

ULRIKE BRANDI

# **LIGHT NATURE ARCHITECTURE**

A Guide to Holistic  
Lighting Design

BIRKHÄUSER

- 7 **Preface by Ian Ritchie**
- 8 **Introduction**

## **NATURE**

- 10 **Learning from Nature: Understanding and Integrating Daylight**
- 12 Phenomena: The Illumination of the Daytime Sky
- 14 Background: The Special Nature of Daylight
- 16 Practical Knowledge: Illumination Levels, Sun Positions, Daylight Factors
- 22 Implementation: Daylight and Artificial Light at Trident Park, Malta

## **EVOLUTION**

- 24 **Evolution and Innovation: The Development of the Eye**
- 26 Phenomena: How Do Gleam and Sparkle Occur?
- 27 Background: Development and Structure of the Human Eye
- 30 Practical Knowledge: Observation, Experimentation, and Design of Light: A Design Methodology
- 34 Implementation: Variants of a Light Theme at the Elbphilharmonie Hamburg

## **PERCEPTION**

- 36 **Three Things Pertain to Good Lighting: Lighting, Space, Perception**
- 38 Phenomena: How Are Shadows Formed?
- 40 Background: The Interplay of Eye and Brain: Neurological and Psychological Aspects of Perception
- 43 Practical Knowledge: The Art of Highlighting or Leaving in the Dark
- 46 Implementation: Open Safe Havens: Light and Space at the Dutch Holocaust Memorial of Names, Amsterdam

## **CULTURE**

- 48 **Seeing the Light rather than the Luminaire**
- 50 Phenomena: What Is the Halo Effect?
- 52 Background: How Lighting Preferences Develop within Various Cultures
- 57 Practical Knowledge: Heeding the Location and Listening to Its Users
- 60 Implementation: Differentiated Lighting Intentions on the Elbphilharmonie Plaza, Hamburg

## **SUSTAINABILITY**

- 62 **The Art of Choosing the Right Light Source**
- 64 Phenomena: How Artificial Light Is Created: Thermal Radiators, Discharge Lamps, Chemical Light Generation
- 66 Background Knowledge: Sustainability Comprises Ecological, Economical, and Social Aspects
- 70 Practical Knowledge: How to Plan with Sustainable Light
- 76 Implementation: The Shop Window Facing Outward: Oldenburg State Theater

## **HEALTH**

- 78 **The Biological Effect of Light**
- 80 Phenomena: Semitransparency and Opacity: A Ping Pong of Light
- 82 Background: How Does Inner Clock Work?
- 85 Practical Knowledge: Healthy Light for Living and Working
- 88 Implementation: How Good Lighting Helps Staying Healthy: Continuous Operation and Shift Duty at Elmshorn Control Center

## **DARKNESS**

- 90 **How Much Light Is Too Much?**
- 92 Phenomena: How Does the Aurora Borealis Occur?
- 94 Background Knowledge: We Need Shade during the Day and Darkness at Night
- 99 Practical Knowledge: Light Pollution and Lurking Dangers: Designing Darkness Using Lighting Master Plans
- 104 Implementation: Low Light Emission as a Concept: Mall of the Netherlands, Leidschendam

## **DYNAMICS**

- 106 **Controlling and Dimming Light Scenes**
- 108 Phenomena: The Vibrant Sky: Wavelengths in White Sunlight
- 110 Background Knowledge: Why Control Light?
- 112 Practical Knowledge: Light Scenes, Integrated Circuits, and Control Charts: A Playground for Technophiles
- 116 Implementation: The Sky Is Aboard: Daylight Moods on the ICE 4 Train

## **COMPOSITION**

- 118 **It's All in the Mix**
- 120 Phenomena: Absorption, Reflection, and Transmission
- 122 Background Knowledge: Variation Stimulates Light Preferences
- 126 Practical Knowledge: Choice of Lighting Instruments
- 128 Implementation: Multifunctional as if in a Living Room: The Light at Centraal Station, Rotterdam

# **ATMOSPHERE, MAGIC**

- 130 **Making the Immaterial Tangible**
- 132 Phenomena: Expansion of Light in Time and Space
- 135 Background Knowledge: Magic: When Space, Light, and Emotions Are in Balance
- 137 Practical Knowledge: Security, Curiosity, Tranquility: Light Concepts and Collective Emotional Fundamental Experiences
- 140 Implementation: Two Poles of the Atmosphere: The Royal Academy of Music, London

- 142 **Acknowledgements**
- 144 **Glossary**
- 156 **Biography**
- 158 **Catalogue raisonné**
- 159 **Further Reading**



## Preface

Philosophers, scientists and artists have always sought to remove the veils from our minds, allowing them to illuminate our world. The sunbeam breaking through clouds of obscurity provides an emotional metaphor for the moments of brilliant human insight that have danced through centuries.

