core shopping area are placed next to the graphs of the wandering area, it can be seen that bustle in the shopping area has a direct influence on the bustle in the wandering area. From monday to friday, moderate increases can be seen during shopping hours
- During the weekend, the insensity of pedestrian activity shifts a little to later hours, but a more constant flow of traffic can be seen. To a certain extent, this also applies for motorized vehicles.

Below we will discuss how the conclusions from the graphs influence the parameters of atmospheric lighting. Because nieuwland street has its own regulations on the admission of motorized vehicles, the street will be treated separately in this chapter. For other streets that will soon become car-free in the area, the same parameters apply.

06:00 - 11:00 Nieuwlandstraat (annotation A)
06:00 - 21:00 Other streets (#6)
Because motorized traffic is present in this street during this period, road safety will have the highest priority here.
This means that the brightness, as discussed in H16, will be slightly higher during this period. Furthermore, high uniformity will be created during this period through the use of monochrome color and the use of purely ambient lighting. Furthermore, there will be no dynamics in the light.



Because this area serves as a residential area for many people, a homely atmosphere will be created with the light.

This means that shades in the warm-white to orange (the color that is perceived as most 'cozy') spectrum are used.
(ranging from 2500K to 3500K)

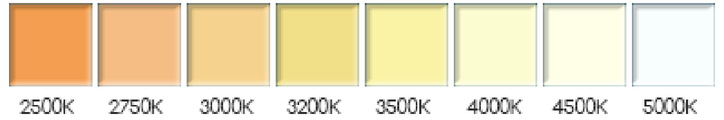
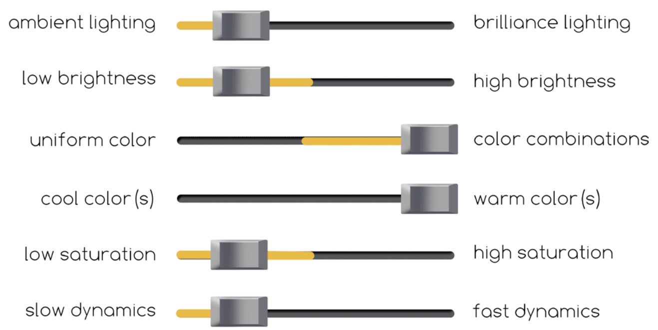


Figure 18.5: Color temperatures 2500K to 5000K

Evening Rush hours @ Nieuwlandstraat (#7)
As can be seen in figure 18.4, indicated with annotation B, there is a lot of activity on the street during the evening rush hour, which lasts from 16:00 to 21:00.
During this time, people come home from work. The light will support the feeling of coming home with lighting that creates a cozy atmosphere. To support the 'cozy' atmosphere, color combinations will be made from warm colors with a low saturation. All possible colors within this scenario are shown in the color circle on the right; the hue's 5RP to 10Y with chroma 3 to 6. Although there are no motorized vehicles on the road, the area is used by many cyclists during this time period. Because the visibility of the elderly is diminishing and this group is also the most vulnerable road users (together with children), road safety is paramount here. As a result, there will be little to no brilliance and dynamics during these hours.

Example

R	255	245	249
G	231	159	190
B	123	143	127

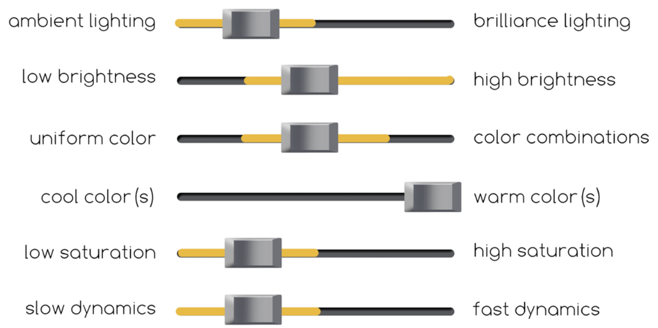


Evening/Night all streets (21:00-06:00) (#8)
There is hardly any motorized traffic within the wander area between 9:00 pm and 6:00 am. Because the maximum speed is everywhere 30km/hour, there is some space for brilliance lighting, dynamics and colored light.
Just like in the rest of the residential area, colors from the left side of the color wheel will be used to support the homely atmosphere of the area.

For parts with motorized faults, it is recommended to use responsive lighting (ch. 7.3) instead of dynamic lighting. Sensors can be used to optimize road safety if there are motor vehicles on the road. All possible colors within this scenario are shown in the color circle on the right; the hue's 5RP to 10Y with chroma 3 to 6.

Example

R	255	245
G	231	159
B	123	143



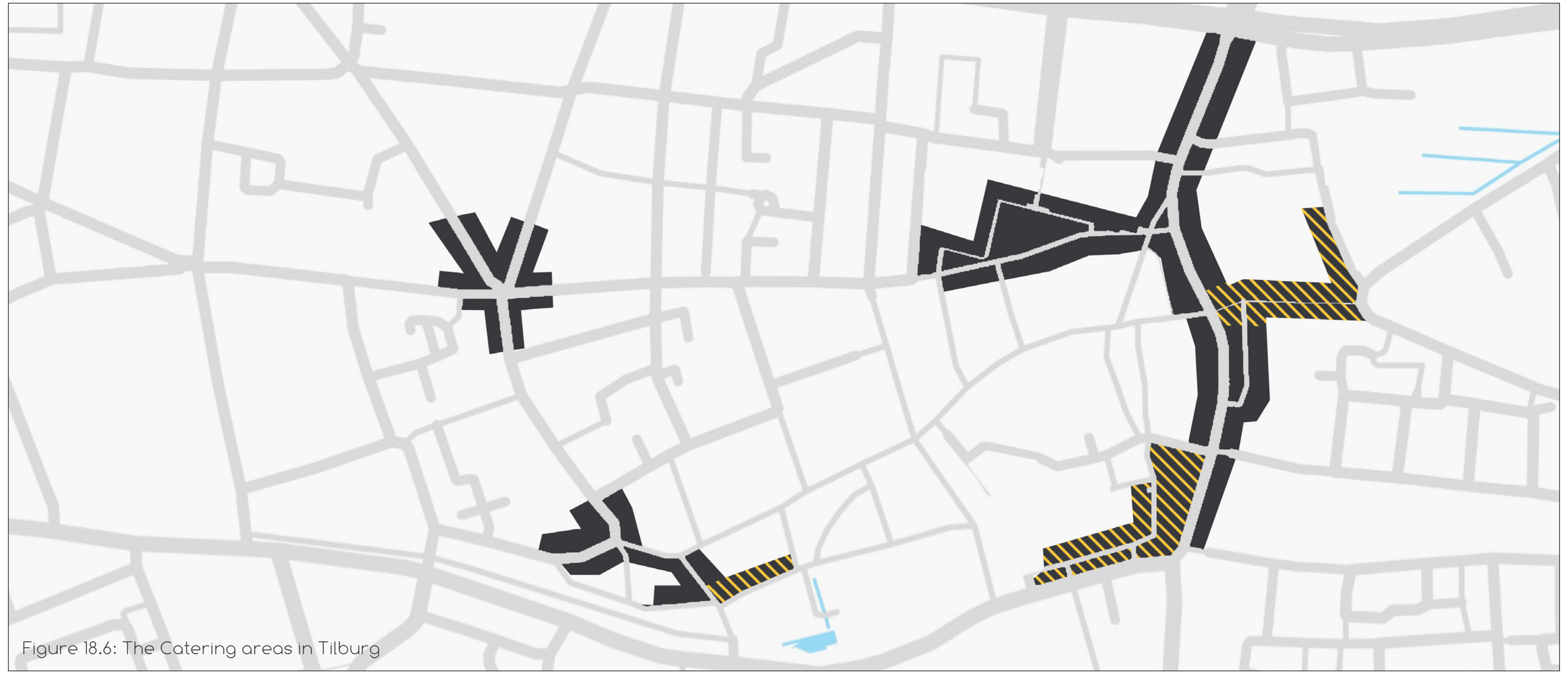


Figure 18.6: The Catering areas in Tilburg

Light Catering
Medium - Heavy Catering

18.1.3 Catering Area

Finally, the catering squares and areas will be discussed. Because there are major differences within these areas with regard to the type of entrepreneurship, the area is subdivided into two categories;

- **Light catering:** businesses that are generally only open during the day and in the evening, and which are primarily focused on offering food and beverages. This includes: cafeteria, lunchrooms, coffee bars, restaurants, bistros, etc.

- **Medium to heavy catering:** Catering facilities that are normally also open for parts of the night (and need this to function properly). This may include bars, cafes, billiards centers (medium), discos, dance halls or night clubs (heavy).These are usually companies that can cause inconvenience to local residents due to their operation.

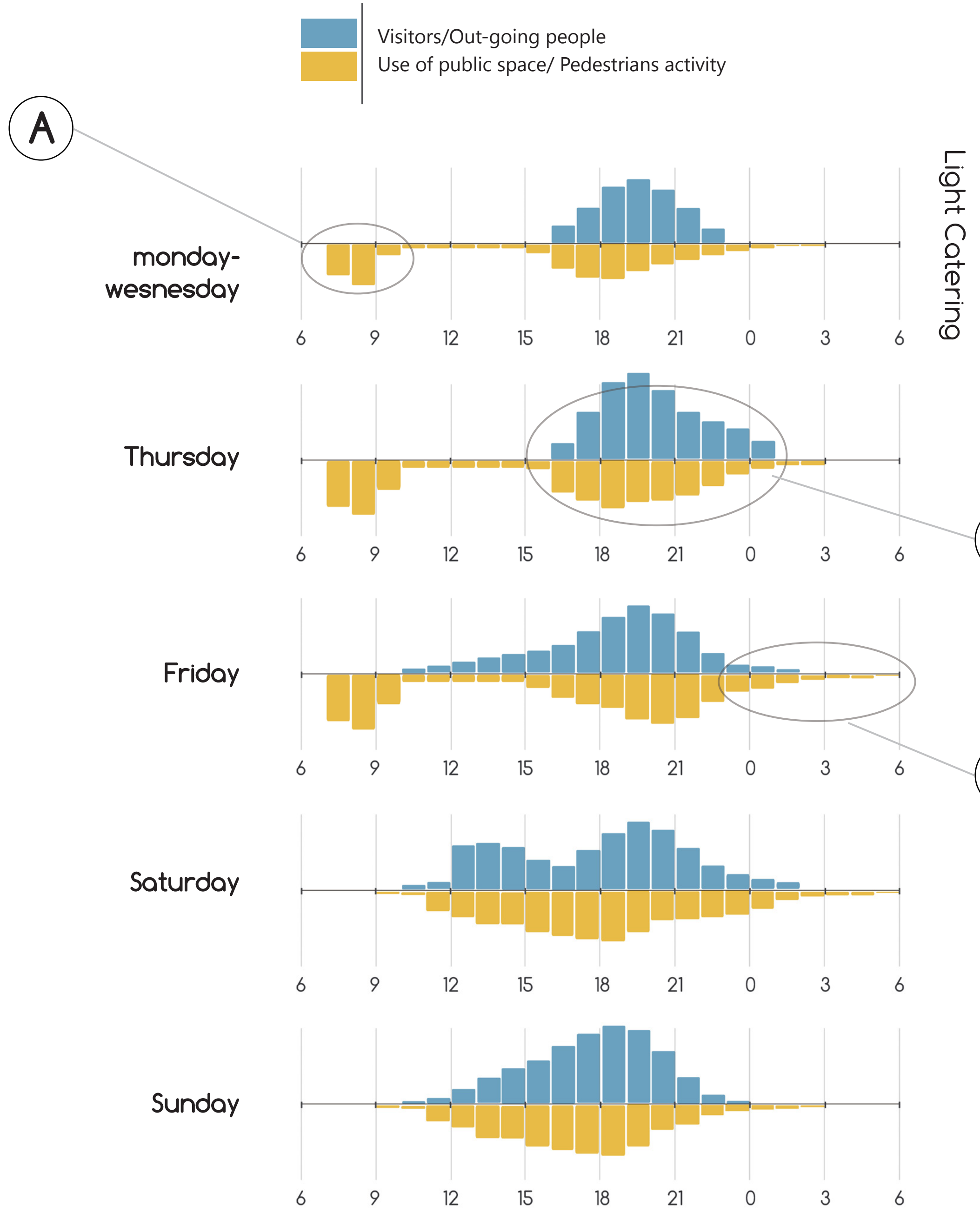


Figure 18.7: An overview of the pedestrian activity in the light catering

As indicated in the legend, medium to heavy hospitality is indicated with yellow stripes. Permits for such hospitality establishments have been put together as much as possible by the municipality, so that the 'nuisance' is centralized and can be managed better. In addition, attempts have been made to place these occasions as far away as possible from the residential areas (such as the wander area).

The graphs show visitors in the catering establishments in blue and the number of pedestrians on the streets around these occasions in yellow.

The areas with light catering are discussed first.

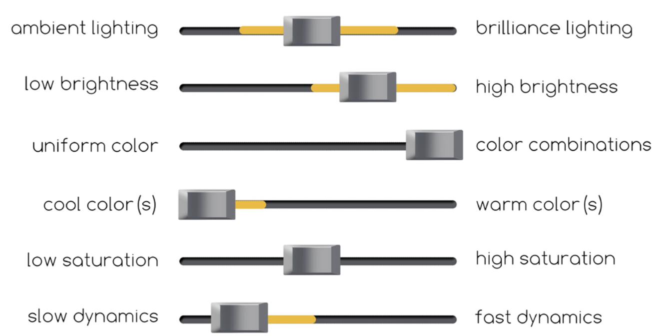
- It can be seen that these areas, because they are usually easily accessible, are influenced by the rush hour in terms of crowds; relatively many people walk and cycle through the streets between 07:00 and 09:00 and between 16:00 and 19:00.
- The crowds in these catering establishments generally decrease from 10 p.m. Most companies close their doors around midnight. Due to the departure of visitors and the heavy catering industry in the areas, it can still be busy on the streets late in the evenings.

As before, we first describe the parameters for areas with light hospitality.

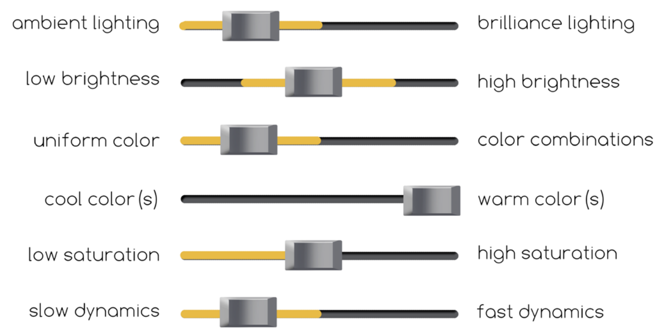
Rush hour (Annotation A) **(#9)**
During peak hours in the morning, many people use the catering area as a routing to their work (shown in figure 18.7 by annotation A)
To assist people in 'starting' the day, an activating light scenario will be created.This will be done through the creation of slow fluctuations in both general lighting and accent lighting, the use of higher color temperatures and higher brightness. The same as with the core shopping area, averagely saturated colors will be used here. A possible color combination that supports this atmosphere is shown on the right.

Example

R	158	104	92
G	124	157	169
B	170	204	151



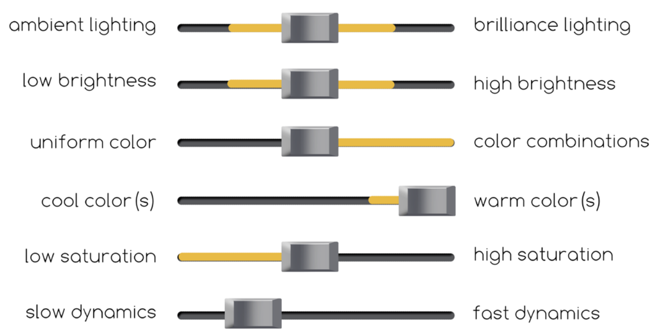
Busy Catering Hours (Annotation B) **(#10)**
As emerged from the questionnaire (ch. 14), there is a wide variety of companies within the light hospitality industry (restaurants, lunchrooms, cafés). Because every occasion wants to create its own atmosphere, a certain restraint is desirable.
The lighting will support a moderately cozy atmosphere. An approximation of its parameters is given below.



Nightly Hours (Annotation C) **(#11)**
During the night hours, especially during the hours when there is still activity to be seen on the street, a more relaxing atmosphere is desired.
This light catering industry, in contrast to the heavy catering industry, is often located on residential areas. This makes it desirable to prevent annoying behavior by influencing the state of mind of the people with the light scenario. All possible colors within this scenario are shown in the color circle on the right; the hue's 5RP to 10GY with chroma 7 to 8.

Example

R	212	248
G	97	176
B	112	96



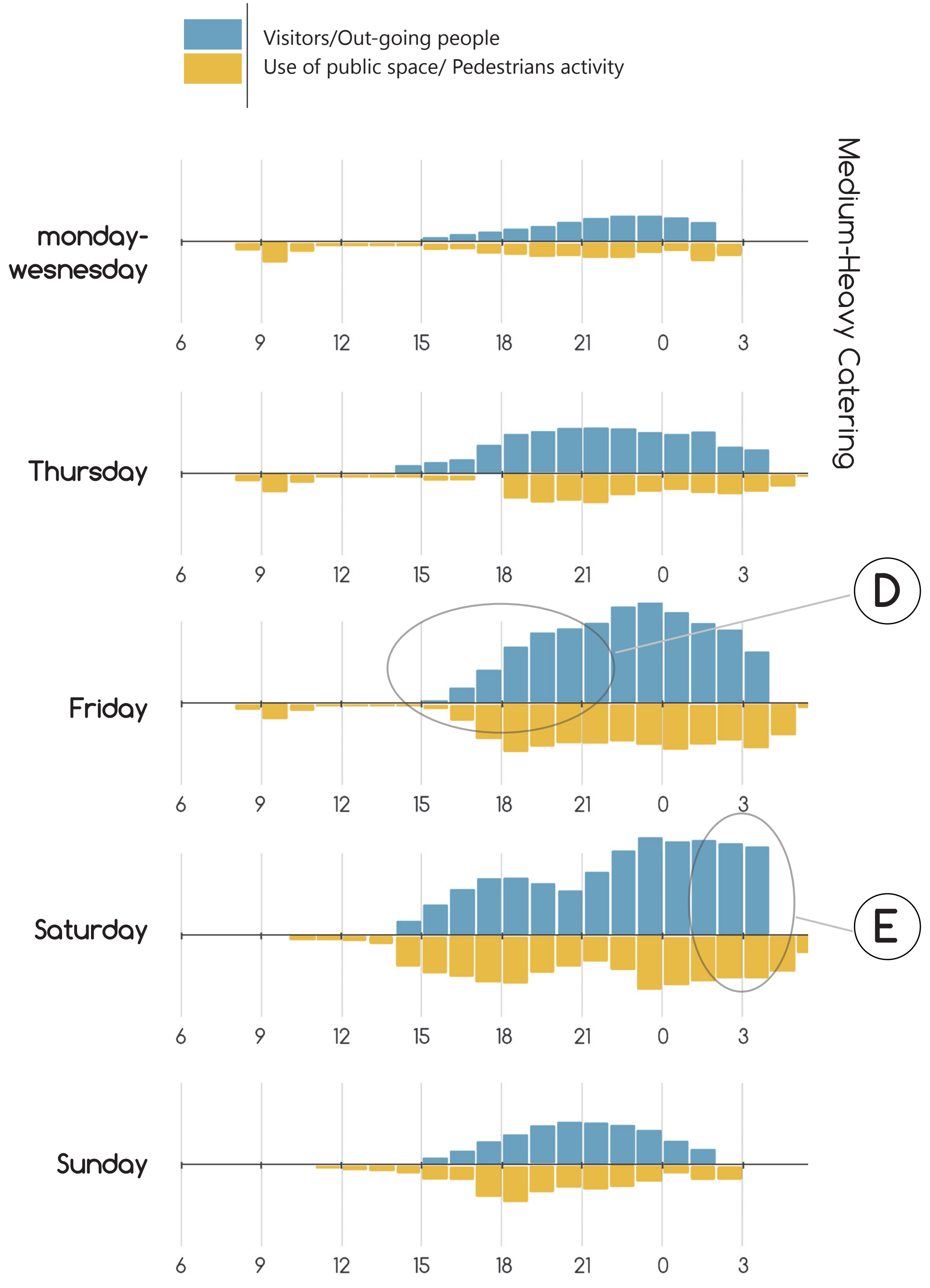


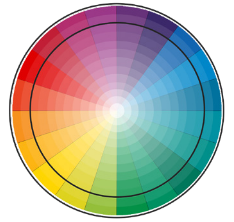
Figure 18.8: An overview of the pedestrian activity in the medium to heavy catering

If we look at the streets with heavy catering, a number of differences can be seen.

- Because the areas are 'closed off' and therefore not or badly accessible for cyclists the bustle on the street is less dependent on the rush hour.
- For the same reason it can be seen that the crowds on the streets are mainly created by people walking to or from such a establishment.
- Because many of these companies are open until the night hours (2 a.m. on Mon-Wed and Sunday and 4 a.m. on Thursdays - Saturdays) it can be seen that even after these hours, the streets remain busy. People eventually go home, but the crowds decrease gradually.

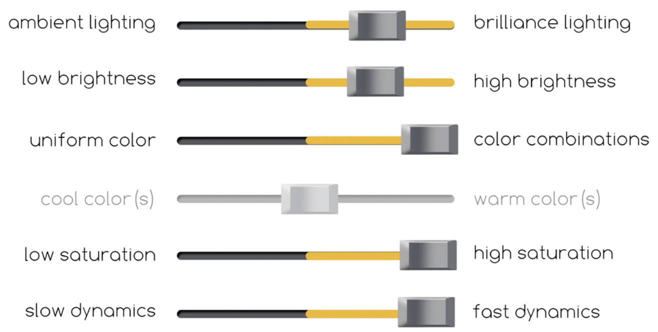
Catering Hours (#12)
Because these areas are closed off from the residential area and there are only (medium-) heavy catering establishments to be found here, the light will be focused on increasing the quality of stay in the those establishments.

During the beginning of the evening, where there is a large number of visitors to such occasions, an exciting atmosphere applies.
This will ensure a cheerful atmosphere and better experiences in the catering venues.
All color combinations are possible within this area, with the colors having a higher saturation. These can be colors in both the cold and warm spectrum of the color wheel; All Hue's (both warm and cold) with a chroma of at least 11



Example

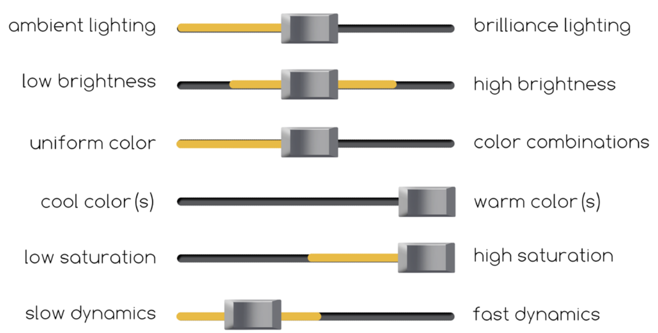
R	179	223	253
G	46	0	181
B	111	0	19



01:00 - 03:00 (#13)
A certain moderation of the exciting atmosphere will occur during the evening: As it gets later, the nuisance of such areas increases significantly (partly due to the increased alcohol promilage of visitors)
To counter this, a slow transition between the exciting atmosphere and 'relaxing' will take place between 01:00 and 03:00. As a result, people leaving the catering area will be in a more relaxed state of mind, causing less nuisance in surrounding areas.
Because it is darker in the surrounding areas, the light will consist of warm colors during this period. By taking warm light, which tends towards red (without involving the association to a red-light district), the adaptation of the eyes to dark environments will be supported (ch. 1.3.3). This ensures increased traffic safety and better perceptual safety, since the areas around the catering area seem brighter. All possible colors within this scenario are shown in the color circle on the right; the hue's 5YR to 10RP with chroma of at least 11.

Example

R	234	223
G	67	0
B	35	0



When all activity in the streets is gone, it will be switched to colors with lower saturation. This is, depending on the days between 04:00 and 05:00

18.2 Weather conditions

In addition to the activities in the various areas in the city center, the lighting will also depend on some weather condictions. Factors that influence the lighting will be discussed.

18.2.1 Temperature

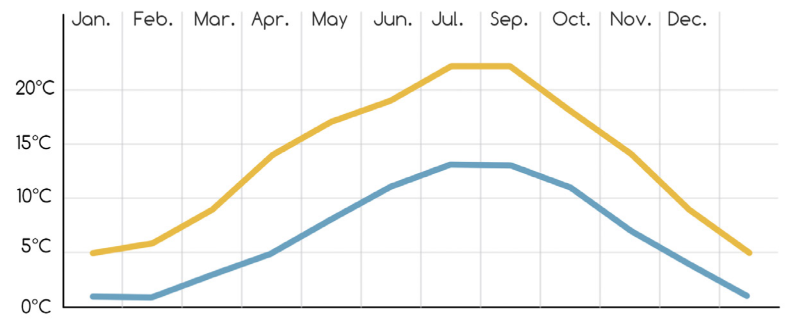
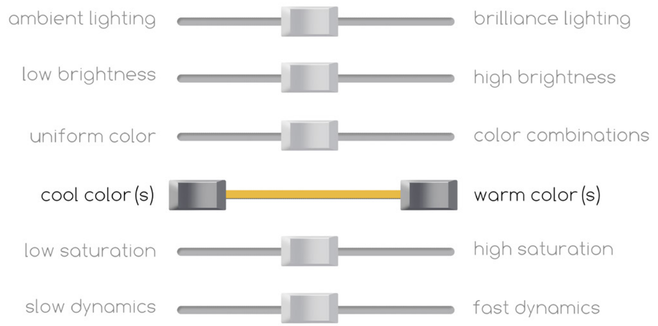


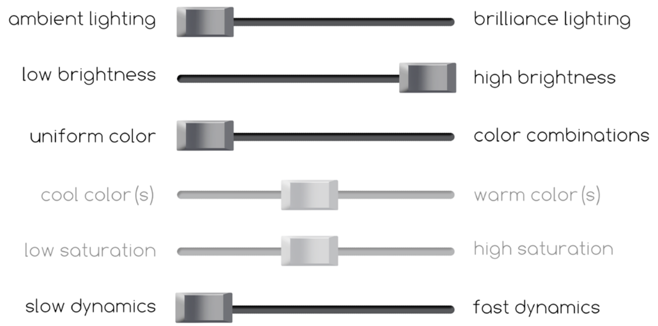
Figure 18.9: Average Temperature in the Netherlandse throughout the year

As can be seen on the image above, the minimum and maximum temperatures fluctuate sharply throughout the year.
Research (Fenko et al., 2010; Yildirim et al., 2007) has shown that colors can influence the physical warmth of people.
As a result, at (extreme) temperature measurements below 5 ° C and above 25 ° C, the lighting will respond to the perceptual heat by adjusting the color tones. At high temperatures cold shades will be used and vice versa. This will be done to such an extent that it has no influence on the atmosphere that is created.



18.2.2 Precipiation and Fog

In the case of precipitation or fog, visibility will decrease considerably. When this occurs, perceptional and road safety is given priority. To increase this, the brightness of the light will increase and the light will mainly consist of ambient light.
Furthermore, the light will become static and consist of monochrome colors.



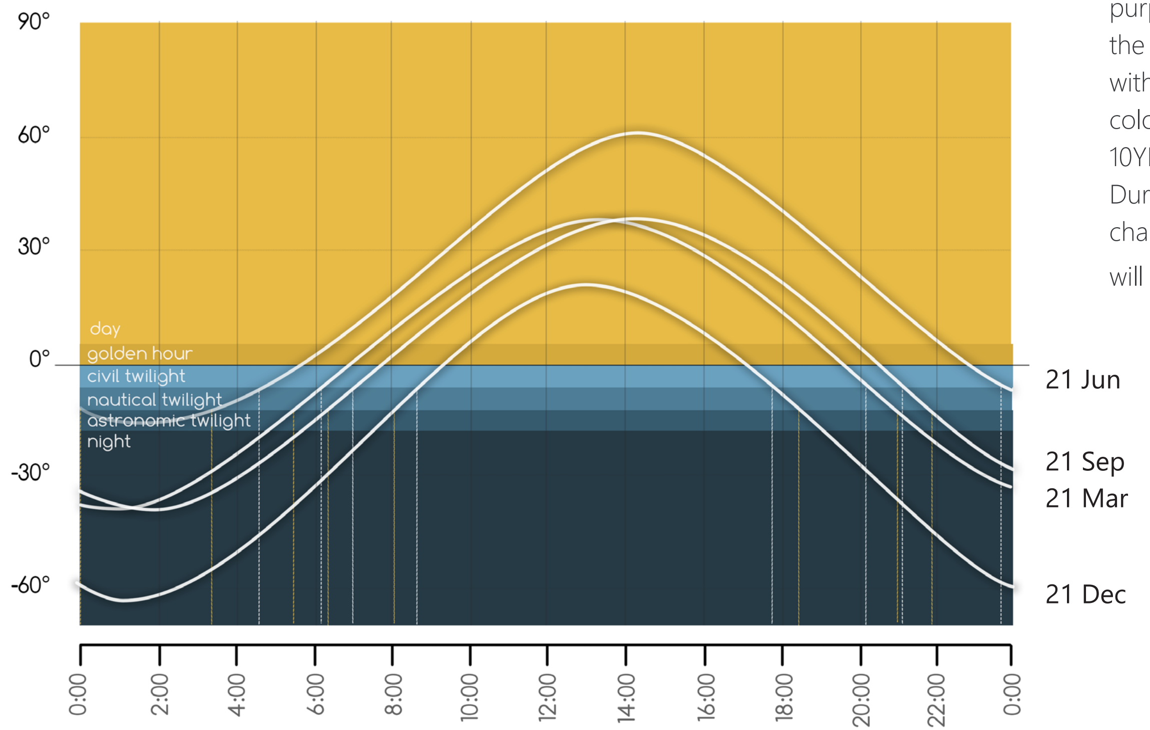


Figure 18.10: Sunset on a clear day in Groningen
Figure 18.11: Sunrise and Sunset in the Netherlands thoughout the year

18.2.3 Sunrise and Sunset

When the civil twilight dawns, the street lights will go on and when it ends in the morning the lights will go out. As can be seen on the image above, the time differs for this part of the night.

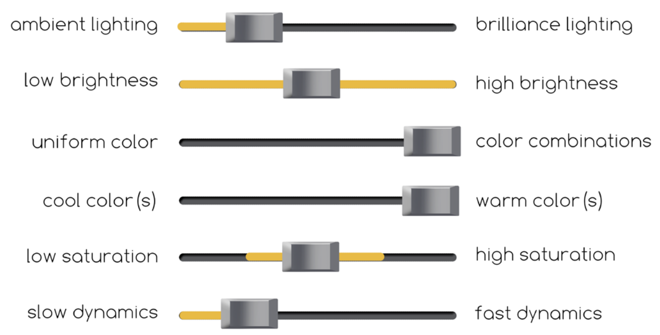
To support the experience of this natural phenomenon, provided the sky is clear, colors of the twilight will be used during the sunrise and sunset; combinations of medium saturated orange, yellow, purple and red. (as can be seen on the image above). All possible colors within this scenario are shown in the color circle on the right; the hue's 5P to 10YR with chroma of 5 to 8.

During the sunrise, the color of the light will slowly change to warm white light, after which the light will gradually be muted.

Example

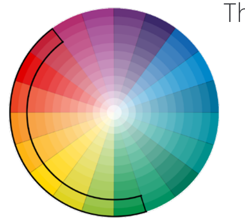
R	191	242	248
G	128	135	184
B	180	115	112

During transitions between light and dark, people with night blindness have extra reduced vision and difficulty focusing. (S. Oke, 2008)
To minimize the effects of this occurrence, little or no dynamic light will be used and the light will mainly consist of ambient light.



18.3 Seasons

As described in chapter 6.7, it has been demonstrated (K. B. Schloss et al. / Cognitive Science 41 (2017)) that only in autumn a deviating preference can be seen when it comes to color. In this season, warmer, highly saturated earthy tones are more preferred in comparison to other seasons.



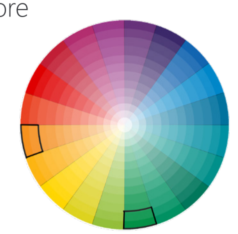
These colors will only be applied if it fits within the desired atmosphere; this is, after road safety, the highest priority.Possible colors that can be used are shown in the color wheel on the right: Hue 10RP to 10GY.

18.4 Events

As discussed in ch. 15.3, there are several major events in Tilburg. If desired, separate light scripts will be written for certain events.
These settings will overwrite all the aforementioned properties. This means that only the event lighting is applicable. To give an example, the atmospheric lighting during the carnival event will be briefly explained.

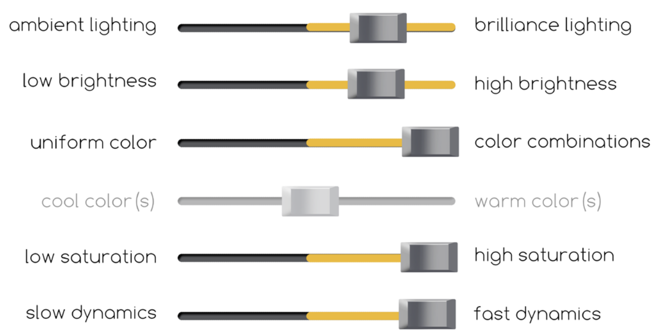
18.4.1 Carnival (#14)

during this Christian celebration, which attracts more than 150,000 people every year, there is a lot of commotion; the nightlife is on the street until the late hours. Along with the music, the lighting in the catering area's and squares will create an activating atmosphere. This will be created through the use of many fluctuations and dynamics, and play of brilliance.
This will be done by light in the colors of 'de kruikenstad' (the jar city); orange and green.
(Hue's 10GY and 5YR, both with chroma 12)



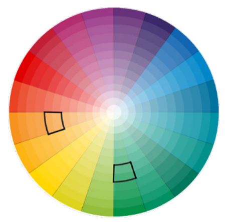
Example

R	247	3
G	146	145
B	30	71



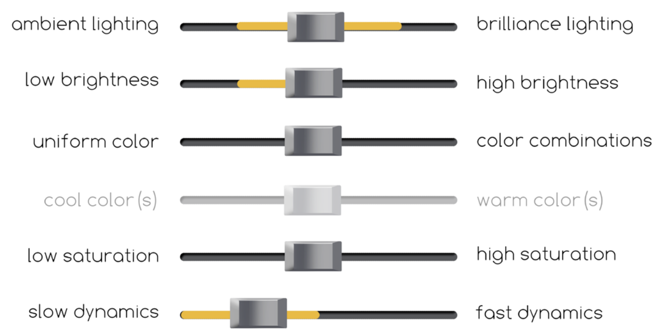
After 11 p.m. (#15)

After 11 p.m. in many places people are expected to relocate to the places of entertainment themselves. The street lighting will try to steer the state of mind of the people who are still on the street to a more relaxed atmosphere, so that nuisance is limited. The light will still consist of the colors orange and green.
(Hue's 10GY and 5YR, both chroma 7 to 8)



Example

R	247	76
G	167	177
B	79	124

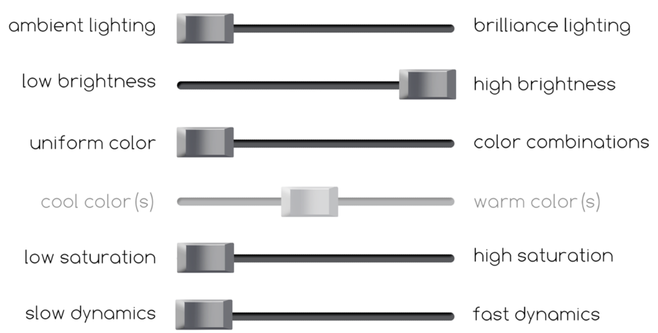


1:00 AM - 3:00 AM (#16)

Just as indicated in 13.1.3, a relaxed atmosphere with very warm colors will be chosen during the night hours, during which many visitors go home. This is to limit nuisance and to support adaptation to the dark.

Example

R	234	223
G	67	0
B	35	0



18.5 Calamities

In the event of an emergency, an unforeseen event that seriously disrupts order in a certain area, the light will switch to 'emergency' lighting.
All luminaires will switch to white ambient light with a high color rendering. The luminaires will thereby increase the capacity to 100%.
Calamities include all events in which emergency services are called. It is therefore necessary for these emergency services to be able to switch on the lighting in this 'emergency' position remotely. More on this will be explained in Chapter 19).

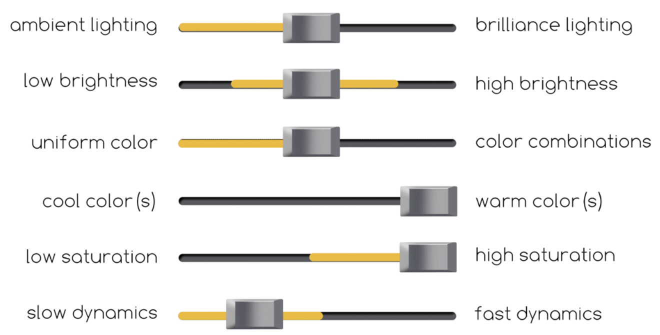



Figure 18.12: A visual representation of the light effect


Figure 18.13: Ambient light with high color temperature (Business-like)


Figure 18.14; Ambient light with low color temperature (Cozy)

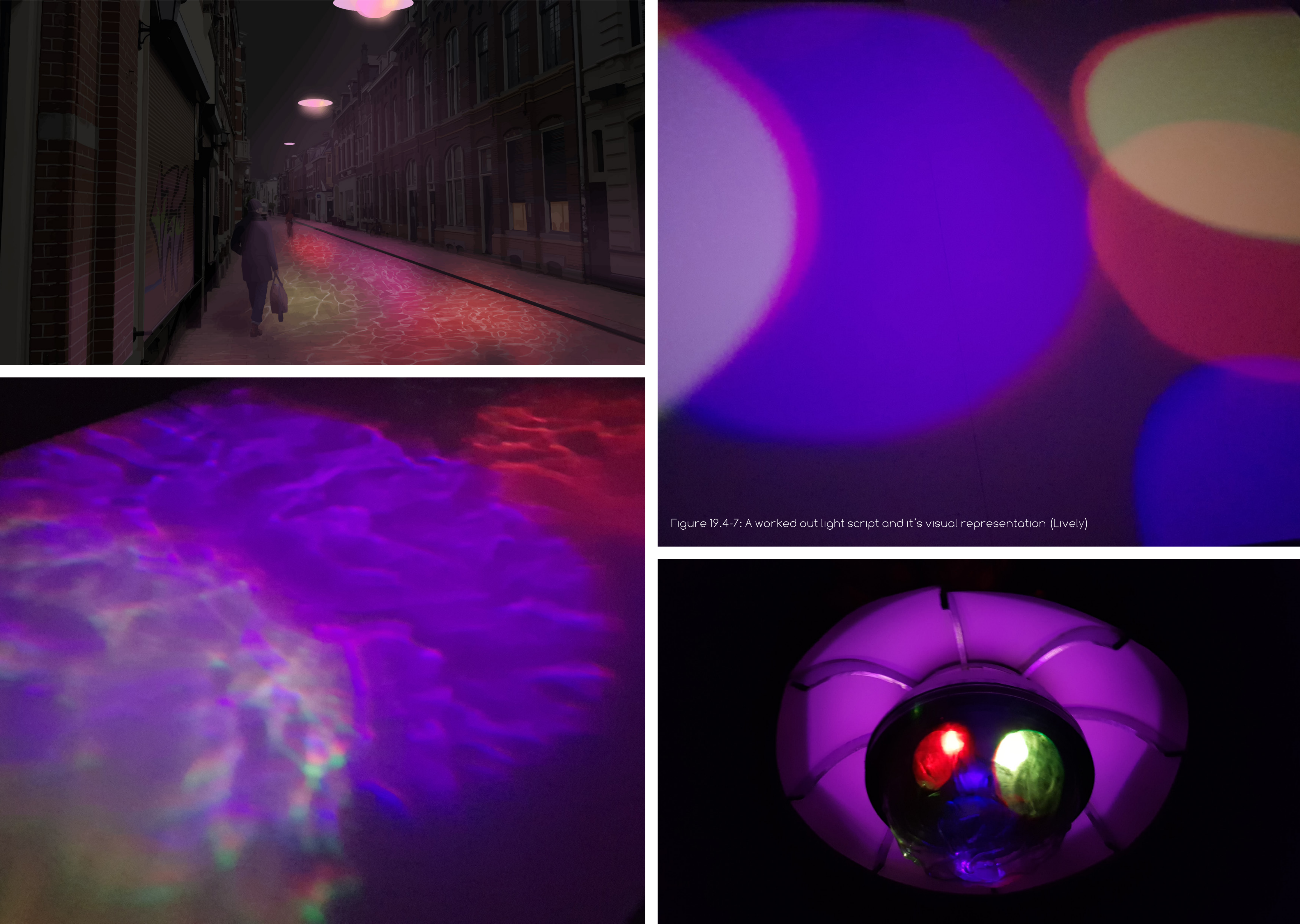


Figure 19.4-7: A worked out light script and it's visual representation (Lively)

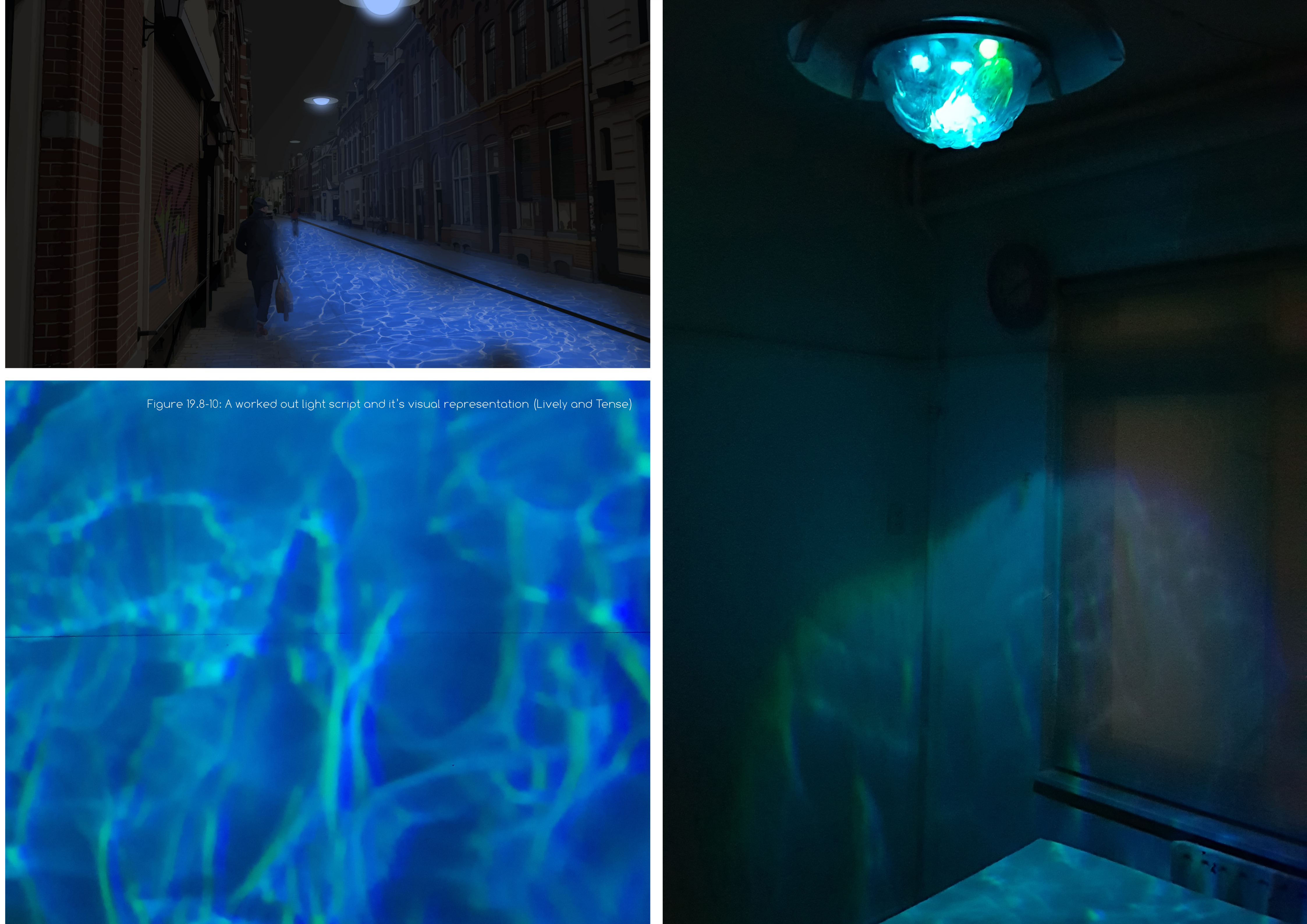


Figure 19.8-10: A worked out light script and it's visual representation (Lively and Tense)

18.5 Hierarchy of Factors

In this chapter a number of determining factors are mentioned when it comes to creating a light scenario. Because these are sometimes contradictory, a hierarchy has been determined. When applicable, the upper of the factors is given priority. If the parameters of other factors with a lesser priority are not inconsistent with the above, the parameters can be combined.

safety {
Calamities, Precipiation and Fog
∨
Activity Motorized Vehicles/ Cyclists
}
∨
Events
∨
Sunrise/Sunset
∨
Pedestrian activity on street
∨
Seasons
∨
Temperature

The system that controls the drivers of the luminaires cycles each set time unit (10 seconds) through the table shown on the left and checks which of the factors apply at that moment.