Dioptrics, one of the most delightful of sciences, has allowed us to explore the future through the infinitesimal, and the past further back in time than ever before, through the agency of the James Webb telescope's segmented "eye" that observes the expanding universe. We experience the world here—and out there—through light, and light conjures the atmospheres of our emotional existence, from the 480nm wavelength in the morning sky that triggers our biorhythms to the romantic candle-lit dinner.

But what of darkness itself, without which no discourse on light is possible? It brings every other sense we have to the fore, and it makes us pause—to reflect, to sleep. It is a reminder that our bodies do not function simply to allow us to "see" our way through the world.

We have so illuminated our physical environment that experiencing darkness outdoors is now almost impossible anywhere close to human habitation. We have lost touch with the cosmos, our place within it and rotation through it, and perhaps in many ways with ourselves. The cosmos is all darkness lit with glimmers of flickering light: stars like dust. And dust, invisible in the air until a crepuscular ray or light beam turns it into a radiant theatrical event.

One can still write or draw at a desk with one candle (though not for long), and watch the wind's kinetic dance in its flame, so do we always need the equivalent of three hundred static candles?

*Homo sapiens* has created environmental crises, and now it is surely time for more of the sapience.

Perhaps we need to learn to stop making so much and to dream more, to enjoy dwelling a little longer in the twilight so that we can better appreciate darkness and light, perceive ourselves anew and gain insights to help make our future habitat healthier.

## Introduction

The best way to learn is from natural light. Nature's light phenomena surround us so elementally that they are often not even consciously perceived. Just a few basic principles can create an atmosphere, either individually or in combination.

Lighting design is the design of our living environment. It does not take place detached from social and ecological context, and that is why I would like to stress the current significance of lighting design: designing the world using light in a pleasant and diverse manner is astonishingly compatible with a careful handling of our planet. For this reason, the important topics of nature, evolution, perception, culture, sustainability, health, darkness, dynamics, composition and aesthetics/magic are closely interwoven in ten chapters.

My approach to lighting design as formulated here expresses the multidisciplinary aspects of the field: planning teams in architecture and urban design have also been working interdisciplinarily on the complex building tasks of our time, and I have repeatedly experienced that within these teams, clever lighting design can make a substantial contribution to averting the looming climate catastrophe.

Moreover, I am inspired by thought models of physics that try to reduce explanations to a few basic rules. It gives me pleasure to demonstrate that so many multivariant atmospheres of light can be created from a simple construction kit of a few laws of physics. The chemical elements—put in wonderful order in the periodic table—have sufficed as building blocks for millions of organic and inorganic substances after all. It is similar with light.

Daylight as a participant and benchmark opens up the common understanding of lighting contexts, design principles, and liberties. The evolution of the eye, the conscious view of light itself, sustainability by optimized natural light in the building, human-centered light, the balance between light and darkness at night, and intelligent lighting control—all these topics define the profession of lighting designers. I offer strategies which combine diverse types of light into beautiful compositions, thus creating atmosphere and, in the best case, a poetry of light.

Each of the ten main topics commences with the juxtaposition of a natural light situation and its implementation in one of my projects for which the respective lighting principle was the inspiration. In addition, I give a description of the physical phenomena and offer background and practical knowledge on the respective key topics. In doing so, I combine new findings from other disciplines such as neurology, medicine, biology, and environmental protection with information that is directly useful for planning. This structure allows for reading the book not only front to back, but also to follow only one thread as needed, to simply look up certain contexts or practical tips and, of course, to closely study the photographs with regard to the effects of light. In any case, it is my wish to give all those interested in lighting the inspiration for designs and ideas for further reading and to try them out.



# NATURE

## Learning from Nature: Understanding and Integrating Daylight

Nature, the great system in which we live and operate, is the origin of my reflections. It is the instructor for good lighting design. That is why I devote myself to natural light. Its main components are daylight and nightlight. Studying natural light phenomena is the starting point of any lighting design. Here, we will find physical laws as well as their aesthetic effects and can integrate the gained knowledge into our projects.

- The blue sky over St. Peter-Ording.
- The light ceiling at Trident Park, Malta.

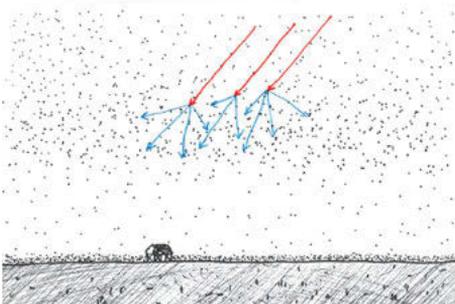
# The Illumination of the Daytime Sky

## Blue Sky: Diffusion in Gas and Aerosols

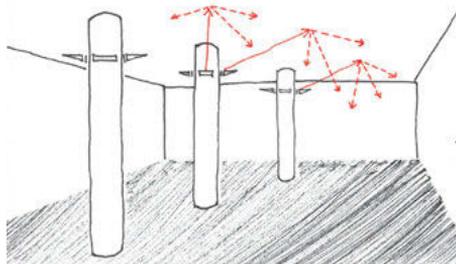
The bright blue sky arises because the parallel rays of the sun collide with air molecules and aerosols such as dust, smoke, and water particles, which they reflect and refract. As a result, the light originally coming only from the direction of the sun is distributed over the entire surface of the sky. It reaches our eye and illuminates objects with many detours and from all directions. On the moon, which has no atmosphere, astronauts see only the black universe rather than a blue sky.