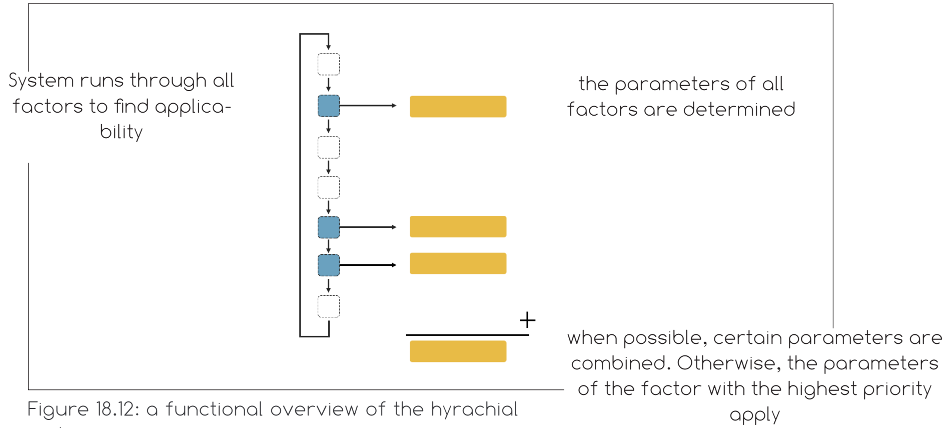
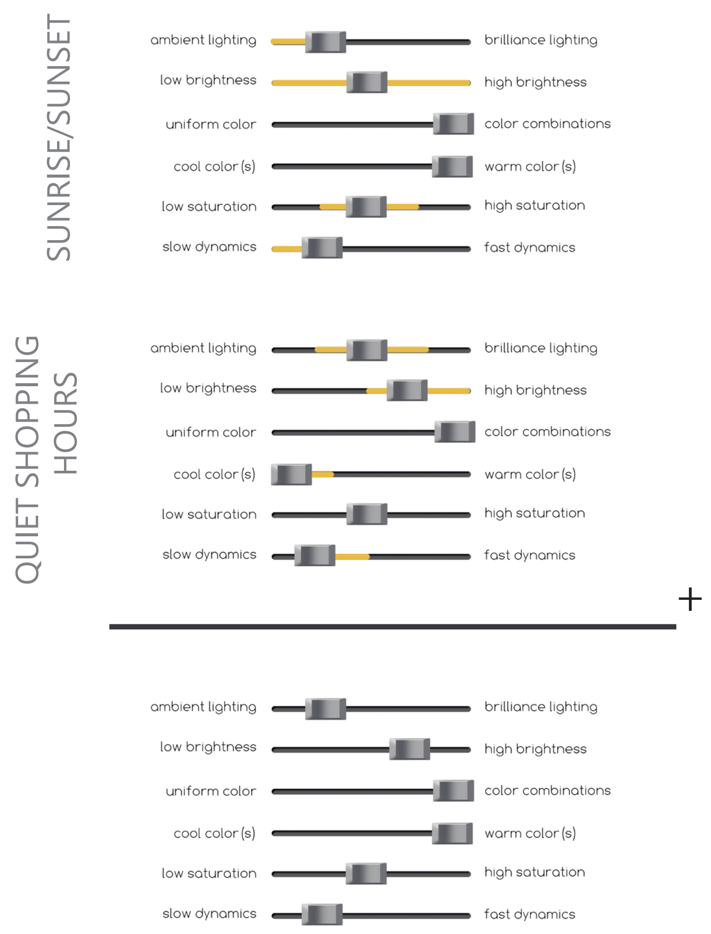


Figure 18.12: a functional overview of the hyrachial system

the factor that is highest in the hierarchy is given the highest priority. Next, the parameters of the other factors that apply at that time are examined.If the parameters of the factors are not contradictory with the factors with a higher priority, these parameters will also be applied.
In this way the system runs through all factors based on their priority and therefore applies either the one with the highest priority or, where possible, a combination.
Although this system will be explained in Chapter 19 on the basis of practical examples, simplified examples will be explained on the left.

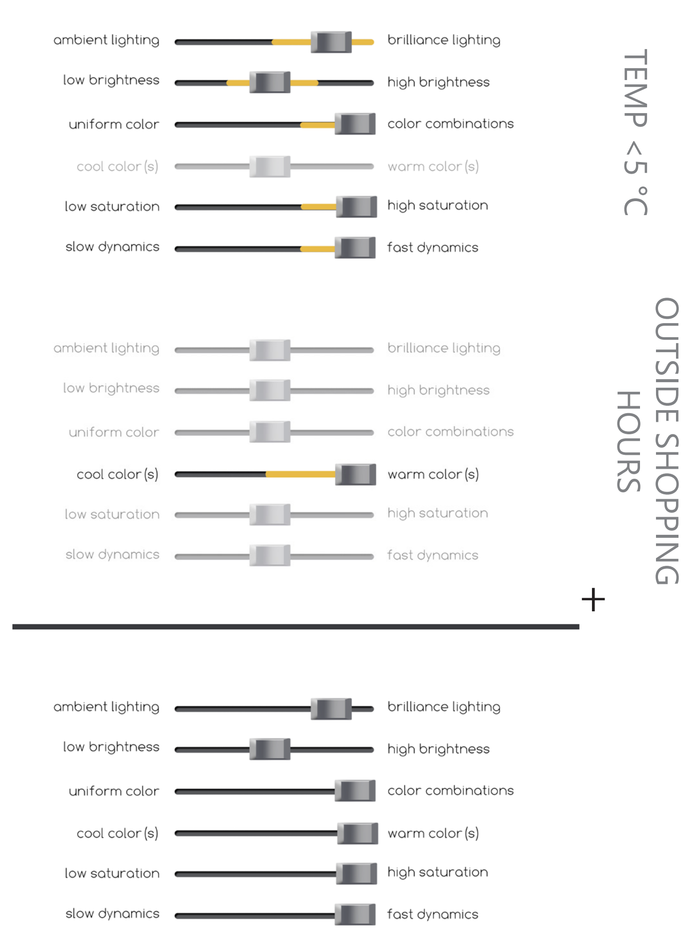


18.5.1 Scenario A

Scenario A describes a sunrise / sunset in a quiet shopping area. The settings during twilight have a higher priority than activating the shoppers. It can be seen that the parameters of the two factors are reasonably contradictory. This means that the parameters of the scenario with the highest priority will apply. Apart from a slight increase in the brightness of the lighting, the properties of the activating atmospheric light are not applied.

18.5.2 Scenario B

Scenario B describes the hours outside opening hours of the same shopping area on a cold winter day. Although the parameters of the upper factor are the priority at this time, it can be seen that the parameters that increase the perceptional temperature do not conflict with this and the parameters can be combined.



19. Light scripts

To show how the input of data is used to determine the parameters of the lighting, four light scripts have been created.In these four scenarios, the parameters for an arbitrary day of the year are explained for the four elaborated areas (residential area, shopping area and the two catering areas).
The input, which is provided for 24 hours per area, is partly based on existing data and partly chosen so that the effect of all different factors and the hyrarchy within these factors can be well demonstrated.

The output, the actual effect on the parameters, will show how the input is translated to the settings of the luminaires.
Where per light script a visual translation of the various parameters can be seen here for 24 hours, Appendix F shows the numerical realization of these parameters.
The input for these four scenarios will be briefly explained.

Note

- The data input has been simplified for illustration purposes to time slots of 30 minutes. In reality, depending on access to certain data (more about this in ch. 20) the system will be able to respond within seconds.
- The output of the data is shown as hard transitions for illustration purposes. In reality, where possible, smooth transitions will be used between the different light scripts that can last up to hours.

19.1 Four Scenario's

19.1.1 Residential Area

General
- Date: Thursday 14 November
- Season: Autumn

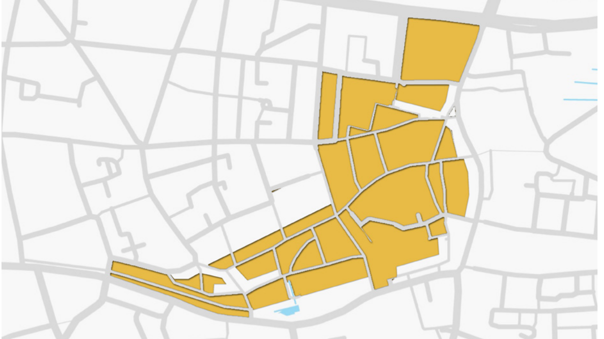
Weather
- Temp max. = 8°C
- Temp min. = 1°C
- Overall Clouded, Precipiation 01:00 - 01:30

Sunrise/Sunset

Ast.	06:00 - 06:41	18:08 - 18:48
Naut.	06:41 - 07:22	17:27 - 18:08
Civil	07:22 - 08:00	16:49 - 17:27
Sunrise/-set	08:00	16:49

Others
- Traffic 06:00 - 11:00

19.1.2 Shopping Area



General
- Date: Thursday 12 November
- Season: Autumn

Weather
- Temp max. = 6°C
- Temp min. = 0°C
- Rainy, Precipiation: 00:00 - 01:30 / 10:30 - 14:00

Sunrise/Sunset

Ast.	06:06 - 06:48	17:22 - 18:03
Naut.	06:48 - 07:32	16:38 - 17:22
Civil	07:32 - 08:13	15:57 - 16:38
Sunrise/-set	08:13	15:37

19.1.3 Catering Area (light)

General
- Date: Friday 1 March
- Season: Winter

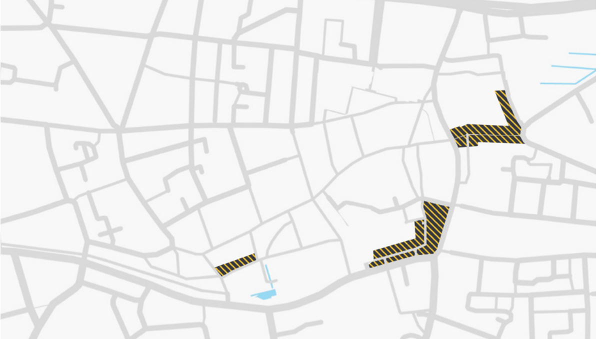
Weather
- Temp max. = 12°C
- Temp min. = 4°C
- Clouded, Precipiation 02:00 - 08:00

Sunrise/Sunset

Ast.	06:44 - 07:25	18:04 - 18:45
Naut.	07:25 - 08:09	17:20 - 18:04
Civil	08:09 - 08:49	16:40 - 17:20
Sunrise/-set	08:49	16:40

Others
- Event 12:00 Start of Carnaval

19.1.4 Catering Area (heavy)



General
- Date: Saturday, 19 September
- Season: Summer

Weather
- Temp max. = 30°C
- Temp min. = 23°C
- Sunny clear sky

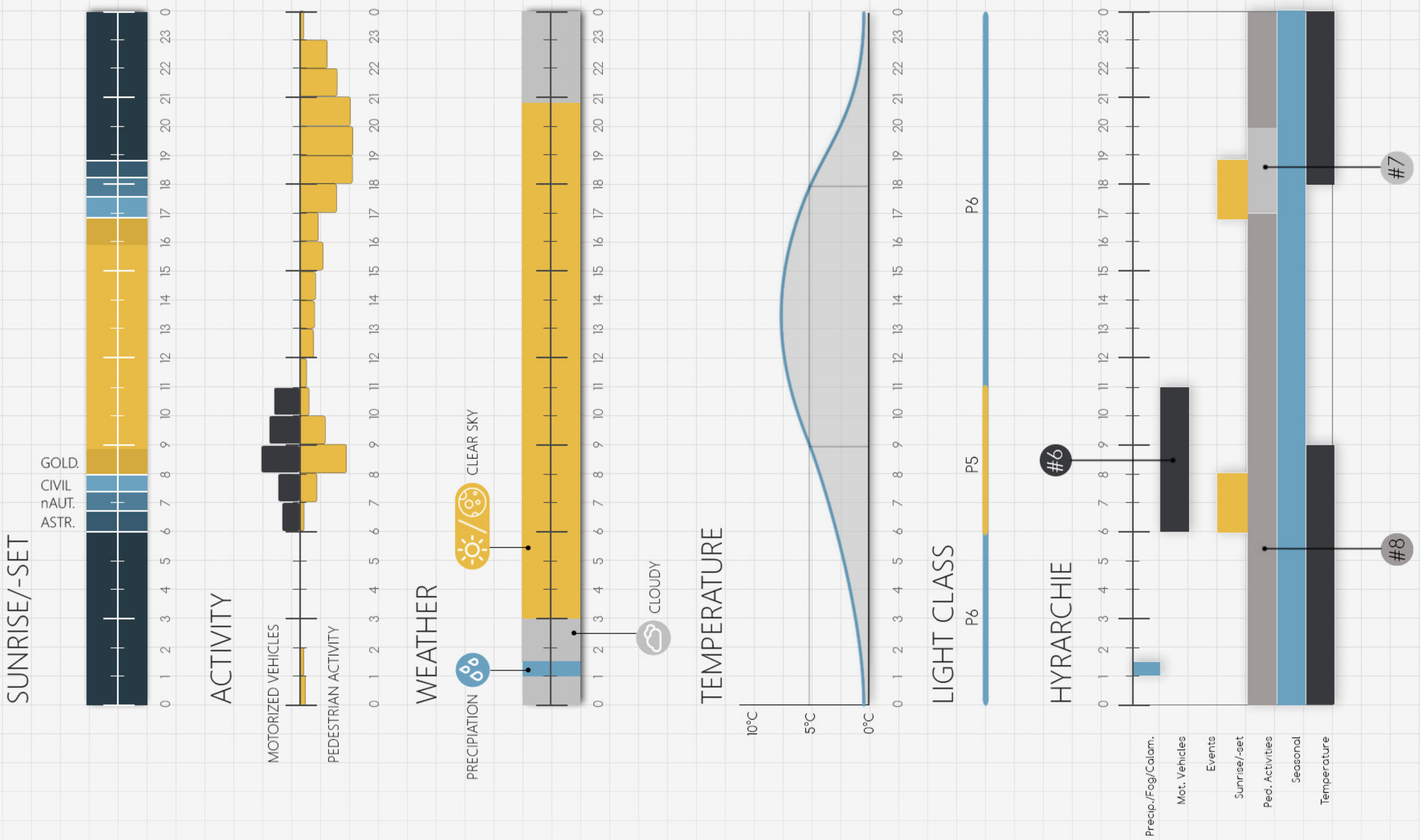
Sunrise/Sunset

Ast.	05:42 - 06:23	20:38 - 21:19
Naut.	06:23 - 07:02	19:59 - 20:38
Civil	07:02 - 07:36	19:25- 19:59
Sunrise/-set	07:36	19:25

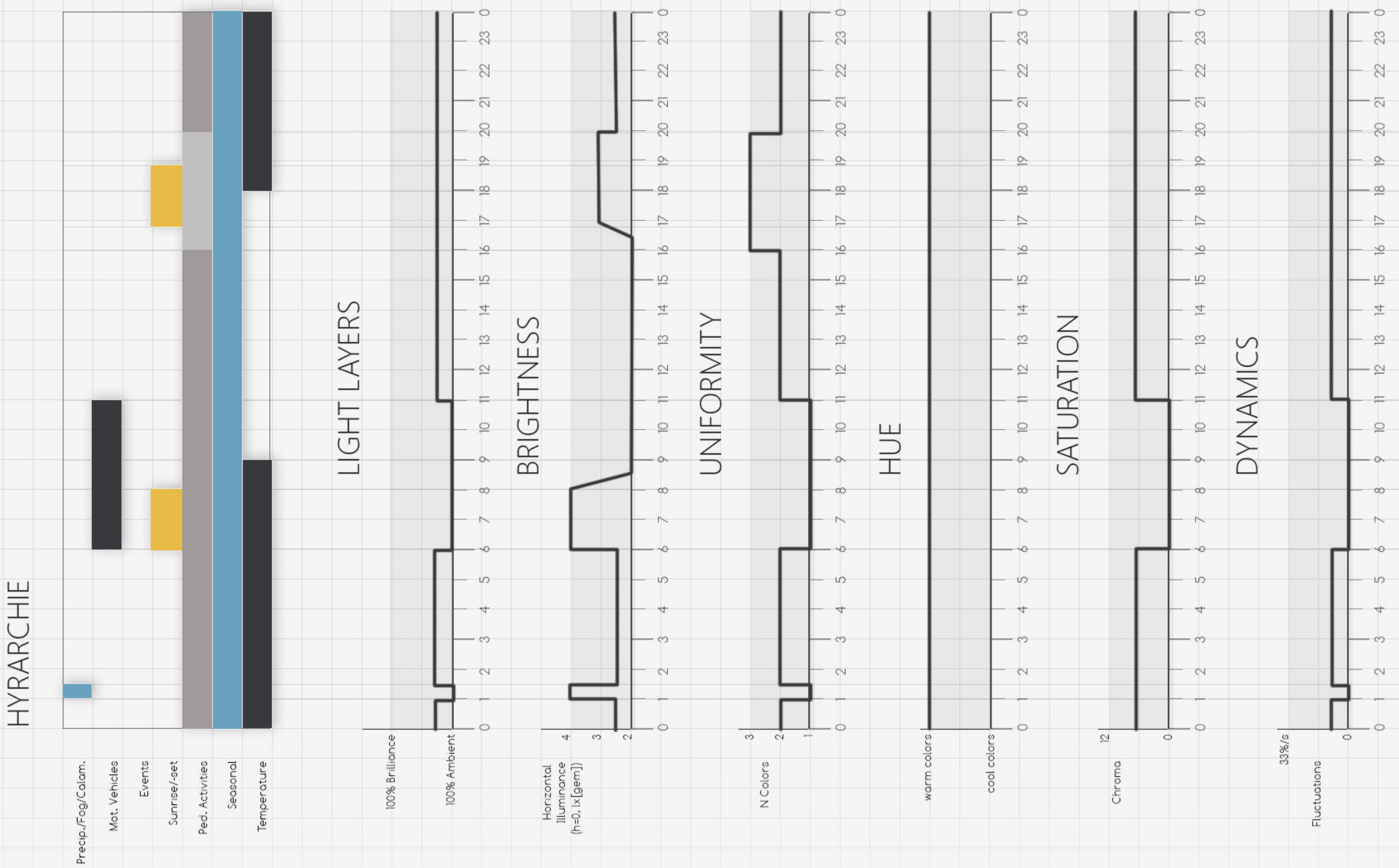
Others
- Calamity 01:30

19.2 Lichtscript 1: Residential Area

19.2.1 Input

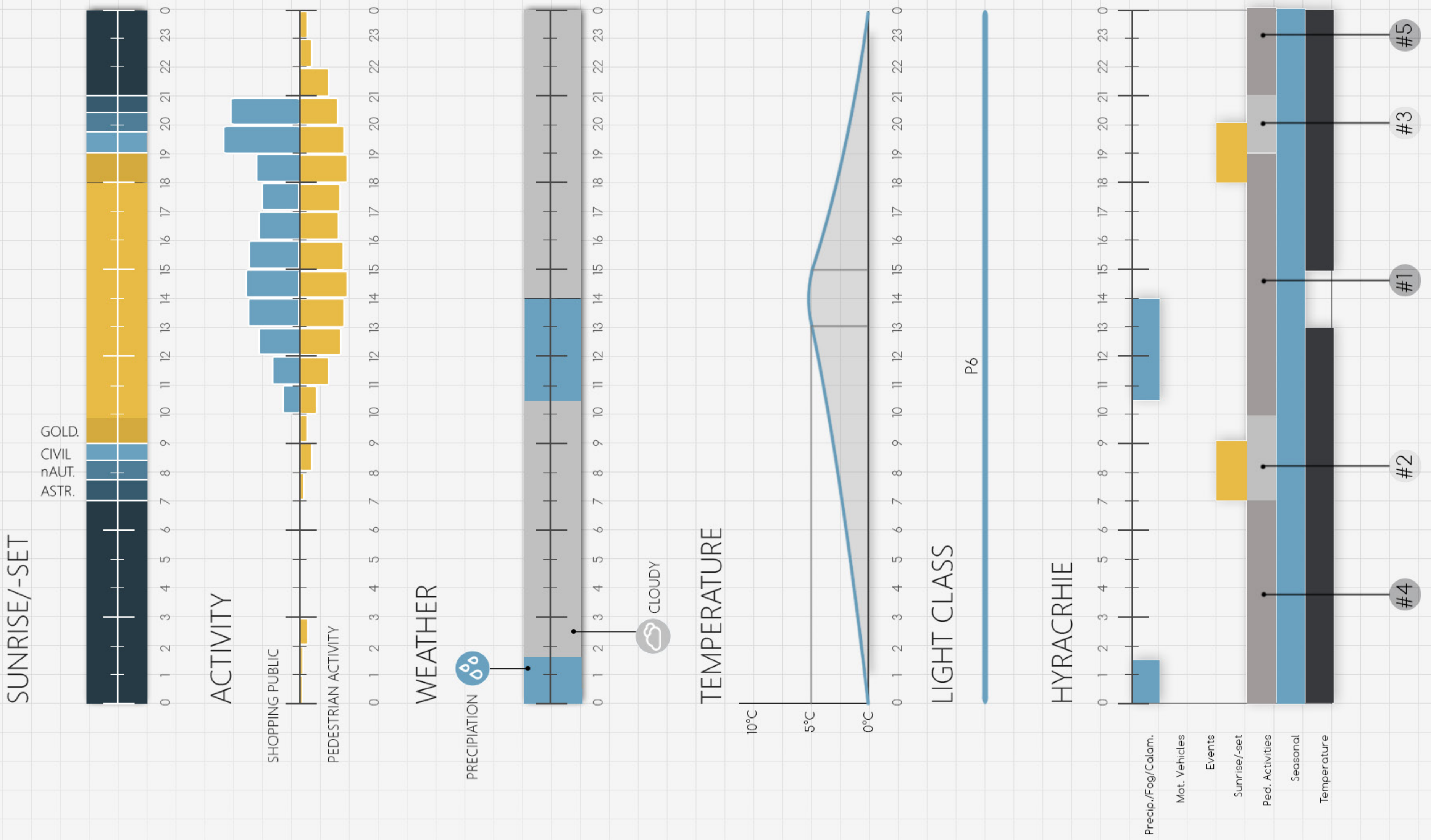


19.2.2. Output

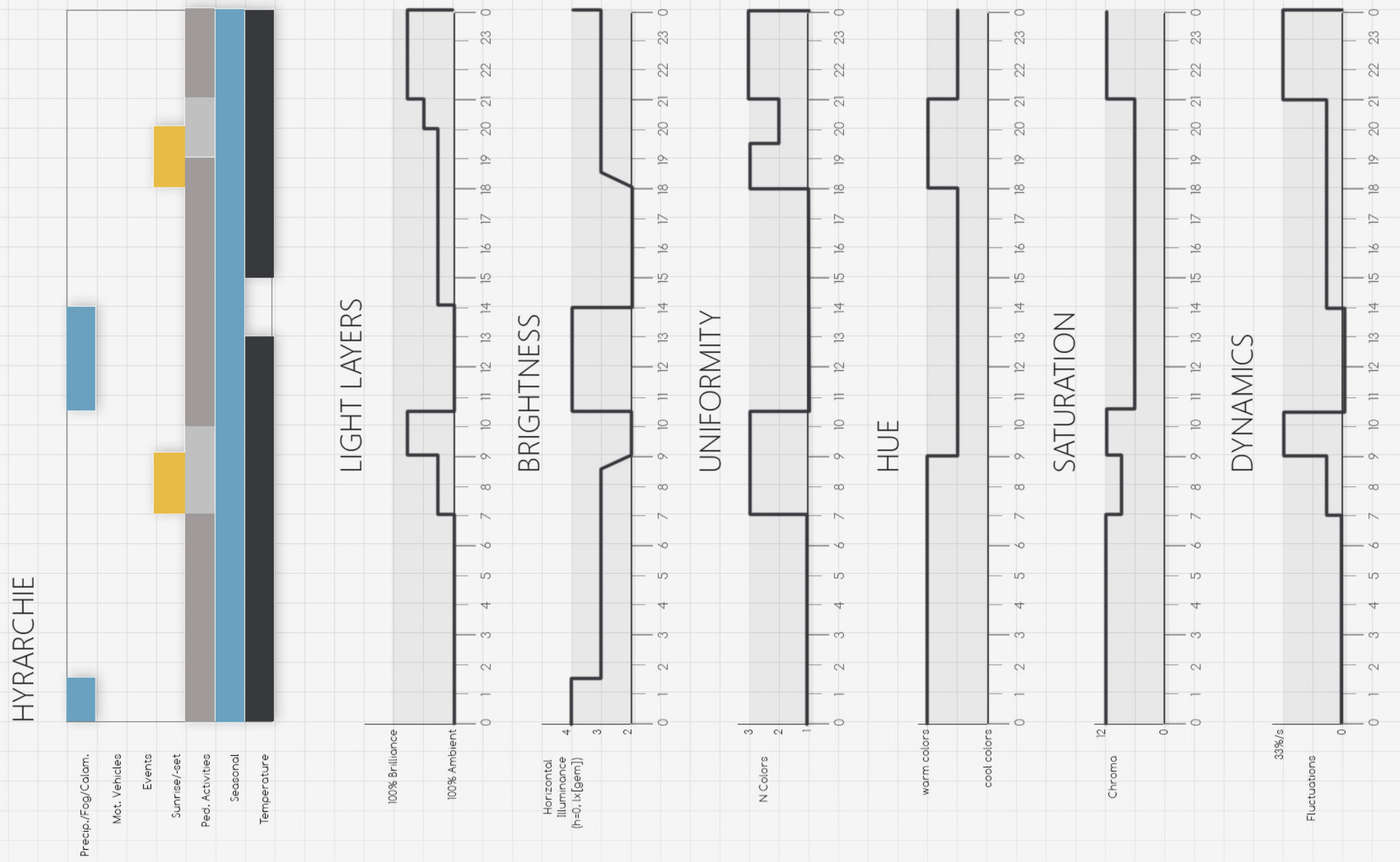


19.3 Lichtscript 2: Shopping Area

19.3.1 Input

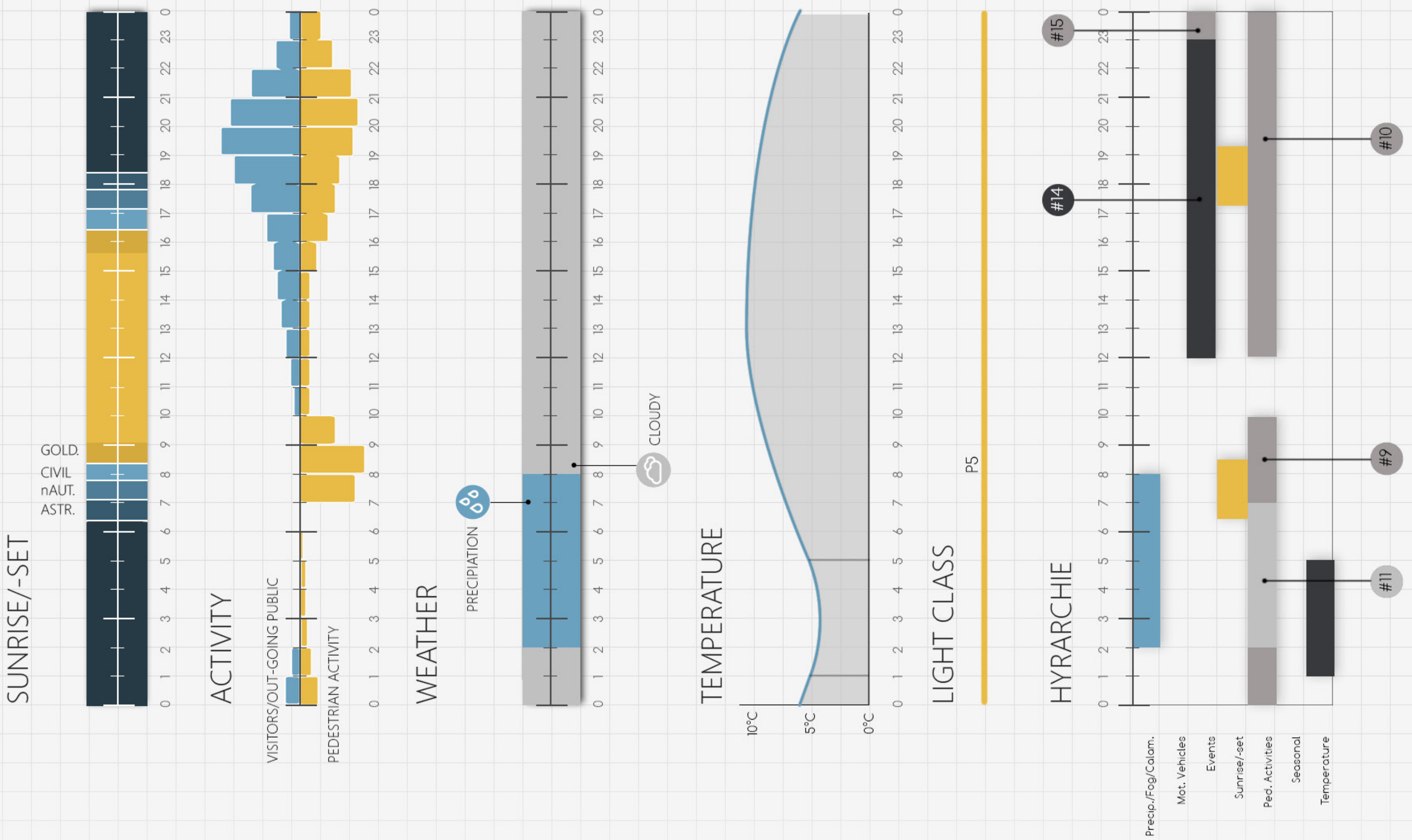


19.3.2. Output

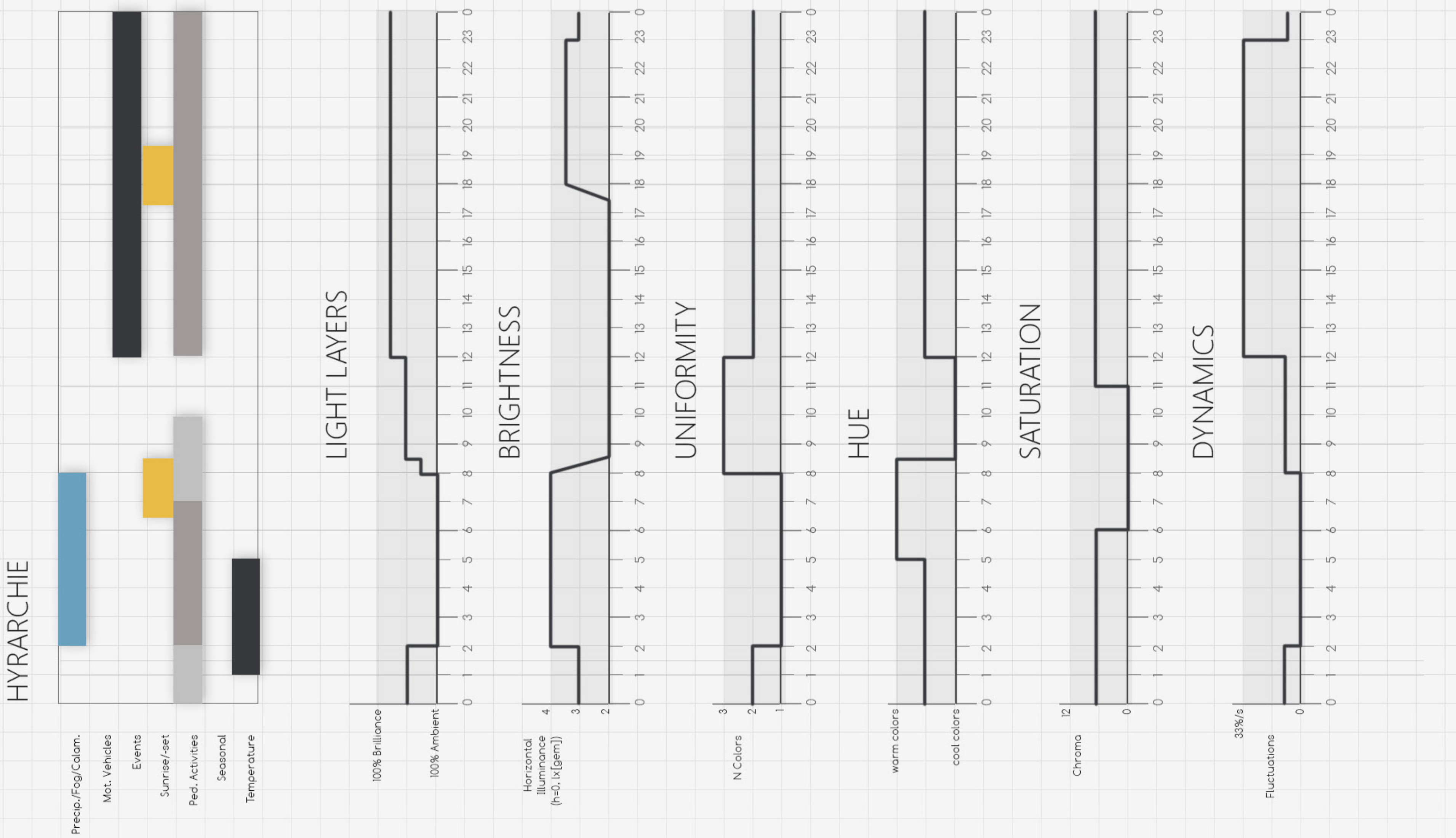


19.4 Lichtscript 3: Light Catering

19.4.1 Input

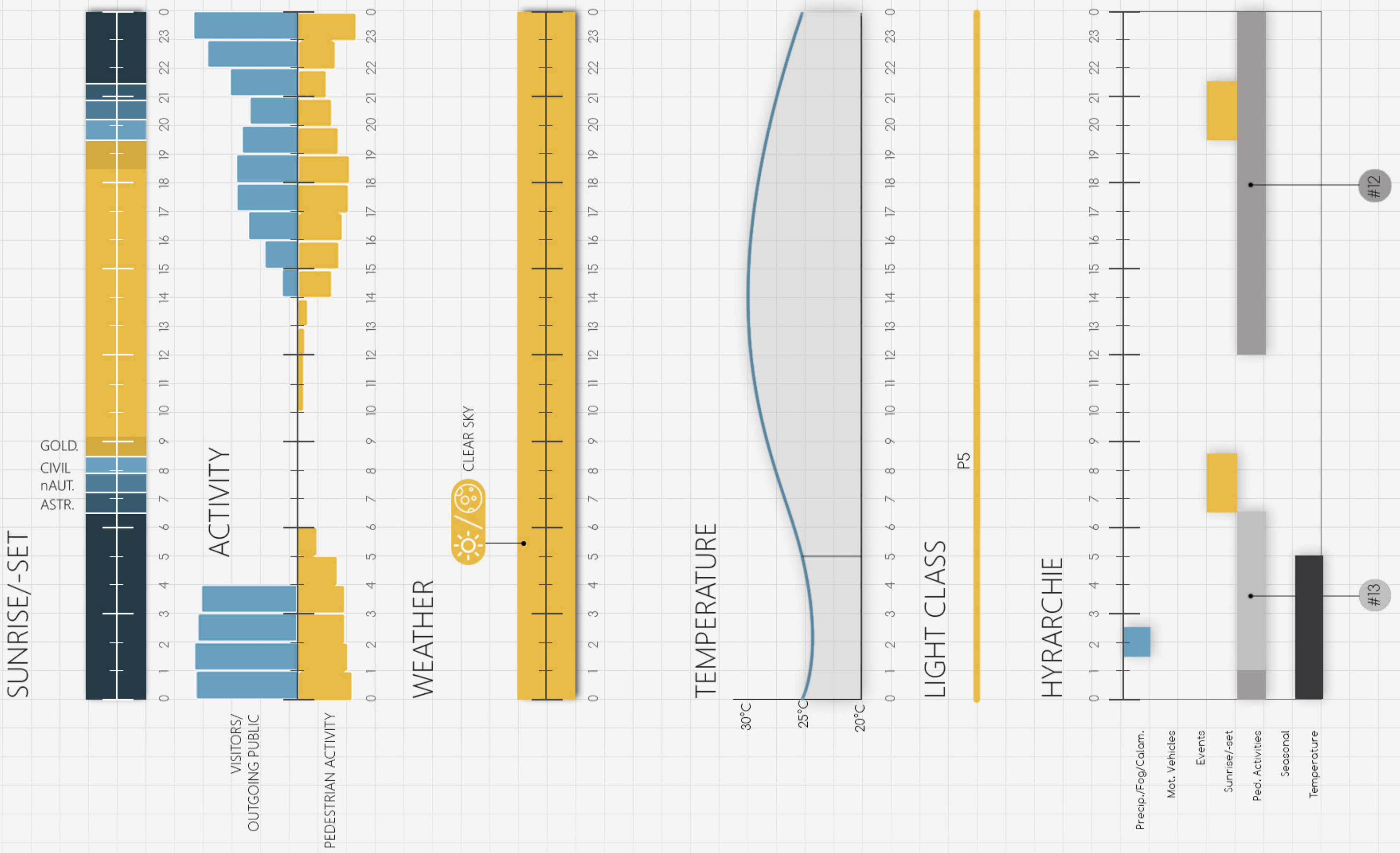


19.4.2. Output

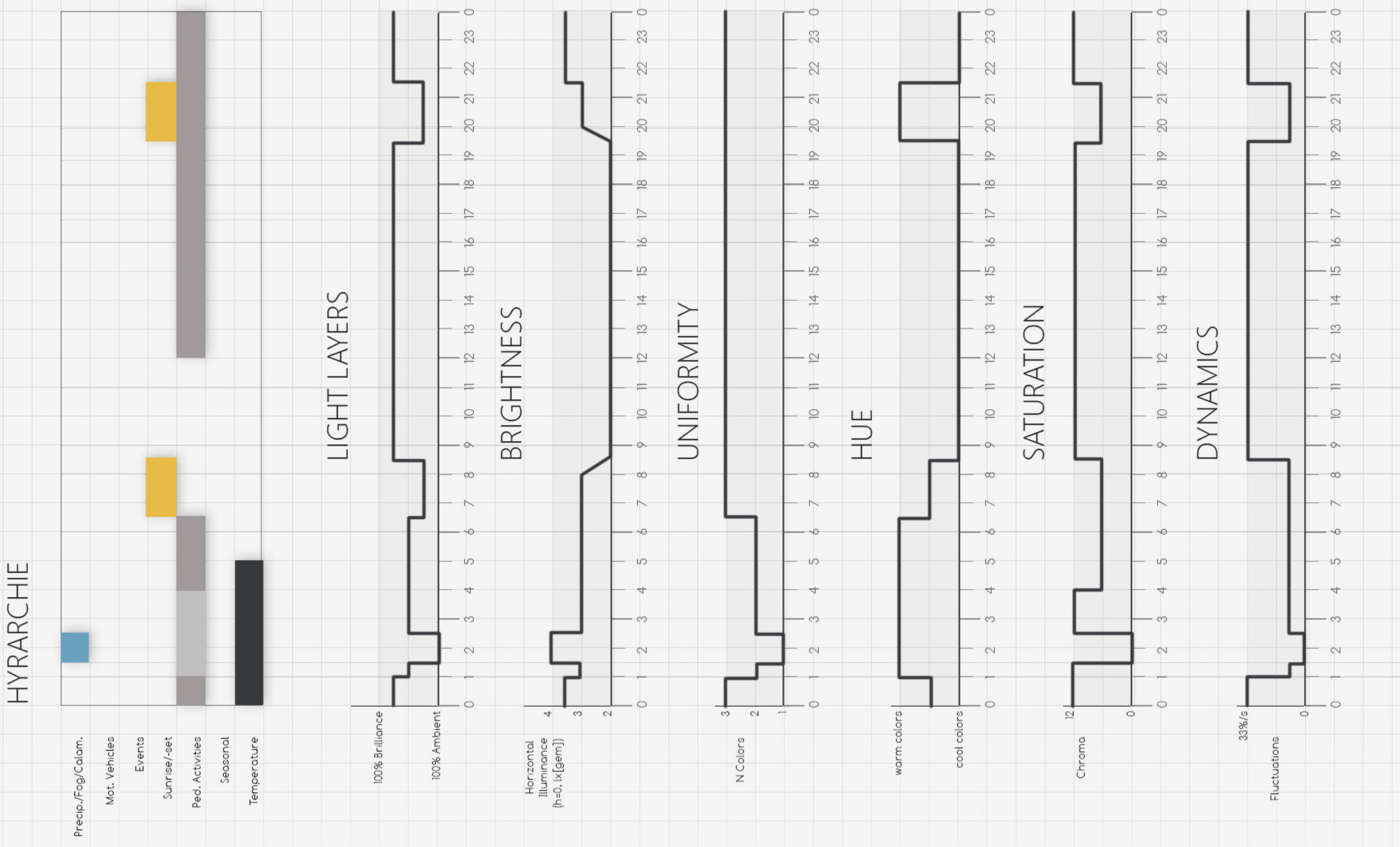


19.5 Lichtscript 4: Heavy Catering

19.5.1 Input



19.5.2. Output



20. Controlling the light

20.1 Control system

20.1.1 Network Management

To be able to control the light, a properly functioning control system is needed. When designing such a system, it is a requirement that municipalities install their own electricity network.

With street lighting that is connected to the networks of the larger network operators (Stedin, Liander, Enexis, etc.), it is currently only possible to dim light pre-programmed.

Responding to live data such as weather conditions is therefore currently not possible. That is why it is desirable for municipalities to take over control of the power grid from these network administrators in the near future. Because this requires a large investment for existing municipalities, the larger municipalities will have to take the lead here or municipalities should engage in certain collaborations.

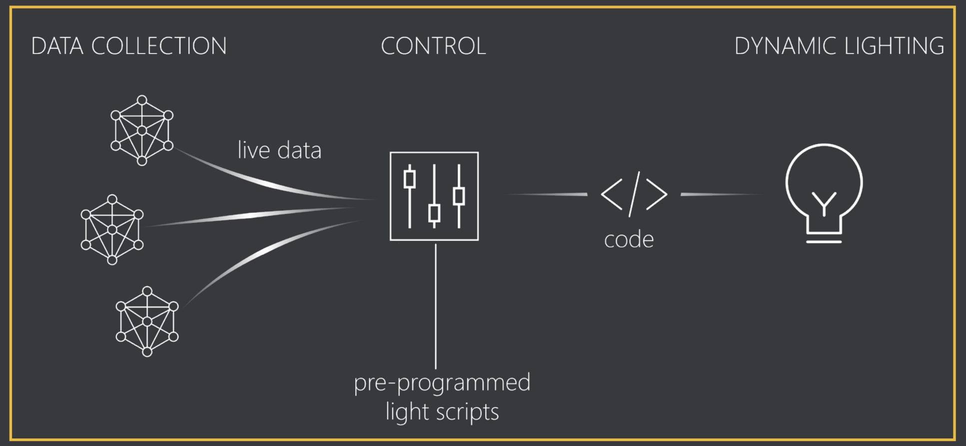


Figure 20.1: a functional overview of the control system

20.1.2 Data Collection

Furthermore, a system will have to be developed in which live data from different sources will be collected. This may include weather conditions (temperature, precipitation, cloud cover), traffic information and emergency services. The system will therefore be an intermediate form of dynamic and responsive lighting (H7.3); it concerns preprogrammed light scripts that respond to external sensor input. Depending on the type of information, the data will be requested per different time units. For example, data such as 'temperature' can be communicated every half hour, but data on emergency services every 30 seconds.

20.1.3 Control

This data will then have to be converted to values of light properties and sent to the relevant luminaires. The conversion of the live data and the preprogramming of light scripts will have to be overseen by light designers (whether or not employed internally at the relevant municipality). The numerical system used (elaborated in Appendix X) to work out the initial light scripts can serve as a basis for data processing.

20.1.4 Data Transportation

All nominal data used for controlling the lighting will be sent via the 4G network to the drivers of the luminaires. When such a network is temporarily lost, the lights will fall back on their pre-programmed settings.

20.2 Future Scenarios

Looking to the future, there are many different possibilities in which such a control system can evolve. The options will be briefly discussed below.

Navigation / Crowd distribution
Smart use of data makes it possible to control traffic in city centers, including pedestrians, by means of light. By reactively controlling the brightness of the luminaires, differences can be created between main roads / routes and secondary roads. As a result,crowds in inner cities can be reduced.

Vehicle Recognition
With the advent of smart systems in cars, it is possible to adjust the light to the road users at that time. In that way, atmospheric lighting is also possible in areas where cars are allowed if no vehicles are detected.

User Profiles
Location services os smart products make it possible to determine which people are located in which part of the city. By creating user profiles, the light can be adjusted for a specific group. (For example, visibility can be increased if there are elderly people in a certain area.)
Obviously, correct legislation must first be drawn up for this and it requires a vision that states which people have priority at what time.

Co-creation with citizens
The inner city is the living space of many residents. The city can respond to current trends (Appendix A, ch. 8.2) by entering into citizen-municipality collaborations when it comes to the creation of light scripts. By increasing the involvement of smart city citizens, a municipality can increase its social representation (ch. 8.2) and thus its residential quality.
The light system could in this way evolve into a system based on interactive data flows.

Energy reduction
A smart light network is the ideal way to further reduce the energy consumption of the city. By constantly measuring the light values, it is possible to determine the minimum light levels for each scenario and thereby also limit light pollution.

Data transportation
Li-Fi, a wireless internet connection that is based on LEDs, was developed in 2011 and can enable street luminaires in city centers to establish a local internet connection. Because this system has the potential to be 100 times as fast as Wi-Fi connections, this can increase the quality of stay in the public space.

21. Design Validation

Test Set-up

21.1 Introduction

This research will focus on the influence of the light properties of this specific fixture on the atmospheric perception of its environment. In a study into the effects of light in an elderly home, it has been proven that the atmospheric dimension has the same influence on the emotional state of the person in that atmosphere. Being in an environment that is experienced as relaxing, ensures that your mood becomes more relaxed.
In this research the light properties of a prototype for street lighting are assessed. Although the luminaire has been developed for outdoor use at a height of 6 meters, due to limited means the properties will be tested indoors in a space of 3 meters high.

The research will be based on a proven method by Vogels (described in Chapter 6) to assess the perceived atmosphere of an environment based on four values.