## The Light Ceiling: Diffuse Reflection from Matte Surfaces

Indirect light creates visual depth over a white ceiling when the distribution of light is soft and even and the surface of the ceiling is matte and reflects in a diffuse manner.



— Refraction of light and its diffusion on air particles in the atmosphere.



— Scattering of light rays on a matte surface.

**“The challenge of contemporary daylighting design is to explore the full potential of design from the inside out and the outside in; to mediate space and surface; and to celebrate practical performance benefits as well as aesthetic, experiential, and ecological dimensions.”<sup>1</sup> —  
Mary Guzowski, 2018**

# The Special Nature of Daylight

Natural light occurs in the rhythm between bright day and dark night. The light reveals, as it does in many other phenomena, the richness and abundance of nature: its quality, its quantity, and its obstinacy. *Obstinacy* does not describe daylight in the sense of human temperament but rather in the sense of dynamism, of unpredictability.

## Spectrum, Color Rendering

The continuous spectrum of radiation visible to humans contains every wavelength from about 400 to about 780 nanometers; we see it in the soft transition in the rainbow and also in the spectrometer. In contrast to this, the discontinuous spectrum of LEDs or fluorescent lighting features individual incoherent color peaks. Like incandescent light, daylight has the best color rendering of Ra 100. There are LEDs that have a color rendering index of Ra 98 but most offices or flats are lit by LEDs with a color rendering index of only Ra 80. While the requirements for cameras and screens increase continuously, we deprive ourselves of color diversity and color brilliance in the real world. This is not good quality and an unfortunate result of the focus on energy efficiency in the use of light.

Natural illuminances on Earth, produced by the sun, vary from 0.00001 to 120,000 lux; brilliance and softness exist in gradients and contrasts. Indoors, we mostly live with illuminance levels of approximately 200 to 500 lux, which is the mandatory standard for artificial lighting in many types of buildings. This is just enough to be able to perform certain visual tasks, but not enough to refresh or synchronize our circadian rhythm on a daily basis, and thus does not serve our health. We keep out so much of the precious commodity of daylight, even though we get it CO<sub>2</sub>-free.



— Spectrum and shade: richness and obstinacy of daylight made visible.

Possible arguments against and for the use of daylight are:

**1. Daylight creates too much heat.**

Yet: To avoid excessive heat input, it is therefore wise to consider cardinal directions and sun positions.

**2. Daylight is not always available, especially in the evening, at night, and on winter days.**

Yet: In offices and factories, we use more electrical light during the day than during the night. The lights are on at all times.

**3. After the invention of electrical light, architects handed over the responsibility for lighting to electrical engineers. As was the case in many other disciplines, a kind of euphoria—“We will do everything that is technically feasible”—developed in dealing with lighting, which has had anything but a sustainable effect.**

Yet: We are just beginning to make good new inventions that reconcile nature and technology, or make them work equally well side by side.

The incalculability, the obstinacy of natural light, which sometimes creates wild changes of lighting moods, is a richness: we should try to understand the value of this dynamic for our psyche and for our health.

— Daylight in Lausanne Cathedral.



# Illumination Levels, Sun Positions, Daylight Factors

A good solution right from the start, meaning: lighting with daylight is better than lighting subsequently with artificial light. When architects, lighting designers, and air-conditioning engineers work together in the early stages of the design of a building, we manage to transform the generous global radiation, taking into account azimuth and elevation angles of the sun, into good daylight factors in the interior without overheating. If we build in a manner that ensures that mostly daylight provides the interior space with light, as is the case at Lausanne Cathedral (see p. 15), then we are planning sustainably.

In order to plan the use of natural light in a building and to decide which orientation is expedient for windows and skylights, what size to design them, and whether they need to be shaded, we need to consider geography and meteorology. Even a clear sky is not equally bright in all places: the zenith shines about three times brighter than the sky at the horizon. About three times as much light enters a room through horizontal skylights than through vertical windows of the same surface area.