Atmosphere Dimensions	Corresponding Items
Tenseness	Tense/Threatening
Coziness	Cozy/Intimate
Liveliness	Lively/Exciting
Detachment	Formal/Business-like

Table 21.1: The atmosphere dimensions and their corresponding items

In this research, the corresponding items that fit these four atmosphere dimensions will be used. (Stokkermans, M. G. M., Vogels, I. M. L. C., de Kort, Y. A. W., & Heynderickx, I. E. J. (2018))
This method will attempt to determine the effects of the following light characteristics.

- Composition of light layers (Ambient VS Brilliance, Uniformity)
- Brightness (Value)
- Color Hue's
- Color Saturation
- Number of used colors
- Dynamics (fluctuations in brightness)

In an earlier study by Seuntiens and Vogels, fifteen different professional lighting designers, among other things, linked the above light properties to the creation of four atmospheres for interior design; cozy, activating, relaxing and exciting.
The results of this study (H6.6) have been used as inspiration for drawing up light scenarios for a residential area, shopping area and entertainment area in the centre of Tilburg (H18). In this study, the influence of the different characteristics of the light, linked to different light scripts for these areas, will be tested in a dark room.

Because context has little influence on the atmospheric perception of light properties (Heynderickx), it is assumed that the properties of the designed light have the same influence on the atmosphere in an interior as in the outdoor space.

The following light scenarios will be used as a reference
Shopping Area
- A- Busy Shopping Hours (Relaxing)

Residential area
- B- Evening Hours (Cozy)
- C- Motorized vehicles, cold light
- D- Motorized vehicles, warm light

Light catering
- E- Morning rush hours (activating)

Heavy Catering
- F- Catering Hours (exciting)

These scenarios are based on the scripts developed for the three areas in Tilburg; the shopping area, the residential area and the catering area (which, as discussed in 18.1.3, is subdivided into light catering and heavy catering). Light scenarios C and D are primarily focused on optimizing visibility and less on creating atmosphere. These two light scenarios have been added to test / validate whether the color temperature influences the perception of light that consists of pure ambient light.

An overview of the above light scenarios and the parameters of the luminaire that can be linked to these scenarios can be seen in Table 21.2

Char. \ Scenarios	A	B	C	D	E	F	X	Y
Brilliance/Ambient [%/%]	50/50	75/25	0/100	0/100	50/50	72/25	100/0	100/0
Brightness [%]	70	55	100	100	85	85	100	70
N Colors [N]	2	3	0	0	3	3	1	2
Color Temp [C/CW/W]	W	W	C	W	C	CW	C	W
Saturation [chroma]	8	6	4	4	8	12	12	6
Dynamics [%/s]	13	13	0	0	17	33	33	22

Table 21.2: All used lightscenarios and their light properties

To achieve a more balanced use of all light properties as data processing, two scenarios have been added; scenarios X and Y.The data in this table will be used to demonstrate possible correlations.To investigate the influences of the transparent cover, all light scenarios will be assessed with a smooth cover and with a cover with relief (creating water-like refractions).
the participants are also asked to assess how faces are perceived in the different light properties. For this, participants judged to what extent they considered it possible to read facial expressions in the light and how the faces were considered as pleasant.
All parameters will be assessed on the basis of a 7 point Likert scale.

21.1.1 Research Question

What effect do the different parameters of the luminaire's have on the perceptual atmosphere of its environment?
(and how do this parameters relate to the facial recognition and the overall pleasantness of beholding faces?)

The aim of the research is to validate whether the devised light scenarios have the intended effect on the perception of the environment. Based on the results, the light scenarios may therefore be adjusted.

21.1.2 Hypotheses

A positive correlation between higher color temperatures and the degree of detachment / liveliness of the observed environment

A positive correlation between lower color temperatures and the degree of coziness of the observed environment.

The relief in the shade will influence the perceptional atmosphere of the environment of the fixture.

21.2 Method

21.2.1 Participants

A total of 18 people participated in this study. A maximum of 5 people per group of participants has been set in advance in order to have enough space in the immediate vicinity of the luminaire. For logistical reasons, the participants are divided into groups of 4, 2, 3, 2, 3 and 4 people respectively (participants were only available for a specific time slot)

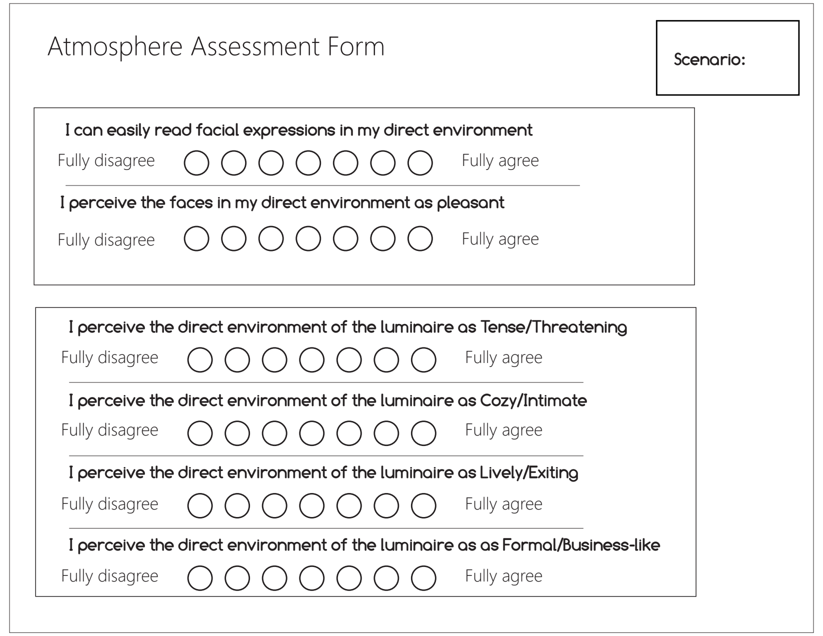
All participants in this research are industrial design students and have an age of 18 to 27 years.

Figure 21.1: the model in the test environment

21.2.2 Environment

The test was conducted in "the Multimedia Lab", a space within the faculty of industrial design that can be made dark.

Although the context determines the perceptional atmosphere to a small extent, it is desirable that there are a number of objects in the room. To simulate a realistic use scenario of the luminaire, objects with different colors and reflection values were required. Together with the shadow work of these objects it makes for a more realistic whole. Mainly furniture has been used for this, since this also gave the participants the opportunity to see the light while seated.



Atmosphere Assessment Form

Scenario:

I can easily read facial expressions in my direct environment
Fully disagree ○ ○ ○ ○ ○ ○ ○ Fully agree

I perceive the faces in my direct environment as pleasant
Fully disagree ○ ○ ○ ○ ○ ○ ○ Fully agree

I perceive the direct environment of the luminaire as Tense/Threatening
Fully disagree ○ ○ ○ ○ ○ ○ ○ Fully agree

I perceive the direct environment of the luminaire as Cozy/Intimate
Fully disagree ○ ○ ○ ○ ○ ○ ○ Fully agree

I perceive the direct environment of the luminaire as Lively/Exiting
Fully disagree ○ ○ ○ ○ ○ ○ ○ Fully agree

I perceive the direct environment of the luminaire as as Formal/Business-like
Fully disagree ○ ○ ○ ○ ○ ○ ○ Fully agree

Figure 21.2: the assessment form

21.2.3. Procedure

In order to find more participants, it was decided that the test should not last longer than 15 minutes. This means that each group has time to handle five light scripts. These light scripts are treated in random order.

The five scenarios contain one scenario with ambient light only and four other scenarios, in which two are tested with transparent cover and two with the cover with relief. (The light scripts that did not use a cover are marked with the number 2)

	Group1 (4)	Group2 (2)	Group3 (3)	Group4 (2)	Group5 (3)	Group6 (4)	Total Resp.
C		X		X		X	8
D	X		X		X		10
A		X		X	X		7
B			X		X		6
E		X				X	6
F	X			X			6
X	X	X					6
Y			X			X	7
A2			X	X			5
B2	X				X		7
E2		X			X		5
F2			X			X	7
X2				X		X	6
Y2	X			X			6

Table 21.3: Overview of the amount of participants per scenario

Because the groups are not equal, is, not all light scripts received the same number of ratings. Although this influences the scientific significance (some assessments weigh more heavily), it was nevertheless decided to use the entire data set for analysis.

21.2.4 Apparatus

The test was carried out with a prototype of the luminaire. Connected to a power source, it is suspended from the ceiling at a height of 2.5 meters. With the help of bluetooth, the various light scripts were sent from a laptop. Images of the test were recorded using a mobile phone. For privacy reasons, participants were not visibly photographed or filmed

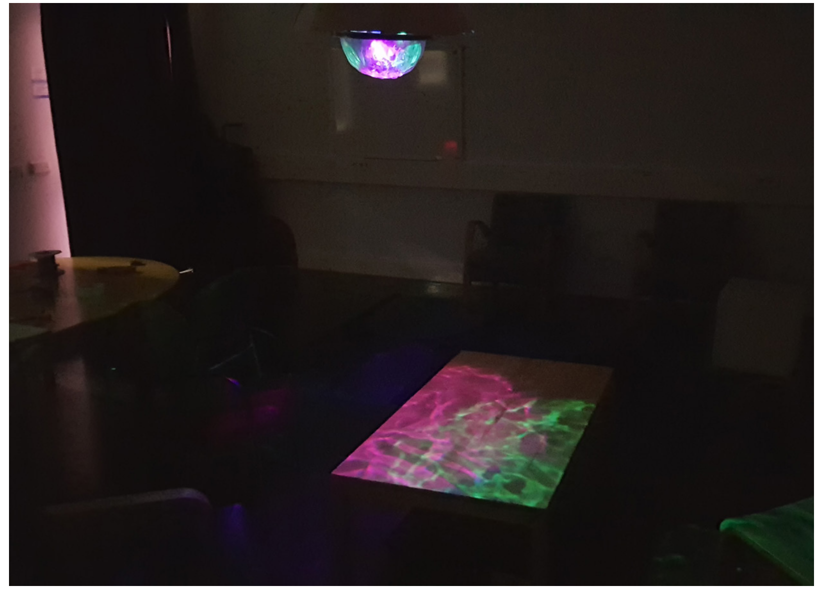


Figure 21.3: the model in the test environment

21.3 Results

Cover

First of all, it was tested to what extent the cover influences perception of faces and the perceptual atmosphere. A Linear Multivariate Model was used for this. The cover is entered as a binary nominal variable (0 or 1).

Cover	N
0	36
1	38

Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Facial Recog.	18.057	1	18.057	9.809	.003
Face Pleasant	5.616	1	5.616	2.737	.102
Tenseness	.063	1	.063	.021	.886
Coziness	2.411	1	2.411	.996	.322
Liveliness	12.928	1	12.928	5.819	.018
Detachment	2.352	1	2.352	1.851	.178

Table 21.4: result multivariate model

This analysis shows a scientifically significant (Sig. <0.05) for the "cover" predictor and the dependent variables "facial recognition" and "liveliness".

- The presence of the cover with relief lowers facial recognition (F = 9.809)
- The presence of the cover with relief increases the perceptional Liveliness (F = 5,819)

Color Temperature Ambient Light

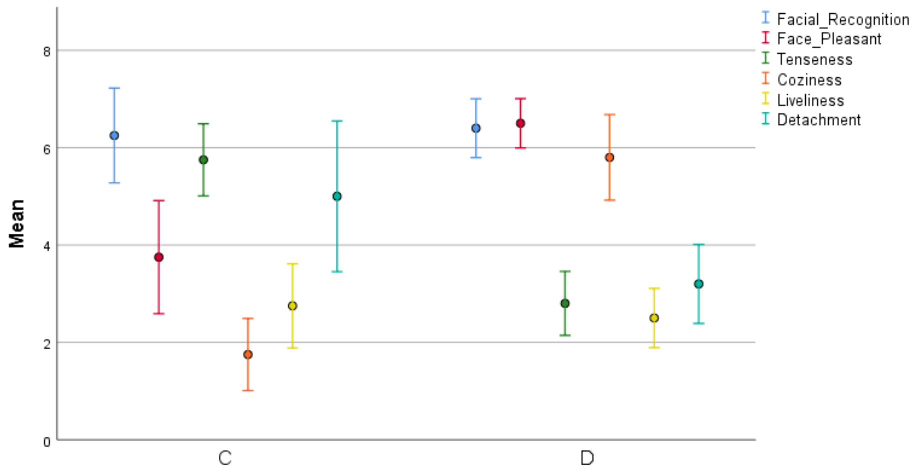


Figure 21.4: Boxplot visualization of influence of cover

To test the influence of the temperature of the light on atmospheric perception in full ambient light, an independent samples t-test was conducted between the light scripts of C and D.

	F	Sig.	t	Mean Difference	Sig. (2-tailed)
Facial Recog.	.913	.354	-.317	-.150	.755
Face Pleasant	2.833	.112	-5.466	-.2.750	0.000
Tenseness	.040	.844	6.873	2.950	0.000
Coziness	1.580	.227	-7.815	-4.050	0.000
Liveliness	.039	.847	.563	.250	.581
Detachment	.745	.401	2.544	1.800	.022

Table 21.5: Result independent t-test on light temperature

Here you can see that the color has a scientifically significant influence on the pleasentness of the faces and the tenseness, the coziness and the detachment of the environment

A combination of linear regression and correlation was used for the remaining analysis. A correlation analysis has the disadvantage that no cause and effect can be demonstrated, because it is not certain that one variable is the cause of the other. it could also be a combination of variables or an unknown variable that causes this correlation.

A linear regression has the disadvantage that it is sensitive to outliers in the data. Because the datasheet of 18 participants (and a total of 92 assessed light scripts) is relatively small, the impact that present outliers have is relatively large. Although this reduces the chance of scientific significance, it has no adverse consequences.

Another feature of linear regression does have direct consequences; the fact that highly correlated predictors distorts the interpretations of their weights. By using a combination of these two types of analysis, the results are more reliable.

21.3.1 Correlations

The bivariate analysis measures the strength of association between two variables and their direction. The values (P-values) are between -1 and +1. +/- 1 indicates a perfect degree of association, numbers closer to 0 a weaker association. Because we are dealing with ordinal data and a relatively small test group, a spearman correlation was chosen.

Below is an overview of all correlations, with the significance assuming below 0.05. The P value is also shown here. (the full tables can be found in Appendix X)

For the light properties applies:

- Brilliance / Ambient : Higher value means relatively more brilliance
- Brightness ; higher value means more brightness
- N Colors ; Number of colors
- Color Temperature ; higher value means lower color temperature, warmer colors
- Saturation ; higher value means higher Chroma values
- Dynamics ; higher value means more fluctuations

	Fac. Recog.	Fac. Pleasant
Brilliance/Ambient	-0.639	-0.414
Brightness		
N Colors		
Color Temperature		+0.501
Saturation	-0.438	-0.433
Dynamics	-0.598	-0.491

Table 21.6: Overview correlations light properties regarding facial recognition

	Fac. Recog.	Fac. Pleasant
Brilliance/Ambient	--	-
Brightness		
N Colors		
Color Temperature		++
Saturation	-	-
Dynamics	--	-

It can be seen that brilliance has a negative influence on facial recognition and a small negative influence on the pleasantness of faces in the immediate area. Furthermore, the color temperature has a major influence on the perception of the faces.

Table 21.7: Overview correlations light properties regarding atmospheres

	Tenseness	Coziness	Liveliness	Detachment
Brilliance/Ambient			+0.683	-0.236
Brightness	+0.561	-0.277		+0.379
N Colors	-0.355		0.324	-0.404
Color Temperature	-0.756	+0.612	-0.338	-0.311
Saturation	+0.245	-0.343	+0.629	
Dynamics		-0.242	+0.747	

	Tenseness	Coziness	Liveliness	Detachment
Brilliance/Ambient			++	-
Brightness	++	-		+
N Colors	-		+	-
Color Temperature	--	++	-	-
Saturation	+	-	++	
Dynamics		-	++	

	Tenseness	Coziness	Liveliness	Detachment
Tenseness		-0.514		+0.027
Coziness	-0.514			-0.268
Liveliness				-0.301
Detachment	+0.027	-0.268	-0.301	

	Tenseness	Coziness	Liveliness	Detachment
Tenseness		--		+
Coziness	--			-
Liveliness				-
Detachment	+	-	-	

Table 21.8: Overview correlations between atmospheres

As can be seen in the table on the left, there is also a certain correlation between the 4 different atmospheres. For example, there is a moderate negative correlation between coziness & detachment and liveliness & detachment. Furthermore, there is a moderate positive correlation between detachment and tenseness and a strong negative relationship between coziness and tenseness.

21.3.2 Regression

To limit the defects from the above analysis, a multivariable linear regression has been applied in addition to the correlation. An overview of all the results can be seen below. (The full tables can be seen in Appendix G). The Beta value is displayed; this indicates how much the independent variables contribute individually to the creation of the dependent variables. It is measured in units of standard deviation.

	Tenseness	Coziness	Liveliness	Detachment
Brilliance/Ambient		+0.960	+0.604	-0.646
Brightness		-0.777	+0.348	
N Colors		+0.616	+0.544	-0.432
Color Temperature	-0.758	+0.718	-0.194	-0.284
Saturation				
Dynamics		-0.969		

	Tenseness	Coziness	Liveliness	Detachment
Brilliance/Ambient		++	++	--
Brightness		--	+	
N Colors		++	++	-
Color Temperature	--	++	-	-
Saturation				
Dynamics		--		

Table 21.10: Overview Regression light properties regarding atmospheres

	Fac. Recog.	Fac. Pleasant
Brilliance/Ambient	-1.189	
Brightness		
N Colors	-0.471	
Color Temperature	-0.274	+0.544
Saturation		
Dynamics		

	Fac. Recog.	Fac. Pleasant
Brilliance/Ambient	--	
Brightness		
N Colors	-	
Color Temperature	-	++
Saturation		
Dynamics		

Table 21.9: Overview Regression light properties regarding facial recognition

21.4 Conclusions Research

The following conclusions can be scientifically substantiated on the basis of the three analyses. It therefore only concerns the conclusions that can be drawn with a certainty of 95%.

Facial Recognition

- More Brilliance results in lower facial recognition (and vice versa). The impact of this variable is large.

Pleasentness of faces

- The use of warm colors results in higher pleasentness when it comes to the perception of faces in the immediate environment (and vice versa). The impact of this variable is large

Tenseness

- The use of cold colors results in a higher perceptual tenseness (and vice versa). The impact of this variable is large.

Coziness

- A higher brightness of the light results in a lower perceptual coziness (and vice versa).
- The use of warm colors results in a higher perceptual coziness (and vice versa). The impact of this variable is large.
- The use of dynamic light results in a lower perceptual coziness (and vice versa).

Liveliness

- More Brilliance results in a higher perceptual liveliness. The impact of this variable is large.
- Combining multiple colors results in a higher perceptual liveliness.
- The use of warm colors results in a lower perceptual liveliness. The impact of this variable is moderate

Detachment

- More Brilliance results in a higher perceptual detachment.
- Combining multiple colors results in a lower perceptual detachment. The impact of this variable is moderate.
- The use of warm colors results in a lower perceptual detachment. The impact of this variable is moderate.

Cover

- The use of a hood with relief results in a lower perceptual facial recognition
- The use of a hood with relief results in a higher perceptual liveliness.

Figure 21.7: Facial regocnition: a Comparison between facial expressions with or without cover in both the same licht script

21.4 Linking light charactritics

A 2D model has been developed based on the complete data set, showing the ratio between the four atmospheres. It should be mentioned that this also includes the data that cannot be stated with a certainty of 95% (sig. Above 0.05).
The proportions show that Coziness is a self-contained atmosphere. It cannot be linked to the other three. There is a positive correlation between Detachment / Tenseness and Tenseness / Liveliness, which makes a combination of this atmosphere possible.

Based on the correlations between the atmospheres and the light properties (again: this also includes all data with a higher significance value of 0.05) a model has been drawn up, which visually indicates where the axes of the six light properties are located.
Theoretically, it is therefore possible to create atmospheres on the basis of this model that lie between these four atmospheres, by taking into account the - and + boxes of each light property.

To verify this model, a larger research should take place, whereby a larger data set is obtained.