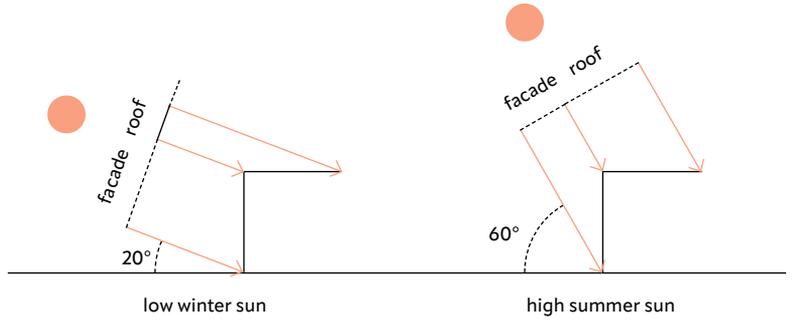
## Sun Positions

The sun moves from east to west at the equinox; in summer it moves from northeast to northwest. The height of their corresponding azimuth and elevation angles depends on the latitude of the respective location. The closer we get from the poles to the tropics, the higher the sun rises at noon. Between the Tropic of Cancer and the Tropic of Capricorn, which lie 2,600 kilometers north and south of the Equator respectively, the sun can stand vertically above us. Sun position charts illustrate the highest solar positions, the course of the sun's path from east to west for each time of day and for each location. Whether the sun shines at all, and for how long, is shown by statistics that record the probability of sunshine temporally differentiated for most places in the world over the course of the year.

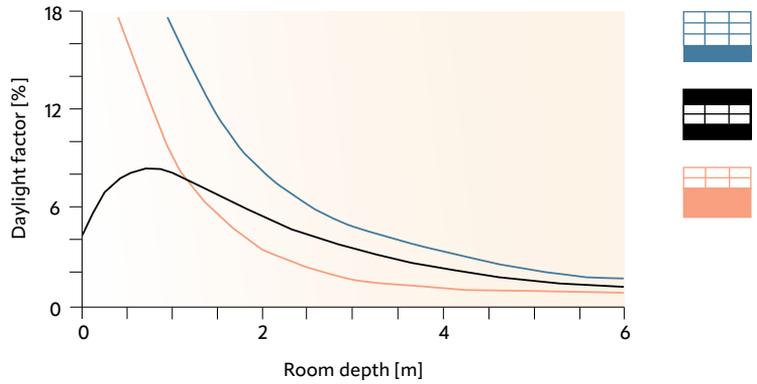
## Daylight Factor and Shading by Surrounding Buildings

In order to provide the depth of a room with sufficient daylight, a higher window is more suitable than a lower window. The ratio of window surface area to room size and proportion is decisive in determining the daylight factor within the space and how evenly it is distributed. The transmittance of the glass describes how much daylight enters the room. Solar control glass has less transmittance and a negative impact on the daylight factor.

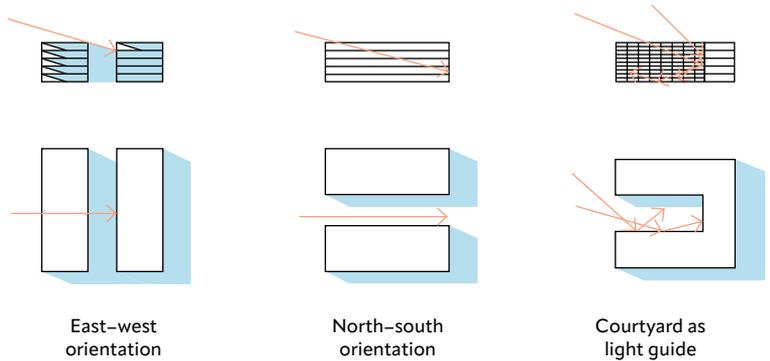
From sun position charts we can conclude how much surrounding buildings or vegetation shade a house. They furthermore show at what times which type of sun screen is appropriate for each elevation. In the south, the sun penetrates more steeply:



— Sun Positions



— The daylight factor depends on window size and height.



— Light obstruction: shading caused by surrounding buildings.

horizontal slats provide optimum protection there, while vertical slats are usually more expedient in the east and west. Flexible shading systems such as pergolas, deciduous plants, or mechanical and thermomechanical systems are ideal. Depending on light and heat quantities, they let light into spaces in a controlled manner without blocking out more sparse daylight during winter.

Buildings with customized facades oriented to the cardinal points and the building structure cleverly follow the insights of daylight simulations. There still remains a lot to invent: movable, changing shading systems react to direct sunlight and do not darken rooms even in gray weather. Exciting suggestions are made in this respect by nature, especially the plant world, as well as traditional regional building methods. New bionic shading systems open and close depending on the sun's rays. From a distance, it looks as if the building is breathing in the light; up close, the geometries of the individual segments are reminiscent of plant leaves. Reflections and shadows change between the interior and the exterior in a logical and expedient way.

## The European Standard on Indoor Daylighting

Following this overview of the main factors, I will now give a short summary of the most important aspects of the European standard on daylight, which defines the terms and gives recommendations for their application in practice. Daylight designers should participate in urban planning drafts and development plans early on in order to ensure optimal lighting of the accommodation on this basis.

The quantitative statement on the amount of daylight within a space is substantial with regard to the daylight factor and its distribution within the space. The aim is not only to light the room in close proximity to the window, but also to light it well deep within the space. Important aspects that additionally bring the room to life are the times of direct sunlight and the view outward.

The standard "EN 17037 – Daylight in Buildings," which has been valid in Europe since 2019, defines standards that enable contracting parties (building owners, employers, occupational health and safety associations, insurers) to contractually stipulate daylight qualities.<sup>2</sup> The standard is a recommendation but not a statutory regulation. The suggested ratings and the corresponding values result from research on the influence of daylight on human health. EN 17037 defines certain minimum illuminance levels for the categories "minimum," "medium," and "high." In practice, these values are usually not checked, not proven, and, unfortunately, often not adhered to. One reason for this is the increasingly dense urban development. The federal energy conservation regulations and the ensuing thicker layers of wall insulation result in deeper window reveals. These additionally shade the layers of the window pane, which become more opaque over time. Qualities of natural lighting that can make a building healthier and more sustainable are thus impeded by energy conservation regulations.

## Recommendations for Daylighting through Daylight Openings in Vertical and Inclined Surfaces

### Low or minimum provision of daylight:

- » In rooms with windows, there should be 300 lux on at least 50 percent of the surface area and 100 lux on at least 95 percent of the surface during 50 percent of daylight hours.
- » For rooms with horizontal skylights, the rule for almost the entire surface area (at least 95 percent) is that 300 lux should prevail during 50 percent of daylight hours.
- » (50 percent of the annual hours are considered daylight hours, which is half of the hours of the year:  $365 \text{ days} \times 24 \text{ hours} / 2 = 4,380 \text{ hours}$ .)

### Medium provision of daylight:

- » In rooms with windows, there should be 500 lux on at least 50 percent of the surface area and 300 lux on at least 95 percent of the surface area during 50 percent of daylight hours.
- » For rooms with horizontal skylights, the rule for almost the entire surface area (at least 95 percent) is that 500 lux should prevail during 50 percent of daylight hours.

### High provision of daylight:

- » In rooms with windows, there should be 750 lux on at least 50 percent of the surface area and 500 lux on at least 95 percent of the surface area during 50 percent of daylight hours.
- » For rooms with horizontal skylights, the rule for at least 95 percent of the surface area is that 750 lux should prevail during 50 percent of daylight hours.

A calculation to prove the respective illuminances includes the overcast sky of the respective region and season as a light source. Data on this is provided by weather services and meteorological institutes. The window or skylight, its position, size, proportion, and the transmittance of its glass determine the amount of light entering the room. The results at the individual points of the room (the calculation area is at a height of 0.85 m) result from the light influence and the room efficiency, a factor of room size, proportion, and reflection levels of the walls, ceiling, and floor.

## Criteria for the Quality of the View Outward

Another criterion for the quality of daylight in rooms is the assessment of the view outward. The sky, landscape / buildings, and the ground are more or less visible; EN 17037 also names various qualities for these factors.

The following criteria apply to the quality of the view outward:

- » Horizontal sight angle
- » Outside distance of the view
- » Number of layers to be seen from at least 75 percent of the utilized area.

If there are buildings opposite the window, only this plane is visible from the depth of the room; this is a very limited view. The building structure has an additional effect on another criterion: sunlight. It is particularly important for well-being in dwellings, common rooms of kindergartens and schools, and hospital wards.

## Criteria for the Quality of Daylight in Interior Spaces

EN 17037 specifies the minimum duration of daylight for interior spaces for a reference date between February 1 and March 21 at a specific point in space. This is at least 1.20 m above the floor and 0.30 m above the window sill. Furthermore, it is on the level of the inside of the external wall in the horizontal center of the window. Only times during which the sun shines into the room above a certain minimum angle of incidence (in Germany, 11 degrees) are taken into account.

# ↗ Start of a Daylight Project

## Studies of Daylight Conditions in a Building

### **Architecture**

- Orientation of the building / cardinal directions
- Integration of the building into the city / landscape (construction, shading, direct sunlight)
- Options for daylight openings in facades / roof / atrium

### **Building usage**

- Room schedule: which types of rooms are best for which cardinal directions
- Daily length of stay
- Time of day
- Activity while in the building

### **User groups**

- Specific groups of people
- Age groups
- Restrictions, special needs

### **Check: have all site-specific data been recorded?**

- Sun position
- Sunshine probability
- Reflective properties of the environment
- Are there other parameters to consider?
- Is there a real / virtual architectural model / model of the surroundings?

# Daylight and Artificial Light at Trident Park, Malta

In the former production halls of a brewery, modern offices were created in the historical substance of the building. The previously compact building was furnished with cut-outs of gardens to provide the new office floors with moderate and generous amounts of daylight. Plants and rigid shutters soften harsh light incursions and provide an interesting view. The ceilings of the modular office floors are relatively low in relation to the floor space. It stood to reason to extend the bright sky of Malta into the interior in an abstract way. The light-flooded ceilings create optical height and width and generate a consistent background light. This can only be successful if the light is evenly distributed all over the ceiling. The clients' desire for cooler color temperatures of 4,000 Kelvin creates freshness in contrast to the Maltese heat outside.

— The facades facing the courtyard.