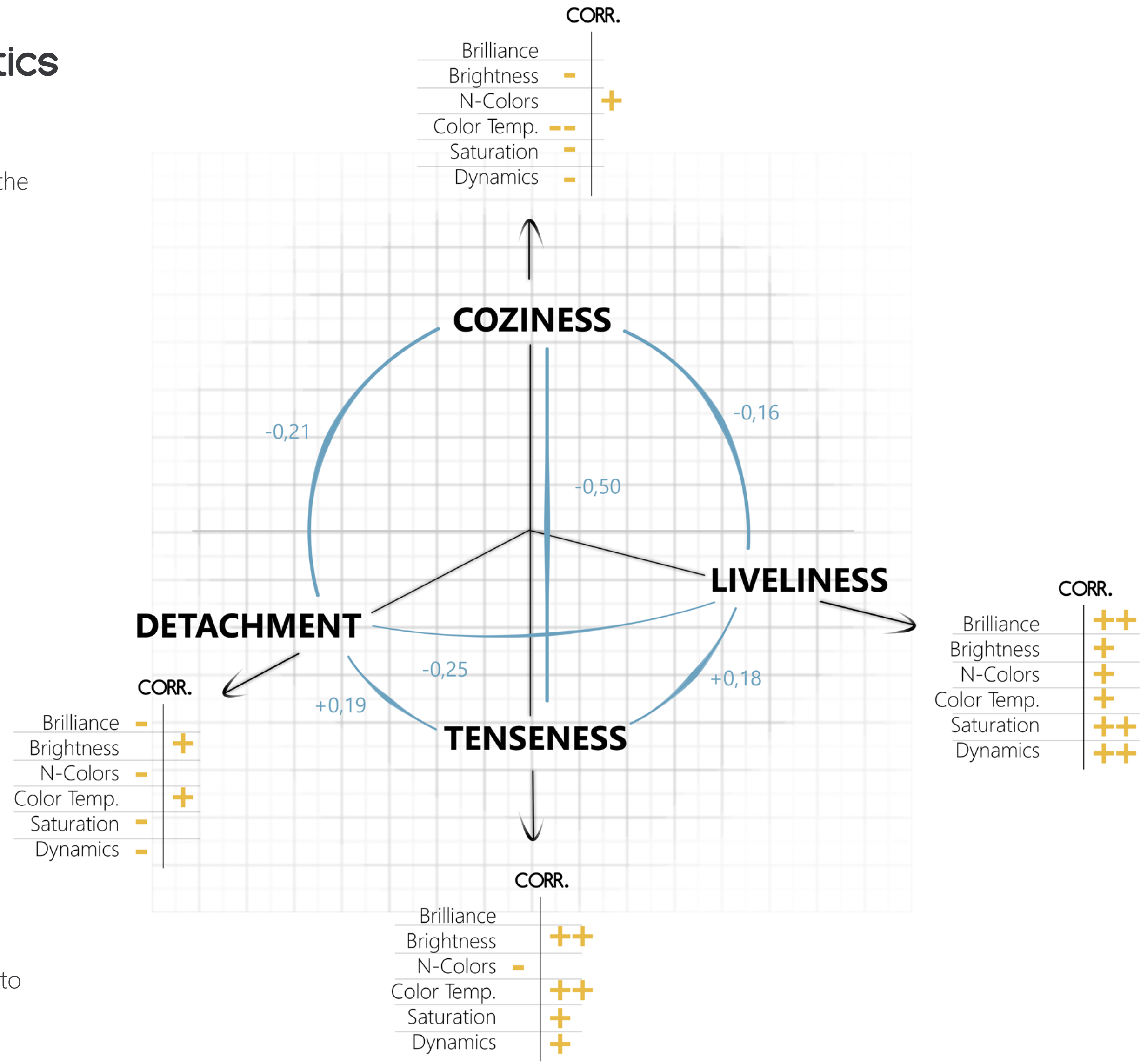


Figure 21.5: 2D model for linking light properties to atmosheres

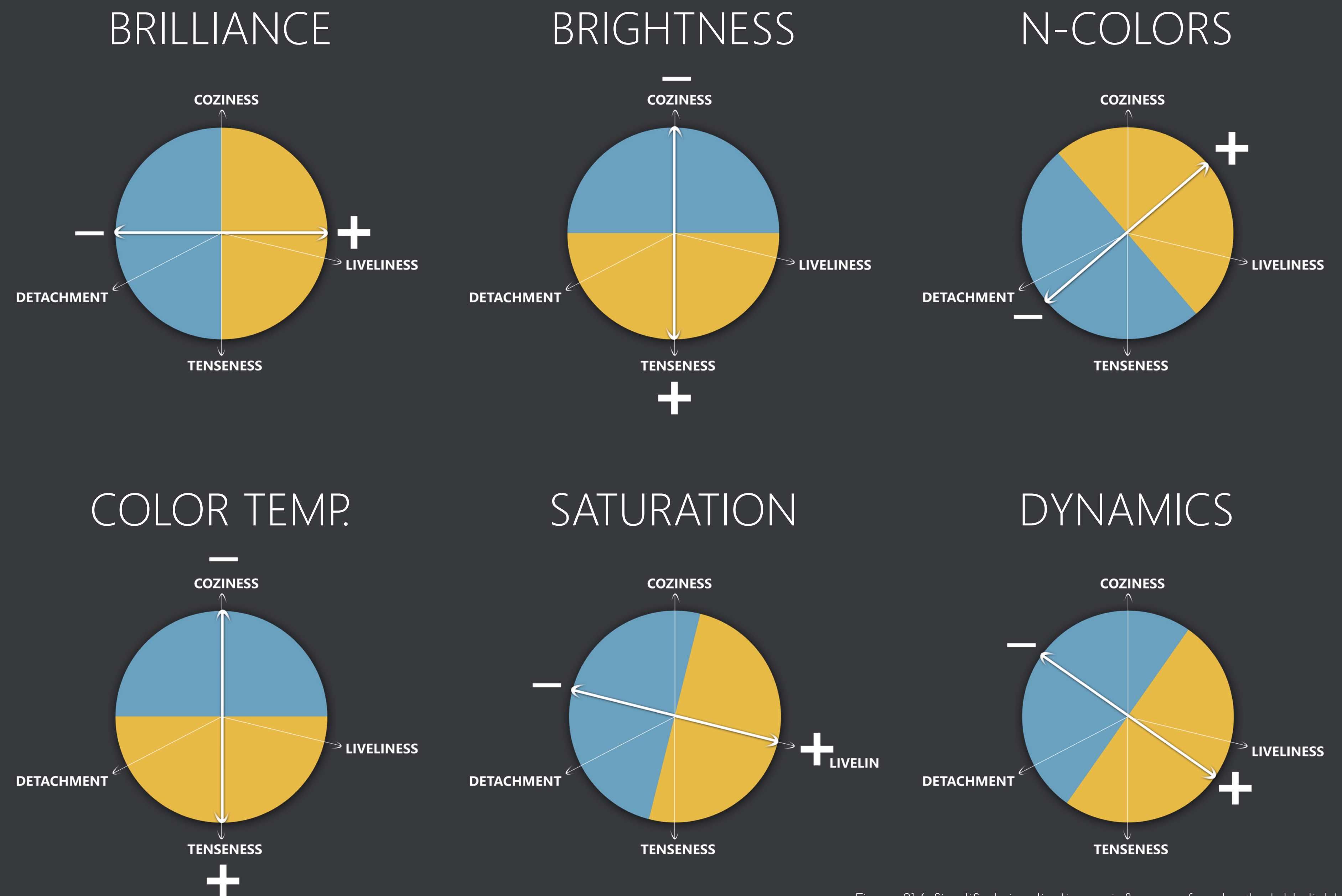


Figure 21.6: Simplified visualization on influence of each adaptable light property

21.5.1 Summary

Although not all assumptions are confirmed, it can generally be concluded that the assumptions made in creating the light scripts for the three areas (H17) are justified.
With this it can also be concluded that previously proven effects of the different light properties (Stokkermans, M. G. M., Vogels, I. M. L. C., de Kort, Y. A. W., & Heynderickx, I. E. J. (2018)) also apply to this luminaire. No evidence has been found to contradict the earlier research.

21.6 Recommendations / future research

- The research shows that the relief in the cover influences the atmosphere. However, more research needs to be done into various types of relief and the associated "projections".
- The research was conducted in a dark room with only one fixture. In order to get a more realistic picture of the influence of the light properties, it is necessary to test at a location where several luminaires are used, which are hanging at a more realistic height and where there is a certain basis of ambient light. (because the public space naturally also has this)
- The research was conducted with students. In order to get a better picture of the influence of light properties, a more representative group should participate in the study. For example, it may be that older people, because they have a lower visual acuity or other cognitive associations, experience the light in a different way.
- Also, since the data are quantitative, the research should ideally be conducted with a higher number of subjects. This lowers the impact of outliers and increases the chance of scientifically linking variables

22. Evaluation & Recommendation

In this concluding chapter, the design will be evaluated on the basis of the design vision and the list of requirements.
Recommendations for future research are made on the basis of this evaluation. This will be substantiated to optimize the viability of the design.

22.1 List of Requirements - Evaluation

22.1.1 Effect/Application

Demands

1. The atmospheric lighting must be based on the (local) identity and the user scenarios of the city where it is placed, in order to increase social representation.	✔	The programmability of the light properties allow for site-specific lighting design. however, the degree of social representation also depends on the co-creation of the light scenarios
2. The luminaire should allow for the creation of brilliance, focus and ambient light (according to Richard Keller's theory).	✔	By varying the ratio between ambient light and brilliance, application of the different light layers according to R. Keller is possible.
3. The luminaire should allow for the change of light colors (based on the results of Vogels) in order to adjust the atmospheric perception of the surroundings. Thereby, the colors of the atmospheric lighting should be in harmony with colors indicated in the lighting plans.	✔	All lights in the fixture are RGB programmable. When considering the municipal lighting plans, the results of the Vogels research (X.X) and the design validation (X.X), it is possible to influence the atmospheric perception of the environment with colored light.

Wishes

The luminaire should be capable of meeting the standards that belong to certain light classes (suitable to certain pavement classifications), in order to replace existing lighting and prevent the increase in the number of light sources. (A1)	✔	The light calculations (X.X) show that for the street types in the category P4 to P6, the luminaire can create sufficient brightness
The luminaire should allow for the creation of light dynamics, which should be adaptive (according to the Vogels & Seuntjes studies), in order to influence the atmospheric perception of the environment.(A2)	✔	The luminaire can create dynamic light through fluctuations in color and brightness.
The atmospheric lighting should improve the identity of the city by helping to convert the day image into the night image (B1)		The extent to which this requirement is met depends on the light scripts.
The atmospheric lighting should allow for the application of bio-mimics. (B2)	✔	The dynamic light in combination with the cover is capable of creating biomimic light. However, more research will have to be done into the influences of such patterns on the atmospheric perception of the environment.
Depending on the user scenario, the atmospheric lighting should allow for the support of warmth-or cold stereotypes by using cognitive association. (C1)	✔	Based on the results of the validation (X.X) it is possible to respond to cognitive associations with light colors. The color of the light has a major influence on how facial expressions are experienced.
The atmospheric light should be capable of matching the atmosphere that comes with the arrival of the winter season. (Similar to decorating a Christmas tree. (C2)	✖	More research needs to be done into the psychological significance of decorating the Christmas tree
The configuration of atmospheric lighting should support the principles of gestalt in order to create orderly chaos (C3)		The gestalt laws have been considered in the technical detailing of the luminaire. The extent to which these laws are applied to the effects of light depends on the design of the transparent cover

22.1.2 Technical/Light Specs

Demands

4. The luminaire should limit the radiation in the spectrum of Ultra-Violet and Infrared	✔	LED radiates in the IR and UV spectrum However, these values are very low and therefore they do not represent a risk.
5. The luminaire should be operational between -10 and 40 degrees Celsius		A fully functional prototype must be developed and tested in extreme circumstances in order to (-in)validate this.
6. The luminaire should have a maximum weight of 25 [kg] so that the luminaire can be carried by one person according to the Working Conditions Act	✔	With a weight of X kilo, the luminaire is well below the maximum weight of 25 [kg].
7. Heat distribution of electronic components must be supported to prevent overheating	✔	The heat sinks support the heat dissipation of the electronic components. This dissipation must be further optimized in collaboration with a possible manufacturer.
8. The electronics of the luminaire must be optimized for standardization of maintenance.	✔	The technical detailing of the fixture supports the easy replacement of electronic components on site.
9. The housing of the luminaire should allow for personalization, in order to fit their surroundings.	✔	The transparent cover and the other housing can be fully personalized.
10. The luminous efficacy of the luminaire should be at least 50 [Lm / Watt]	✖	Although LED is generally very efficient, this applies to a lesser extent to RGB LEDs. These have a luminance efficiency of 45 [lm/W]. Due to the interchangeability, it is possible to install new modules as soon as the efficacy has increased

Wishes

The luminaire must prevent light diffusion into the air to limit light pollution (A3)	✔	The housing of the fixture prevents all possible light pollution.

The atmospheric lighting must be dimmable (A4)	✓	All integrated LED units are dimmable.
The atmospheric lighting should not increase the average illumination of its area by more than 5[lux] (B3)	✓	The illuminance can be accurately determined. Unless desirable, overexposure can be prevented at all times.
Atmospheric lighting must minimize the reduction in facial recognition. (B4)	✗	Validation of the fixture (X.X) shows that the atmospheric lighting in which brilliance is used has an adverse effect on facial recognition.
The luminaire should not have moving parts (to allow for dynamic lighting) (B5)	✓	
Depending on the location, the luminaire should allow for both pendant and upright installation. (B6)	✓	Although the fixture comes out better with a pendant application, it is possible to mount the fixture upright. In that case, the fixture must be fixed more than 80 [cm] from the pole.
The luminaire should allow for adaptations in spatial distribution of the light, appropriate to the location (B7)	✓	The design of the top cover (bulging) and the settings and adjustments of the six spotlights allow for the fixture to be optimized for its environment during installation.
The use of bright cool colors must be avoided to minimize the impact on the life of nocturnal animals (D1)	✓	Although the use of cool light is desirable for certain atmospheres (liveliness, detachment, tenseness), it is possible to avoid the use of cool bright colors.

22.1.3 Material

Demands

11. The luminaire must be vandalism proof or should allow for installation on an unreachable location.	✓	Aluminum has good mechanical properties. Furthermore, the fixture will be installed in inaccessible places.
12. The housing of the luminaire should prevent rainwater from entering and should be resistant to other weather conditions	✓	The housing prevents rainwater from penetrating. The ventilation membrane removes any pressure differences and allows cooling without moisture entering the housing.
13. The luminaire should prevent the installation of an extra mast, unless this can be combined with other functionalities	✓	The fixture is optimized for a pendant application and does therefore not require a pole. If this is not possible, the fixture can be mounted on existing poles.

Wishes

The luminaire must be made from durable (in relation to its life span) materials. (A5)	✓	The fixture is mainly made of aluminum. In addition to being very durable, this material is also easy to recycle (and requires 95% less energy than primary production).

The material of the housing must be available in several colors or it should allow for (spray-) painting to match the environment. (B8)	✓	The fixture can be sprayed in any desired color, as long as the inside of the top cover retains its reflection value. Treating the aluminum with paint does however have an adverse effect on recyclability

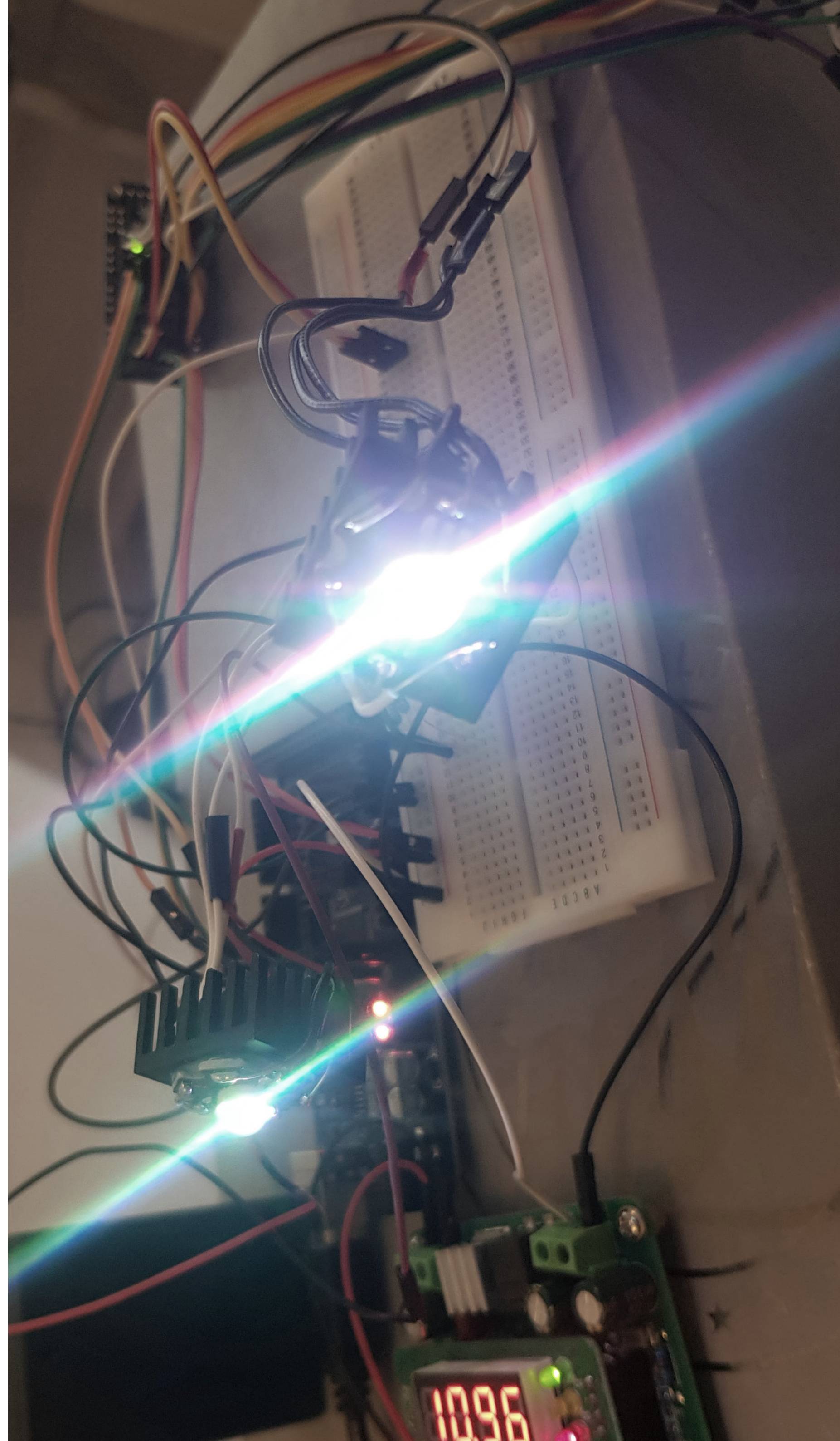
22.1.4 Safety

Demands

14. The atmospheric lighting must not adversely affect vehicle road safety	✓	By using pure ambient light, road safety can be optimized when necessary..
15. The luminaire must prevent annoying glare (The atmospheric lighting must not negatively affect the safety of the visually impaired (the elderly))	✗	The six spot lights can cause glare, espacially in combination with a fully transparent cover. (Although this is entirely dependent on how the spots are installed) On-site testing will show to what extent this is bad for passers-by and to what extent this can be prevented
16. Electronic components must be covered In order to prevent shock hazards.	✓	

Wishes

The atmospheric lighting should not affect the brightness in the occurrence of calamities (C4)	✓	In the event of an emergency, the luminaire can respond adequately to circumstances.



22.2 Recommendations & Future Research

22.2.1 Design Vision

"DEVELOP A PROGRAMMABLE LUMINAIRE WHICH HAS THE MAIN FUNCTION OF POSITIVELY INFLUENCING THE STATE OF MIND OF BYSTANDERS BY USING ITS ADAPTIVE LIGHT PROPERTIES TO CREATE DESIRED ATMOSPHERES"

Customizability is central to the design of the luminaire:

- The luminaire should be **adaptable** during installation to ensure that the quality of the light is optimized for its environment.
- In contrast to the electronic components, which are optimized for standardization or maintenance, the housing offers a certain **design freedom** to match the identity of the city.
- **Programmable** light properties enable the luminaire to vary between layers of light and by means of light scenarios improve the residential quality of cities.

The luminaire will be installed in areas where pedestrians are the main or only traffic participants

22.2.2 Future Work

Looking back on the initial design vision, it can be concluded that the end product has the potential to fully meet the set design goals. However, a number of steps are still needed to optimize the viability of the project.

1. Design optimization

In collaboration with possible manufacturers of such a fixture, the following should be optimized:

- Weight - although the fixture weighs less than 25 [kg], it is still considerably heavier than other fixtures.
- Heat emission and watertightness - By testing in extreme conditions, these two values must be optimized.
- Production Costs - By reducing the number of parts and using existing parts, the production costs must be reduced as far as possible.
- Driver - The driver is still designed as a 'black box'. this must be designed in collaboration with a manufacturer
- Efficiency - The efficacy of the LED modules must be optimized.

2. Light effects

Further research is also required into the influence of certain light effects.

- Lenses - Through further tests, the lenses for the spotlights must be optimized. It should also examine alternatives to ordinary fresnel lenses (circular beams are not required)
- Biomimicry - Because the transparent cover has a lot of influence on the perception of light, research has to be done into the effects of patterns within light dynamics and especially within biomimic / biophilic lighting design.

3. Pilot

Before Tilburg can be used as a case study, a pilot must first be carried out. This should include:

- Personalization - The design freedom of the luminaire must be used to make it more urban. (An example would be the use of wool patterns)
- Glare reduction - research has to be done into the glare of the luminaire and into solutions for this. To what extent does a wet road surface create glare? The conclusion from this can be that the use of brilliance is not desirable in wet weather. Research into the effects of light dynamics on the elderly is also desirable.
- Orientation - How can the fixture help with the need for orientation, described by William Lam.
- Control system - Within the pilot, a possible control system (Hx.x) for the light must also be considered.

After all this, it is possible to use the luminaire and atmospheric light in general on a larger scale. This makes it ready to evolve with the future needs of the cities.

Appendix A: Trend Analysis

A few things have already been discussed about trends in the development of light and light within public spaces. Other relevant trends are briefly discussed in this chapter. The trends will be divided into six categories: Demography, Economy, Sustainability, Technology, Ecology and Politics.

A.1 Demographic

Open city -The "open city" is also called the "indefinite city". Jane Jacobs is one of the founders of the principle. It means that within the development of cities, there is space for for diversity and obstinacy. Where many municipalities continue to strive for order and unity, there is a growing encouragement towards the use of public spaces that do not comply with that order.

Increasing habitants cities - More and more people are moving to the city, these are both immigrants and residents of the country. By 2030, at least 60% of the population is expected to live in cities.

Aging - A trend that has been going on for decades is the aging of people (especially in Western Europe). Because women live on average 3 years longer than men and this difference seems to be increasing, there will be more and more women in the Netherlands.

Walkable city - Cities (within Japan and Australia and North American & European countries) are increasingly focusing on the movement of its inhabitants by means of walking or cycling. This is due to the social- (health, social interaction, sense of community and identity), economic- (higher turnover companies & attracting investors (every euro invested in improving bicycle and walking paths yield up to 11.80 euros)), political- (reduction in pollution, fewer traffic accidents, increase in inclusiveness) and environmental benefits (increased wildlife habitat, CO2 reduction).

Figure A.1: Concept figure for a new walkable city

A.2 Economical

Citizen-Municipality collaborations - The government is starting to work with citizens on more and more fronts. The cooperation gives the residents of cities a sense of inclusiveness, and it also encourages citizens' initiatives.

Social shopping - Making good and honest products is becoming increasingly important. People increasingly base their purchases on the opinions of those close to them that are conveyed through word of mouth or social media. The need for companies to invest in marketing is therefore declining.

Personalization Commerce - If a company nevertheless chooses to promote its products or services, this is increasingly being done by using. persuasive technology. The increase in information about potential buyers and the increase in psychological knowledge ensure that companies can increase the efficiency of their marketing

Increasing Tourism - A trend that has been going on for some time is the increase in tourism (in the Netherlands). Tourism spending increased by 6.9% in 2018 alone to a total of 82.1 billion euro. 75% of these expenses were made by foreign tourists.

A.3 Social-Cultural

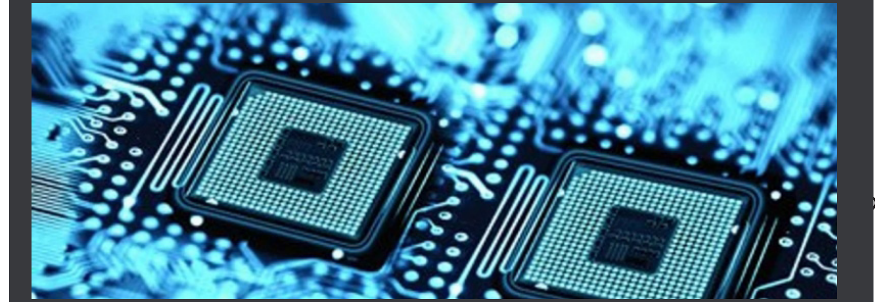
Media completion - Media completion will be the trend until 2020. More and more the digital world determines how we behave. This determines what kind of groceries we buy up to how we raise our children.

Involvement of smart city citizens - With the arrival of smart cities, citizens are becoming increasingly involved in the policy of these cities. Through local meetings, apps or other on-line platforms, both citizens and local businesses & initiatives are involved in the policy.
This is also linked to the increase in attention for safety when it comes to alerting people in the event of disasters or other emergency situations. Finding victims or perpetrators and sending warnings are often a necessity here.

A.4 Technological

Photonics - With the constant demand for expansion of the network, a network supported by light seems to be a possible solution. Photons can carry more data than electrons and can work faster and energy-saving.

Figure A.2: The use of light as a means of transportation of data



More Customization - As a community we increasingly want customization, it gives us the feeling of being understood and as if everything was made especially for us. This does not only apply to consumers, but also when it comes to purchases made by municipalities.

Passive VS active entertainment - There is a growing market for the mix between passive and active entertainment media. Both groups are increasingly moving towards each other. Examples of this are the film and gaming industry: films are becoming more interactive (you can make choices as a viewer), with the storyline becoming increasingly important in the gaming industry. People want to be entertained, but still want to remain involved in the process.

Growth IOT - IDC expects the so-called Internet of Things to grow to 7.1 trillion in 2020 (compared to 1.9 trillion in 2013). It is estimated here that over 34 billion devices will be connected to the internet in 2020 compared to 10 billion in 2015. (It should be mentioned that these estimates are on the cautious side and given the growth the estimates may be 10 times higher)

Figure A.3: Transparent 3D printed artwork

Transparent 3D printing - One of the applications that can be very relevant for applications within the light industry is 3d printing with transparent plastics.

A.5 Ecological

Attention for Fauna - With the increase in knowledge about animals that have their habitat in the cities, the attention for these animals is also growing. Conservation of habitats (despite the growth of the city) and the increasing space for nesting of birds are examples of this. When it comes to light, a shift can also be seen. More and more parks and other green areas are being kept intentionally dark, in addition, dimming lighting during night hours is becoming the new standard.

Sustainability discussions - Attention is paid to the increase in sustainable / green energy and the reduction of energy consumption as a whole. Hereby there is also increasing attention for sustainability at the local level. Smart city applications such as smart lighting / lamp posts can contribute to this.

Full transparency of organizations - Companies, but also governmental organizations of the government play with open cards. Mutual trust forms the basis for future collaborations.

Bringing Nature inside - The symbiosis between nature and city life is growing. Even in the largest cities people are looking for contact with nature. Municipalities are responding to this by an increase in the creation of green areas or vertical gardens. Furthermore, within architecture one tries to reduce the contrast between outside and inside.

Figure A.4: Biophilic Architecture

A.6 Political / Legislation

Reduction of light pollution - In the field of light pollution, increasingly stricter requirements are set. From 2010, annual revisions are written about the handbook for the relationship between light and dark. This describes standards for the economic sector (for example, greenhouse horticulture), but also for municipalities.

Energy reduction - 87% of Dutch municipalities have included energy reduction in their policy plan. The first step is often to determine the energy consumption per building, neighborhood or sector. The way in which energy reduction policy is implemented differs per municipality.

Appendix B: Light Calculations

To verify whether the luminaire meets the requirements of the Dutch municipalities, the light level has been calculated. These calculations are based on the lumens produced by the ring with LED units, because they provide ambient light and therefore determine the illuminance values on the street.

On the respective ring of the luminaire 12 will RGB LED units are mounted. These units, with dimensions of 40 X 40 mm, will be placed at a distance of 20 mm to leave room for the wiring.

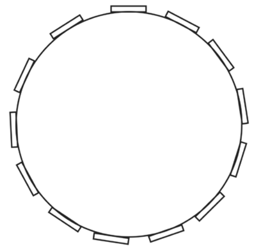


Figure B.1: Used light modules

These modules, which are IP65 classified (No damage if sprayed (12.5 l / min) at any angle), consist of 4 sets of RGB LEDs.

- 4 RGB LEDs
- 11.0 g
- IP65
- 120 ° beam angle

The different colored LED's have a different maximum luminous flux

- Red = 12 [lm]
- Green = 24 [lm]
- Blue = 15 [lm]

Total = 51 [lm]

The maximum luminous flux of one module is therefore 4 * 51 [lm]
The total lumen that the luminaire can deliver with 12 of these modules will be approximately 2448 lumens. However, in this scenario all LEDs are switched on at full power (255/255) and the light will therefore be white.

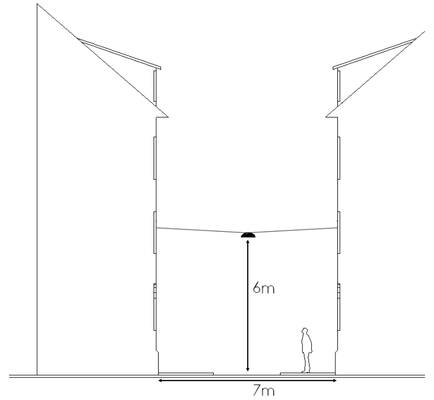
		φ
R	255	12
G	255	24
B	255	15
		51

		φ
R	255	12
G	248	23
B	193	11
		46

		φ
R	247	12
G	146	14
B	30	2
		28

The number of lumens that the luminaire can deliver in the colors warm white and orange will be 2208 (46 * 4 * 12) and 1344 (28 * 4 * 13).

Figure B.2: Installation Height



Pendant luminaires are mounted by many municipalities at a minimum height of 5.5 meters. The current luminaires in Tilburg are at a height of 6 meters and have a mutual distance of 20 meters. The average width of a street is 7 meters. These values will be used to calculate the light from the fixture.

In theory, 1344 lumens is enough light to illuminate such a street surface
*Ev (lx) = φv (lm) * A (m ^ 2)*
*Ev (lx) = φv (lm) * Road width * distance between luminaires*
*1456 / (20 * 7) = 10.4 lx on average.*

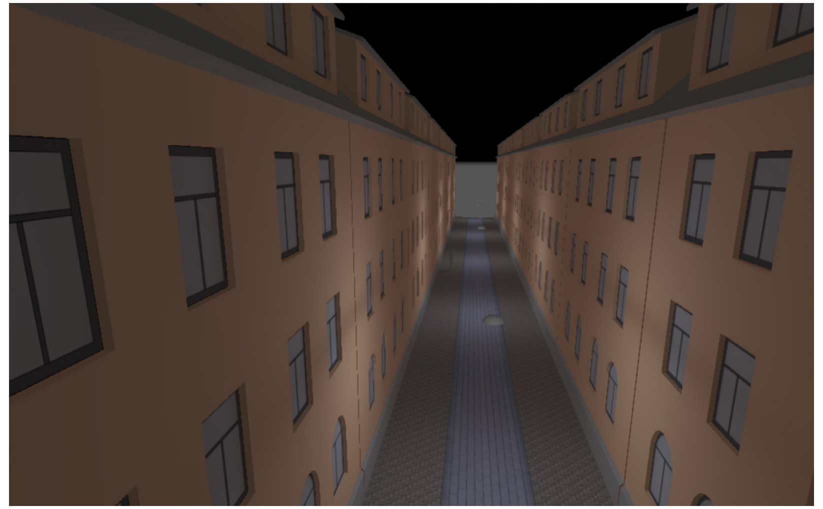


Figure B.4: Visual from Dialux Evo

However, in practice, parts of the facades are also exposed and light is lost because the ambient light is created by means of reflection.
To get a better picture of the luminous flux of the luminaire, a representation has been set up of such a street in Dialux, where models of the luminaire are used.
The results are as follows:

White light maximum power:

- Egem = 10.1 [lx]
- Emin = 3.5 [lx]
- Uv (Emin / Egem) = 0.35

Warm white light maximum power:

- Egem = 8.9 [lx]
- Emin = 2.9 [lx]
- Uv (Emin / Egem) = 0.33

Orange light maximum power:

- Egem = 5.7 [lx]
- Emin = 1.71 [lx]
- Uv (Emin / Egem) = 0.30

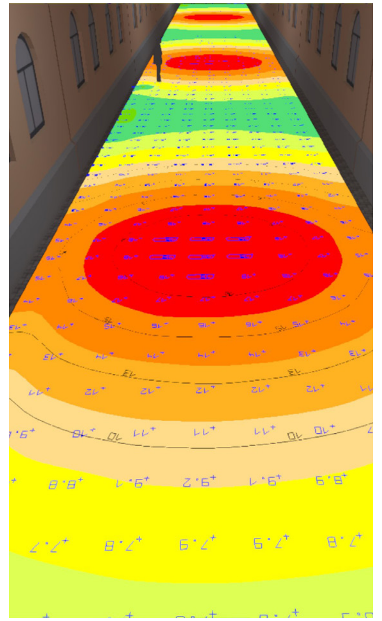


Figure B.3: Calculations in Dialux Evo

From this it can be concluded that, given that the luminaires are not suspended above a height of 6 meters and no further than 20 meters from each other, the luminaires meet the requirements for illuminating the street surface of types P6, P5 and P4.

Appendix C: Lighting Classes (NSVV)

C.1 Class Catering Area's

Parameter	Option	Description	WF*	Score
maximum permitted speed	Low	> 30 km/h	1	
	Very Low	< 30 km/h	0	0
Use Intensity	Extremely busy		1	
	Very Busy		0.5	
	Busy		0	
	Normal		-0.5	-0.5
	Quiet		-1	
	Very Quiet		-2	
Traffic Composition	All traffic		2	
	All vehicles	All vehicles except pedestrians	1.5	
	Bycicles & pedestrians		1	
	Only pedestrians		1	1
	Only Bycicles		0	
Parked Vehicles	Present		0.5	
	Absent		0	0
ambient luminance	High	this does not occur in the Netherlands	1	
	Average	(examples: shopping street, station are	0	0
	Low	normal' situation	-1	
Facial Recognition	Needed	additional quality criteria		Needed
	Not needed			
		Sum all weighing factors		0.5

*Weight Factor

6 - 0.5 = 5.5 -> P5

C.2 Class Shopping Area

Parameter	Option	Description	WF*	Score
maximum permitted speed	Low	> 30 km/h	1	
	Very Low	< 30 km/h	0	0
Use Intensity	Extremely busy		1	
	Very Busy		0.5	
	Busy		0	0
	Normal		-0.5	
	Quiet		-1	
	Very Quiet		-2	
Traffic Composition	All traffic		2	
	All vehicles	All vehicles except pedestrians	1.5	
	Bycicles & pedestrians		1	
	Only pedestrians		1	1
	Only Bycicles		0	
Parked Vehicles	Present		0.5	
	Absent		0	0
ambient luminance	High	this does not occur in the Netherlands	1	
	Average	(examples: shopping street, station are	0	0
	Low	normal' situation	-1	
Facial Recognition	Needed	additional quality criteria		Needed
	Not needed			
		Sum all weighing factors		1

*Weight Factor

6 - 1 = 5.0 -> P5

C.3 Class Residential Area

Parameter	Option	Description	WF*	Score
maximum permitted speed	Low	> 30 km/h	1	
	Very Low	< 30 km/h	0	0
Use Intensity	Extremely busy		1	
	Very Busy		0.5	
	Busy		0	
	Normal		-0.5	-0.5
	Quiet		-1	
	Very Quiet		-2	
Traffic Composition	All traffic		2	2
	All vehicles	All vehicles except pedestrians	1.5	
	Bycicles & pedestrians		1	
	Only pedestrians		1	
	Only Bycicles		0	
Parked Vehicles	Present		0.5	
	Absent		0	0
ambient luminance	High	this does not occur in the Netherlands	1	
	Average	(examples: shopping street, station are	0	
	Low	normal' situation	-1	-1
Facial Recognition	Needed	additional quality criteria		
	Not needed			Not needed
		Sum all weighing factors		0.5

*Weight Factor

6 - 0.5 = 5.5 -> P5

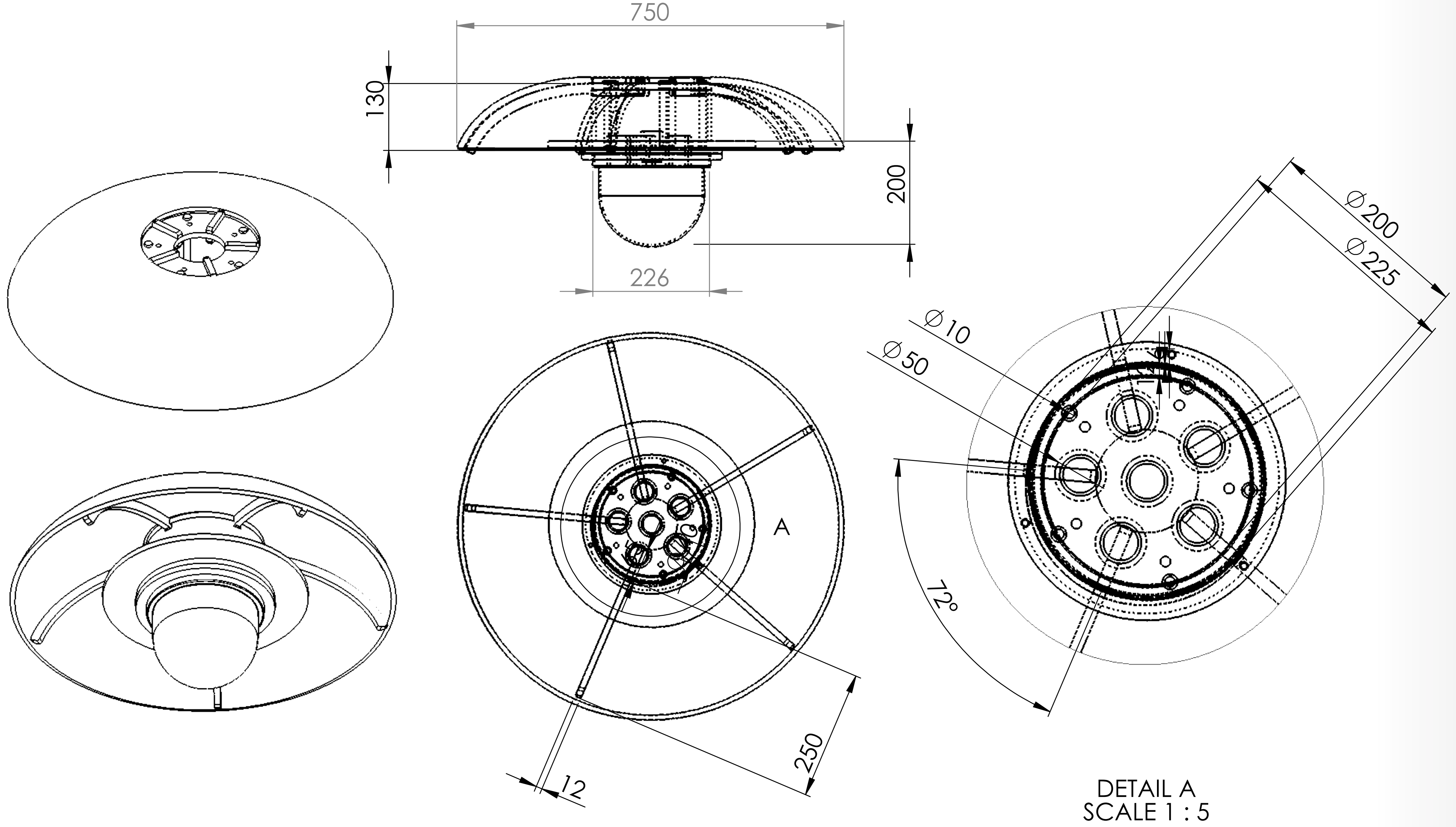
C.4 Class Carfree Residential Area

Parameter	Option	Description	WF*	Score
maximum permitted speed	Low	> 30 km/h	1	
	Very Low	< 30 km/h	0	0
Use Intensity	Extremely busy		1	
	Very Busy		0.5	
	Busy		0	
	Normal		-0.5	-0.5
	Quiet		-1	
	Very Quiet		-2	
Traffic Composition	All traffic		2	
	All vehicles	All vehicles except pedestrians	1.5	
	Bycicles & pedestrians		1	1
	Only pedestrians		1	
	Only Bycicles		0	
Parked Vehicles	Present		0.5	
	Absent		0	0
ambient luminance	High	this does not occur in the Netherlands	1	
	Average	(examples: shopping street, station are	0	
	Low	normal' situation	-1	-1
Facial Recognition	Needed	additional quality criteria		
	Not needed			Not needed
		Sum all weighing factors		-0.5