1 Mary Guzowski, *The Art of Architectural Daylighting* (London, 2018), 6.

2 DIN e. V., ed., *EN 17037 – Tageslicht in Gebäuden* (Berlin, 2018).





# EVOLUTION

## Evolution and Innovation: The Development of the Eye

Nature + Life = Evolution

Evolution is the paragon for our lighting design processes. To playfully create new inventions using light means creating new designs. The evolution of the eye demonstrates how the system of living organisms interacts with light. Plants use light differently than animals: the reception systems for light have developed very differently in the course of evolution. For the implementation, it is useful to know how the eye works. For our planning methodology, we understand that experimenting is indispensable for innovation.

- Raindrops on a ginkgo leaf highlight the natural light.
- The glass sphere luminaires in the great hall at the Elbphilharmonie Hamburg shine in a brilliant light.

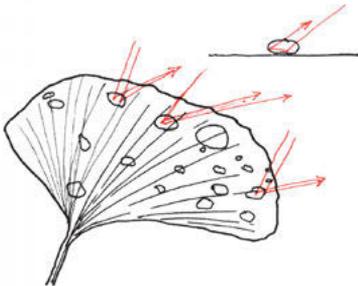
# How Do Gleam and Sparkle Occur?

## Refraction, Gleam, Light Rays in the Water Lens

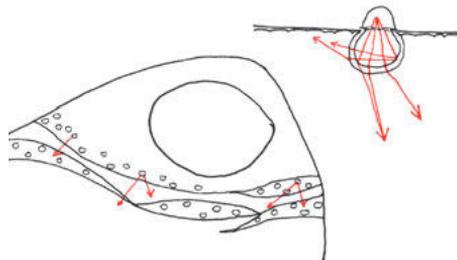
Waterdrops, glass, and lenses focus incident light rays because these change direction on the border between denser and less dense media. This is how brilliant light is created. The waterdrops on the ginkgo leaf collect the sunlight in such a way that it reaches our eyes in a focused manner.

## Refraction in Thick-Walled Glass Spheres, Brilliance in Front of a Bright Surface

As opposed to waterdrops, the 1,300 hand-blown glass spheres in the Elbphilharmonie are hollow and have such unevenly thick walls that they refract the light of the downlights installed above them like lenses, casting it sparkingly in different directions. It either hits our eye directly, having a brilliant effect, or it hits the ceiling and walls first and illuminates these.<sup>1</sup>



— Beam path with multiple total reflections within water droplets and the resulting light reflections.



— Refraction of light in the walls of a thick glass sphere and total reflection at the transition point between air and glass.

# Development and Structure of the Human Eye

The evolution of the eye shows its complex development over time with regard to its capabilities, also in comparison to those of other living beings. This helps us to fine-tune our planning to the respective sensors with a broadened horizon.

There are three types of eyes that have developed over the course of evolution:

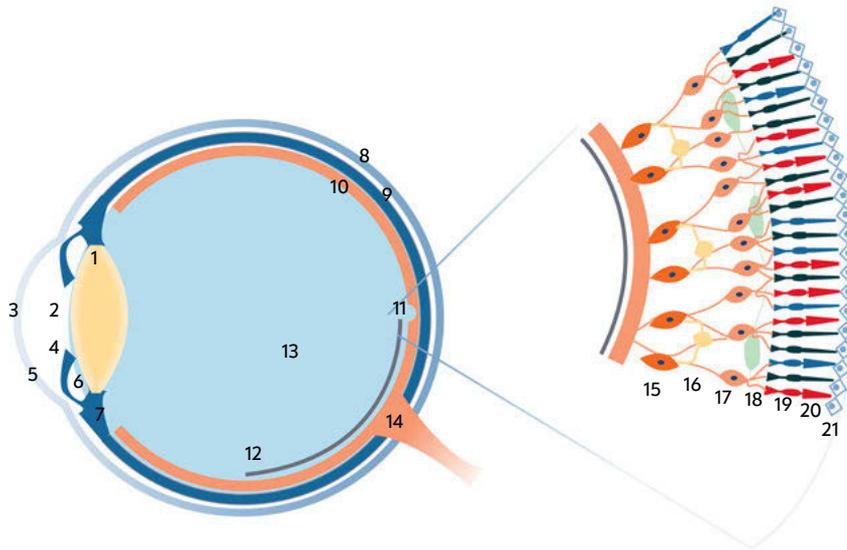
- » The “camera eye,” with a lens,
- » The “complex eye,” with the addition of many individual light sensors, and
- » The “mirror eye,” consisting of reflectors and photoreceptors.<sup>2</sup>

## The Development of the Human Eye

The first photoreceptors developed 600 million years ago; the visual pigment-protein opsin spread as eyespots over the entire body. Consequently, photoreceptors with an outer membrane developed, followed first by synapses for signal transmission to the brain.

The retina was not yet capable of creating an image. There was only a translucent outer skin. In the Middle Cambrian, various new photoreceptor cells emerged: cones, bipolar cells, and ganglion cells. Five hundred million years ago, lenses developed that were capable of accommodation: with an iris and the dilation of the pupil as a consequence thereof. Subsequently, muscles developed that enabled eye movement. The biomembrane myelin made the signal faster, and rhodopsin enabled the development of rods, the receptors for very weak light. From now on, the eye was capable of adaptation, the adjustment to darkness. These latter photoreceptors would disappear again 200 millions years later for nocturnal vertebrates.<sup>3</sup>

The illustration on the next page shows the human eye in section. When land vertebrates evolved 430 million years ago, their eye lens adapted to the refractive index between air and lens material; at the same time, the eyelid evolved. The vision of different creatures is related and yet different. We know how differently the eyes of vertebrates and humans developed corresponding to their living conditions. In lighting design, knowledge not only of human vision but also of that of animals is of significance: even though birds barely perceive certain wavelengths of white light, humans can use light sources outdoors that are less likely to disturb animals at night.



#### Sections of the human eye

- 1 lens
- 2 pupil
- 3 cornea
- 4 iris
- 5 anterior eye chamber
- 6 posterior eye chamber
- 7 ciliary muscle
- 8 sclera
- 9 choroidea
- 10 retina
- 11 macula
- 12 area of greatest sensitivity to blue light
- 13 vitreous body
- 14 optic nerve/blind spot
- 15 ganglion cells
- 16 amacrine cells
- 17 horizontal cells
- 18 bipolar cells
- 19 rods
- 20 cones
- 21 pigment epithelium

**“Oliver was an observer. That’s why in the beginning, Oliver didn’t get respect from the science community. See, some people think that you have to have a hypothesis in a controlled experiment to have science, and I say, Okay, what is astronomy then? The Hubble Space Telescope just looks at things. It’s observation. Observation is part of science. Because without observation, you couldn’t even make up a hypothesis. What Oliver did is sort of like the Hubble Space Telescope of neurology. It’s astronomy of the mind.”<sup>4</sup> — Mary Temple Grandin, 2020**

# Observation, Experimentation and Design of Light: A Design Methodology

Just as evolution leads to innovation through trial and error, playing with light and extensively considering the effects opens up new designs.

As a child I wanted to become an astronomer. I used to watch the stars for hours on end. I am shortsighted, and when I got glasses at the age of thirteen, I was overwhelmed by the multitude of stars.

The image on the right shows me observing a transit of Mercury. My mother rented a telescope from a photography shop for this event, and I learned to turn a glass plate into a filter using soot. This method is inadequate. Nowadays, there are far more reliable ready-made solar filters protecting the eyes from the concentrated rays of sunlight.

Today, observing the sky, whether by day or by night, seems like an enjoyable meditation.



## Candle in a Dark Room

For a workshop at the Architectural Association in London, we rented a cellar and lit the approximately 80 m<sup>2</sup> room with a single candle. After a while, we saw more than just the flame. At some point it became dazzlingly bright; the slightly smooth floor began to shine somewhat, and eventually the distant walls appeared. It was a process similar to that of a picture slowly revealing itself while being developed in the darkroom: magical. We experienced firsthand the ability of our eyes to see even with the smallest amount of light. We took our time for that. I added further candles until there were four candles on the floor in the center of the room. Students observed the changes, and it was their task to sketch the situation using a white pen on black paper. For the next step, I introduced a big change: I placed the four candles in the four corners of the room. The walls lit up; they became more present, restricting and defining the space. The atmosphere changed due to the interplay of light and space. The photo (top) was taken at Domaine de Boisbuchet when I held the workshop "Less light is more light." You can see one of the four candles in one of the corners of the room and the effect it has on its immediate surroundings.

## Transformation of Space Due to Varying Position and Direction of Light

In the exhibition *Europe–Japan* at AIT Architektursalon in Hamburg, we tested various lighting situations in the space installation of Studiospazio. In the picture (center left), a pendant luminaire shines on a dichroic slanted pane of glass; in the other (center right), two table luminaires of varying color temperatures and different heights illuminate the room, creating a completely different mood.

## The Pleasure of Looking and Taking It In

Indulgence is open and attentive perception, and it repeatedly takes place in nature and in projects, flaring up in between or as a pleasant permanent state. Who does not love the brilliance, the sparkle of the moonlit path? The moonlit path is the sum of all glittering reflections on a moving water surface between the moon and the viewer. This phenomenon remains faithful, for it follows us who walk along the edge of the lake, and it always creates the shortest connection between the moon and the observer.



— A student sketching the light of a candle in a dark room, Domaine de Boisbuchet.



— The different positions and directions of light transform the space, AIT Architektursalon, Hamburg.



— A moon reflection path on Lake Geneva, Switzerland.