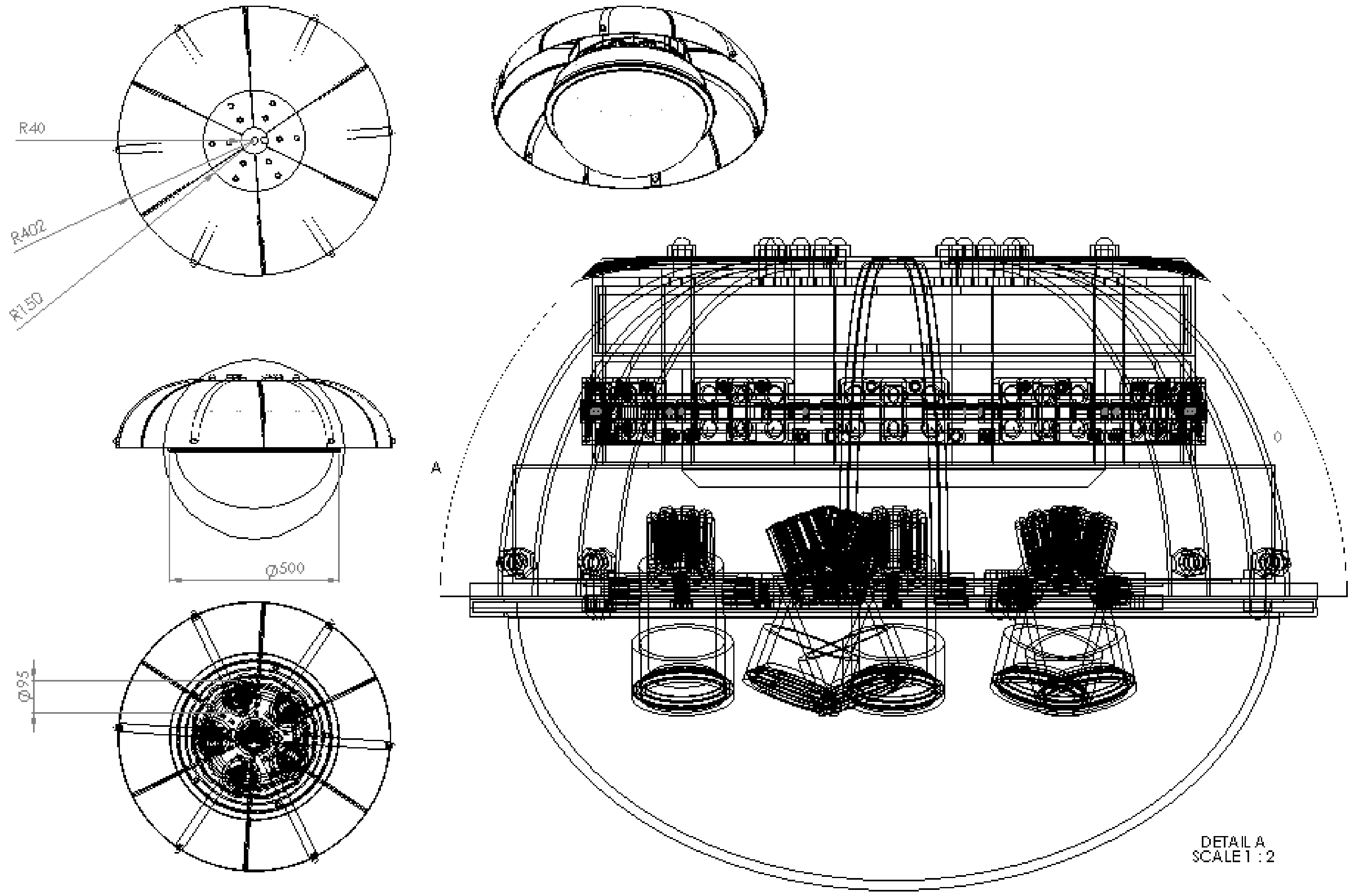
*Weight Factor

6 -- 0.5= 6.5 -> P6

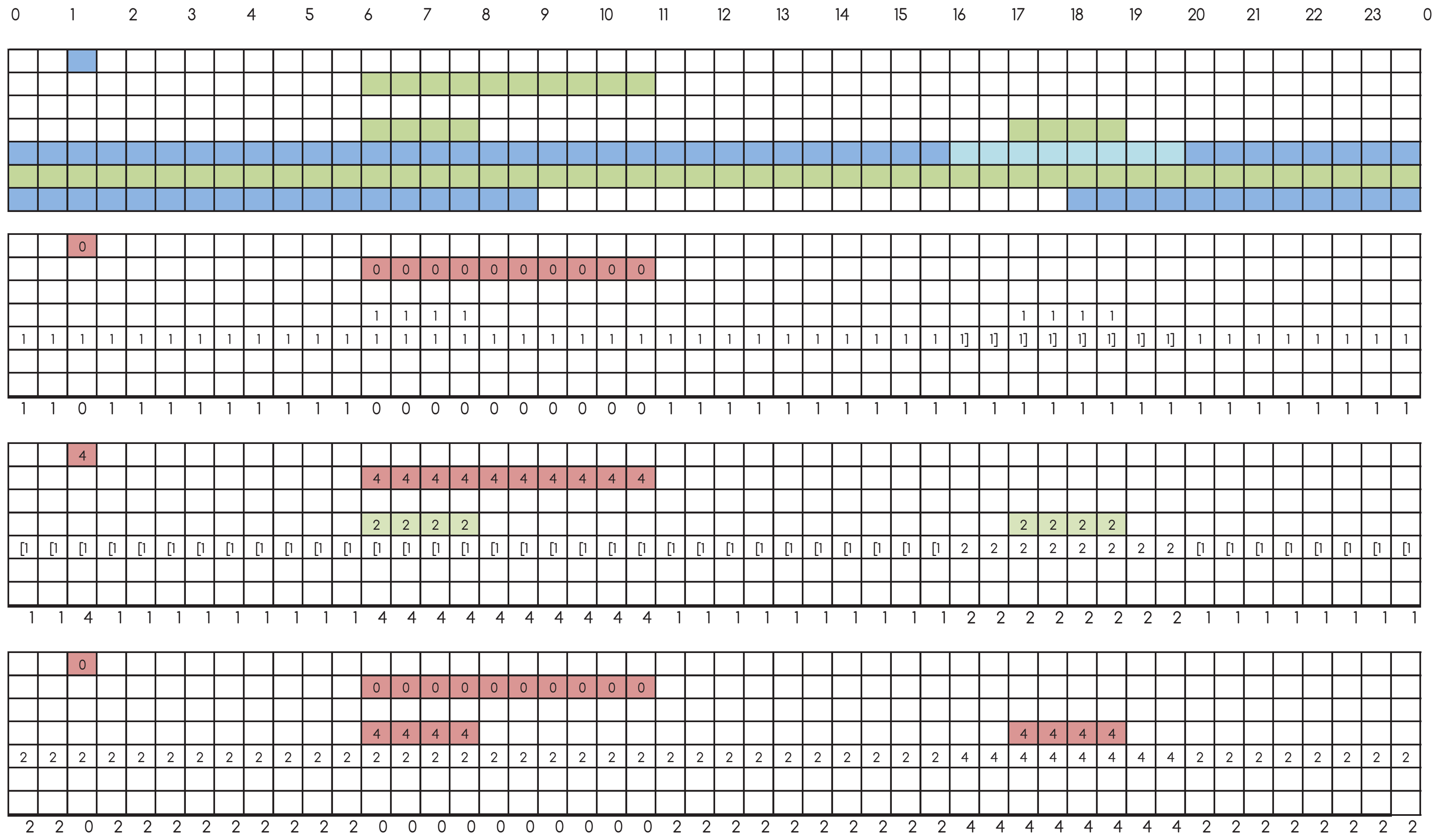
Appendix D: Technical Drawing Prototype

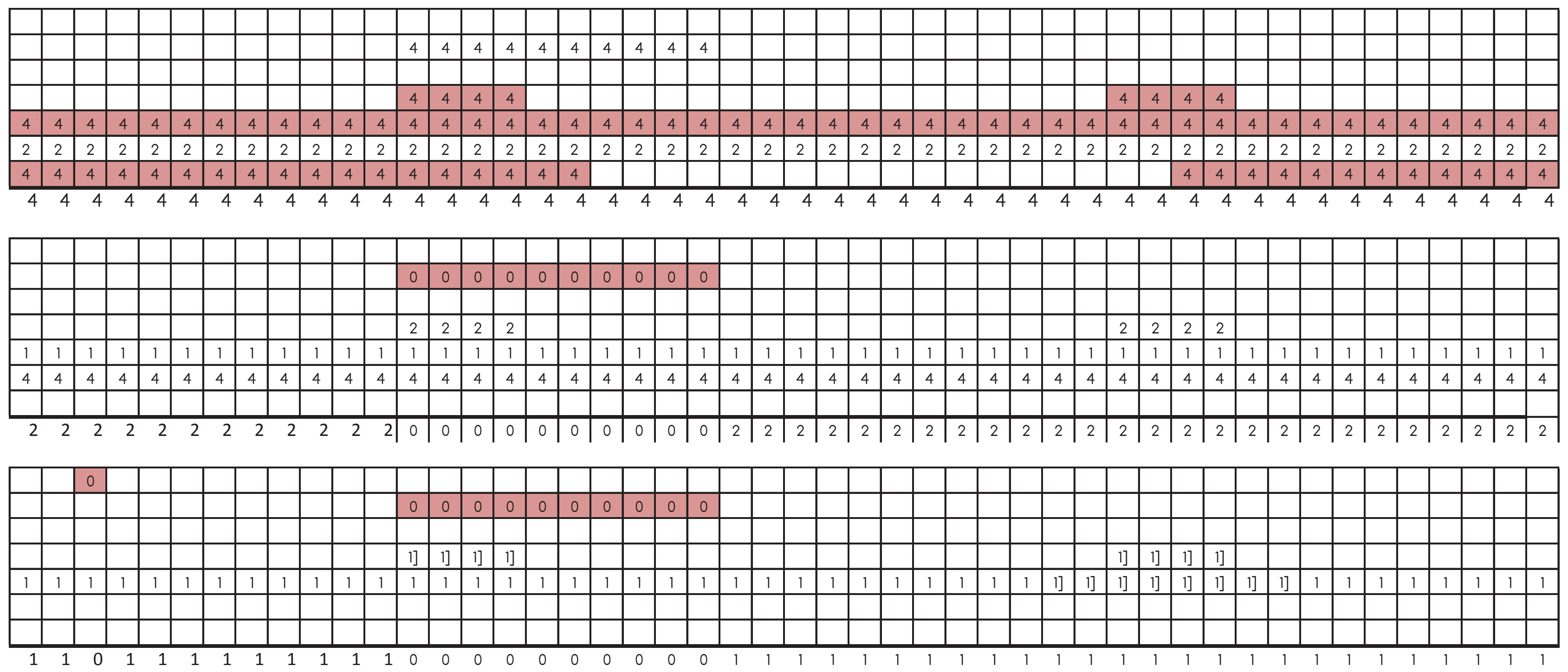


Appendix E: Technical Drawing Final Design



Appendix F: Light Scripts Data





	0		1		2		3		4		5		6		7		8		9		10		11	
Ambient - Brilliance	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Brightness	1	1	4	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4	4	4	4	1	1
Uniformity	2	2	0	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	2
Color Temperature	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Saturation	2	2	2	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	2	2
Dynamics	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1

	12		13		14		15		16		17		18		19		20		21		22		23		0
Ambient - Brilliance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Brightness	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	
Uniformity	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	
Color Temperature	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Saturation	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Dynamics	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Appendix G: Data Analysis

G.1 Data Sheet

	Fac. Expr.	Faces Pl.	Tense	Cozy	Lively	Formal	amb/bril.	bright.	N Colors	Temp	Satur.	Dynamics	Cap
C	7	4	6	1	2	6	0	4	0	0	0	0	1
C	7	6	5	3	3	4	0	4	0	0	0	0	1
C	6	2	6	1	5	1	0	4	0	0	0	0	1
C	7	3	6	2	2	5	0	4	0	0	0	0	1
C	5	2	4	1	3	7	0	4	0	0	0	0	1
C	4	4	7	1	2	5	0	4	0	0	0	0	1
C	7	4	6	2	2	6	0	4	0	0	0	0	1
C	7	5	6	3	3	6	0	4	0	0	0	0	1
D	7	7	3	7	2	3	0	4	0	2	0	0	1
D	7	7	3	4	3	5	0	4	1	2	0	0	1
D	7	7	3	5	2	4	0	4	1	2	0	0	1
D	6	6	4	6	2	1	0	4	1	2	0	0	1
D	7	5	1	6	3	3	0	4	1	2	0	0	1
D	7	7	3	7	4	3	0	4	1	2	0	0	1
D	5	6	4	5	3	3	0	4	1	2	0	0	1
D	6	7	2	4	2	4	0	4	1	2	0	0	1
D	5	7	2	7	3	2	0	4	1	2	0	0	1
D	7	6	3	7	1	4	0	4	1	2	0	0	1
A1	4	5	2	5	4	2	2	2	2	2	2	1	1
A1	7	6	2	3	4	1	2	2	2	2	2	1	1
A1	5	4	4	2	6	1	2	2	2	2	2	1	1
A1	5	5	3	6	4	3	2	2	2	2	2	1	1
A1	3	3	2	5	4	2	2	2	2	2	2	1	1
A1	4	5	3	7	5	2	2	2	2	2	2	1	1
A1	4	5	1	5	4	3	2	2	2	2	2	1	1
B1	5	4	3	4	3	2	1	1	3	2	1	1	1
B1	6	7	1	7	4	2	1	1	3	2	1	1	1
B1	5	4	2	3	3	4	1	1	3	2	1	1	1
B1	4	5	1	2	4	5	1	1	3	2	1	1	1
B1	6	3	3	4	2	2	1	1	3	2	1	1	1
B1	5	4	4	4	5	1	1	1	3	2	1	1	1
E1	3	3	6	3	7	2	2	3	3	0	2	2	1
E1	5	6	5	7	7	2	2	3	3	0	2	2	1
E1	5	4	3	5	5	2	2	3	3	0	2	2	1
E1	4	6	5	5	5	3	2	3	3	0	2	2	1
E1	3	3	6	3	6	1	2	3	3	0	2	2	1
E1	3	3	7	2	7	4	2	3	3	0	2	2	1
F1	2	4	6	3	7	2	2	3	3	0	2	2	1
F1	3	3	3	3	7	1	3	3	3	1	4	4	1
F1	5	5	4	3	6	3	3	3	3	1	4	4	1
F1	3	4	2	4	5	2	3	3	3	1	4	4	1
F1	2	3	3	5	7	3	3	3	3	1	4	4	1
F1	4	2	3	2	7	1	3	3	3	1	4	4	1
X1	2	2	7	1	7	3	4	4	1	0	4	4	1
X1	3	5	3	1	7	2	4	4	1	0	4	4	1
X1	5	4	5	4	6	2	4	4	1	0	4	4	1
X1	5	2	2	3	4	6	4	4	1	0	4	4	1
X1	2	4	7	3	7	2	4	4	1	0	4	4	1
X1	1	2	7	1	7	3	4	4	1	0	4	4	1
Y1	2	3	2	5	6	2	4	2	2	2	1	3	1
Y1	5	4	4	5	5	2	4	2	2	2	1	3	1
Y1	4	6	2	7	7	3	4	2	2	2	1	3	1
Y1	3	3	2	6	7	2	4	2	2	2	1	3	1
Y1	2	2	3	5	4	3	4	2	2	2	1	3	1
Y1	2	3	2	4	6	2	4	2	2	2	1	3	1
Y1	3	3	1	5	6	4	4	2	2	2	1	3	1
A2	6	5	2	5	3	3	2	2	2	2	2	1	0
A2	6	6	4	4	2	3	2	2	2	2	2	1	0
A2	6	6	3	5	4	2	2	2	2	2	2	1	0
A2	5	7	2	5	2	4	2	2	2	2	2	1	0
A2	5	5	3	7	3	1	2	2	2	2	2	1	0
B2	7	6	2	4	3	2	1	1	3	2	1	1	0
B2	6	6	1	3	2	1	1	1	3	2	1	1	0
B2	6	5	2	5	3	3	1	1	3	2	1	1	0
B2	5	4	2	4	6	2	1	1	3	2	1	1	0
B2	7	7	4	2	3	5	1	1	3	2	1	1	0
B2	7	7	1	4	2	2	1	1	3	2	1	1	0
B2	5	6	3	3	3	1	1	1	3	2	1	1	0
E2	4	4	5	3	5	3	2	3	3	0	2	2	0
E2	3	2	6	5	4	5	2	3	3	0	2	2	0
E2	4	3	5	2	5	2	2	3	3	0	2	2	0
E2	4	4	4	3	5	3	2	3	3	0	2	2	0
E2	2	3	3	3	7	3	2	3	3	0	2	2	0
F2	5	3	3	3	6	3	3	3	3	1	4	4	0
F2	5	3	3	4	6	2	3	3	3	1	4	4	0
F2	4	3	6	3	7	3	3	3	3	1	4	4	0
F2	6	6	2	2	5	4	3	3	3	1	4	4	0
F2	7	5	3	3	7	3	3	3	3	1	4	4	0
F2	3	2	4	5	7	4	3	3	3	1	4	4	0
F2	5	2	3	2	6	3	3	3	3	1	4	4	0
X2	4	3	6	1	5	4	4	4	0	0	4	4	0
X2	4	4	5	2	4	1	4	4	0	0	4	4	0
X2	6	3	7	2	5	3	4	4	0	0	4	4	0
X2	3	4	6	3	5	5	4	4	0	0	4	4	0
X2	4	3	3	2	6	4	4	4	0	0	4	4	0
X2	4	3	6	2	5	4	4	4	0	0	4	4	0
Y2	3	5	2	5	5	2	4	2	2	2	1	3	0
Y2	3	6	4	4	4	2	4	2	2	2	1	3	0
Y2	4	5	2	5	6	1	4	2	2	2	1	3	0
Y2	5	7	2	6	5	3	4	2	2	2	1	3	0
Y2	5	3	1	5	4	2	4	2	2	2	1	3	0
Y2	4	5	2	5	6	2	4	2	2	2	1	3	0

G.2 Data Correlation

Correlations

		Facial_Recognition	Face_Pleasant	Tenseness	Coziness	Livelyness	Detachment	Ambient_Brilliance	Brightness	N_Colors	Color_Temperature	Saturation	Dynamics
Facial_Recognition	Pearson Correlation	1	,555**	-,180	,116	-,670**	,202	-,639**	,014	-,211*	,250*	-,438**	-,586**
	Sig. (2-tailed)		,000	,086	,271	,000	,053	,000	,894	,044	,016	,000	,000
	N	92	92	92	92	92	92	92	92	92	92	92	92
Face_Pleasant	Pearson Correlation	,555**	1	-,368**	,467**	-,491**	-,057	-,414**	-,176	-,011	,501**	-,443**	-,491**
	Sig. (2-tailed)	,000		,000	,000	,000	,589	,000	,093	,915	,000	,000	,000
	N	92	92	92	92	92	92	92	92	92	92	92	92
Tenseness	Pearson Correlation	-,180	-,368**	1	-,514**	,186	,231*	,008	,561**	-,355**	-,756**	,215*	,113
	Sig. (2-tailed)	,086	,000		,000	,076	,027	,942	,000	,001	,000	,039	,285
	N	92	92	92	92	92	92	92	92	92	92	92	92
Coziness	Pearson Correlation	,116	,467**	-,514**	1	-,161	-,268**	-,088	-,277**	,190	,612**	-,343**	-,242*
	Sig. (2-tailed)	,271	,000	,000		,125	,010	,404	,007	,070	,000	,001	,020
	N	92	92	92	92	92	92	92	92	92	92	92	92
Livelyness	Pearson Correlation	-,670**	-,491**	,186	-,161	1	-,301**	,683**	,053	,324**	-,338**	,629**	,747**
	Sig. (2-tailed)	,000	,000	,076	,125		,004	,000	,615	,002	,001	,000	,000
	N	92	92	92	92	92	92	92	92	92	92	92	92
Detachment	Pearson Correlation	,202	-,057	,231*	-,268**	-,301**	1	-,236*	,379**	-,405**	-,311**	-,131	-,164
	Sig. (2-tailed)	,053	,589	,027	,010	,004		,023	,000	,000	,003	,213	,117
	N	92	92	92	92	92	92	92	92	92	92	92	92
Ambient_Brilliance	Pearson Correlation	-,639**	-,414**	,008	-,088	,683**	-,236*	1	-,064	,123	-,141	,687**	,913**
	Sig. (2-tailed)	,000	,000	,942	,404	,000	,023		,545	,243	,181	,000	,000
	N	92	92	92	92	92	92	92	92	92	92	92	92
Brightness	Pearson Correlation	,014	-,176	,561**	-,277**	,053	,379**	-,064	1	-,683**	-,646**	,170	,090
	Sig. (2-tailed)	,894	,093	,000	,007	,615	,000	,545		,000	,000	,105	,396
	N	92	92	92	92	92	92	92	92	92	92	92	92
N_Colors	Pearson Correlation	-,211*	-,011	-,355**	,190	,324**	-,405**	,123	-,683**	1	,274**	,190	,192
	Sig. (2-tailed)	,044	,915	,001	,070	,002	,000	,243	,000		,008	,069	,067
	N	92	92	92	92	92	92	92	92	92	92	92	92
Color_Temperature	Pearson Correlation	,250*	,501**	-,756**	,612**	-,338**	-,311**	-,141	-,646**	,274**	1	-,424**	-,317**
	Sig. (2-tailed)	,016	,000	,000	,000	,001	,003	,181	,000	,008		,000	,002
	N	92	92	92	92	92	92	92	92	92	92	92	92
Saturation	Pearson Correlation	-,438**	-,443**	,215*	-,343**	,629**	-,131	,687**	,170	,190	-,424**	1	,845**
	Sig. (2-tailed)	,000	,000	,039	,001	,000	,213	,000	,105	,069	,000		,000
	N	92	92	92	92	92	92	92	92	92	92	92	92
Dynamics	Pearson Correlation	-,586**	-,491**	,113	-,242*	,747**	-,164	,913**	,090	,192	-,317**	,845**	1
	Sig. (2-tailed)	,000	,000	,285	,020	,000	,117	,000	,396	,067	,002	,000	
	N	92	92	92	92	92	92	92	92	92	92	92	92

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

G.3 Linear Multivariate Test Cover

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Facial_Recognition	18,057[a]	1	18,057	9,809	,003
	Face_Pleasant	5,616[b]	1	5,616	2,737	,102
	Tenseness	,063[c]	1	,063	,021	,886
	Coziness	2,411[d]	1	2,411	,996	,322
	Livelyness	12,928[e]	1	12,928	5,819	,018
	Detachment	2,352[f]	1	2,352	1,851	,178
Intercept	Facial_Recognition	1356,867	1	1356,867	737,105	,000
	Face_Pleasant	1302,319	1	1302,319	634,695	,000
	Tenseness	863,955	1	863,955	282,813	,000
	Coziness	1078,735	1	1078,735	445,591	,000
	Livelyness	1870,333	1	1870,333	841,912	,000
	Detachment	499,650	1	499,650	393,230	,000
Cap	Facial_Recognition	18,057	1	18,057	9,809	,003
	Face_Pleasant	5,616	1	5,616	2,737	,102
	Tenseness	,063	1	,063	,021	,886
	Coziness	2,411	1	2,411	,996	,322
	Livelyness	12,928	1	12,928	5,819	,018
	Detachment	2,352	1	2,352	1,851	,178
Error	Facial_Recognition	132,538	72	1,841		

G.4 Data Regression

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2,787	1,226		2,273	,026
	Ambient_Brilliance	,020	,302	,019	,066	,948
	Saturation	,122	,188	,114	,653	,516
	Dynamics	-,487	,370	-,469	-1,317	,191
	Brightness	,371	,263	,252	1,407	,163
	Color_Temperature	,923	,208	,544	4,431	,000
	N_Colors	,109	,216	,077	,504	,615

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2,960	1,187		-2,494	,015
	Ambient_Brilliance	1,128	,292	,960	3,863	,000
	Saturation	-,152	,181	-,129	-,839	,404
	Dynamics	-1,108	,358	-,969	-3,098	,003
	Brightness	1,261	,255	,777	4,945	,000
	Color_Temperature	1,341	,201	,718	6,655	,000
	N_Colors	,958	,209	,616	4,573	,000

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7,828	1,111		7,046	,000
	Ambient_Brilliance	-1,286	,273	-1,189	-4,706	,000
	Saturation	,153	,170	,140	,900	,371
	Dynamics	,614	,335	,584	1,835	,070
	Brightness	-,423	,239	-,283	-1,772	,080
	Color_Temperature	,471	,189	,274	2,496	,015
	N_Colors	-,675	,196	-,471	-3,443	,001

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,293	1,003		,292	,771
	Ambient_Brilliance	,713	,247	,604	2,892	,005
	Saturation	-,123	,153	-,103	-,803	,424
	Dynamics	,099	,302	,086	,329	,743
	Brightness	,568	,215	,348	2,634	,010
	Color_Temperature	-,365	,170	-,194	-2,142	,035
	N_Colors	,851	,177	,544	4,809	,000

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5,695	1,114		5,110	,000
	Ambient_Brilliance	,130	,274	,108	,473	,638
	Saturation	,053	,170	,044	,313	,755
	Dynamics	-,284	,336	-,244	-,846	,400
	Brightness	,028	,239	,017	,118	,907
	Color_Temperature	-1,440	,189	-,758	-7,608	,000
	N_Colors	-,176	,197	-,111	-,893	,374

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5,523	1,181		4,678	,000
	Ambient_Brilliance	-,607	,290	-,646	-2,090	,040
	Saturation	-,210	,181	-,221	-1,161	,249
	Dynamics	,566	,356	,619	1,591	,115
	Brightness	-,206	,254	-,159	-,813	,419
	Color_Temperature	-,424	,200	-,284	-2,114	,037
	N_Colors	-,538	,208	-,432	-2,583	,012

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Appendix I: Image References

Chapter 1:
1.1, 1.2, & 1.5 - 1.13 are own creation

1.3 Gemeente Rotterdam (2009)
1.14 Neil S.GittingsJames L.Fozard, Age related changes in visual acuity
1.15 Ir. H. Hahn (1946)
1.16 Marina Difesa (2011)
1.17 Readers Digest
1.18 Helvar Lighting Controls

Chapter 2:

2.2 Bellerophon I Gemological laboratory analysis
2.3 Wikimedia Commons.
2.4 Patreek Joshi
2.7 Erco Handbook of Lighting Design
2.8 Erco Handbook of Lighting Design

Chapter 3:
3.4, 3.6 & 3.7 are own creation

3.1 Waveform Lighting
3.3 NASA ISS
3.5 Warren Photographic
3.8 Peggy2012CREATIVELENZ
3.9 Greg Johnson
3.10 Den belitsky
3.11 Brian Webb (2006)
3.12 Unknown
3.13 James McDaniel (2010)
3.14 Maja Petric
3.15 James McDaniel (2011)
3.16 James McDaniel

Chapter 4:

4.1 ERCO
4.2 ERCO
4.3 ERCO
4.4 ShutterStock

Chapter 5:

5.1 Erco Handbook of Lighting Design
5.3 Ariane, Discover out loud (2015)
5.4 Lumimore
5.5 Creative Commons
5.6 Unknown
5.7 Erco Handbook of Lighting Design
5.8 Wikimedia Commons
5.9 Erco Handbook of Lighting Design
5.10 Erco Handbook of Lighting Design
5.11 Lunis (2014)
5.12 Erco Handbook of Lighting Design
5.13 Hawk Galleries
5.14 Optics Balzers
5.15 Elekpro (2015)
5.16 Deon Rogers (2019)
5.17 Uknown
5.18 John Lewis and Partners (2017)
5.19 Traxon (2015)
5.20 UNEX
5.21 Unknown (1929)
5.22 Willemskwartier Nijmegen (2007)

Chapter 6:
6.1 & 6.3 are own creation

6.2 Unknown
6.4 Unknown

Chapter 7:

7.1 Maas-Jan (2009)
7.2 Philips Lighting
7.3 Gemeente Amsterdam
7.4 Unknown
7.5 IndiaMart (2011)
7.6 Todd Carlson (2003)
7.7 NAM, Philips

Chapter 8:
8.1 & 8.2 are own creation

Chapter 9:
9.9, 9.11, 9.18, 9.30 & 9.31 are own creation

9.1 Corinne
9.2 IPV Delft
9.3 IPV Delft
9.4 Hogro
9.5 IPV Delft
9.6 IPV Delft
9.7 Gemeente Rotterdam
9.8 Alex Bussenius (2016)
9.10 irina van aalst (2011)
9.12 Gemeente Rotterdam
9.13 Roel Dijkstra Fotografie
9.14 Studio Hans Wilschut (2011)
9.15 Gemeente Rotterdam
9.16 Gemeente Rotterdam
9.17 Gemeente Rotterdam
9.19 Gemeente Amsterdam
9.20 Gemeente Amsterdam
9.21 Gemeente Amsterdam
9.22 Gemeente Amsterdam
9.23 Gemeente Amsterdam
9.24 Gemeente Amsterdam
9.25 Joris Buijs (2012)
9.26 Lightronics (2018)
9.27 Camiel van de Wijdeven (2018)
9.28 Gemeente Tilburg (2016)
9.29 Freddie de Roeck (2016)

Chapter 10:
10.1 is own creation

Chapter 11:
11.1 - 11.31 are own creation

Chapter 13:
13.1, 13.3, 13.7, 13.8, 13.12-13.17 are own creation

13.2 Unknown
13.4 Regionaal Archief Tilburg
13.5 CarnavalStichting Kruikenstad
13.6 Hoge Raad van Adel
13.9 Unknown
13.10 Javana Graphics

Chapter 14:

14.1 Karen Andrews (2011)
14.2 Chelsea Brown
14.3 Jan Bouwhuis (2017)
14.4 AF Lighting
14.5 TILT Light Designers
14.6 Philips Ligthing
14.7 Marc Dumas
14.8 Unknown
14.9 Ines Esnal
14.10 Coen ten Hagen (2018)
14.11 Altitude Services

Chapter 15
15.1-15.21 are own creation

Chapter 16:
16.1 - 16.12 are own creation

Chapter 17
17.1, 17.3- 17.5 are own creation

17.2 Wikimedia Commons.

Chapter 18
18.1-18.10, 18.12 are own creation

18.11 Think Brink Fotografie (2018)

Chapter 19:
19.1 - 19.10 are own creation

Chapter 20:
20.1 is own creation

Chapter 21:
21.1- 21-8 are own creation

Appendix A
A.1 明報專訊 (2016)
A.2 Unknown
A.3 Neri Oxman (2019)
A.4 VORM

Appendix B

B.2 - B.4 are own creation

B1 Polumics

Appendix J: References Trend Analysis

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