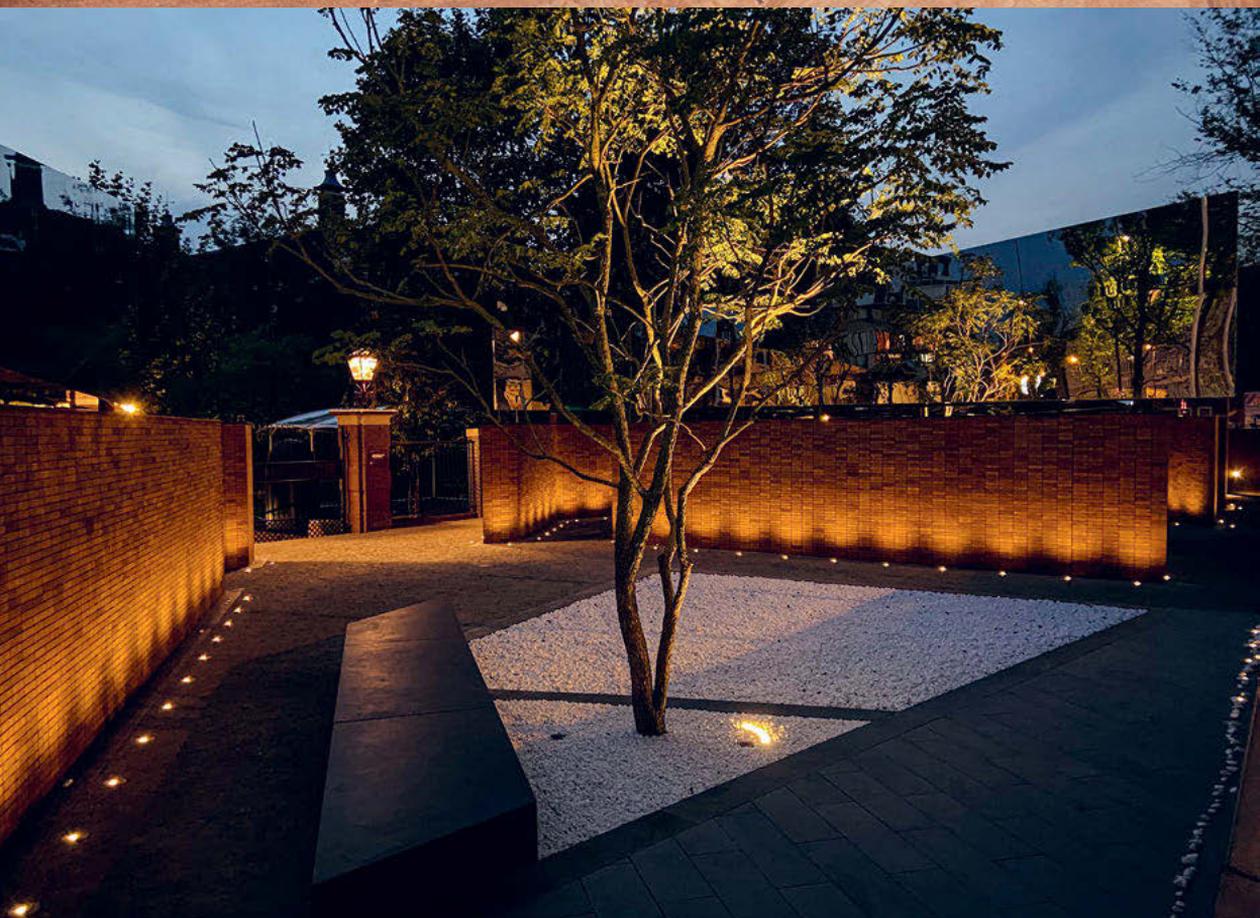
# Variants of a Light Theme at the Elbphilharmonie Hamburg

The surface of the water of Lake Geneva shows softly distorted and repeated reflections of the moon. The facade of the Elbphilharmonie creates an alternating image of sky sections and clouds. It consists of a multitude of convex and concave mirrors, which are vapor-deposited with different densities between the glass planes. From the inside, you can look out unhindered; from the outside, the facade reflects to varying degrees. In every weather, every time of day, and every viewing direction, the sky "plays" differently on the facade, and in the evening the electric light from the foyer adds a component of warm white light.

— Facade of the Elbphilharmonie,  
including the plaza.

- 1 Herzog & de Meuron hold the copyright for the luminaires.
- 2 Walter J. Gehring, "Wie sich das Auge entwickelte," on: [unibas.ch/de/Aktuell/Uni-Nova/Uni-Nova-111/Uni-Nova-111-Auge.html](http://unibas.ch/de/Aktuell/Uni-Nova/Uni-Nova-111/Uni-Nova-111-Auge.html) (accessed February 21, 2022), UNI NOVA 111/2009, Darwin und die Evolution UNI NOVA, Wissenschaftsmagazin der Universität Basel. Published by the public relations department (Direction: Hans Syfrig), 12.
- 3 Trevor D. Lamb, Shaun P. Collin, and Edward N. Pugh Jr., "Evolution of the Vertebrate Eye: Opsins, Photoreceptors, Retina and Eye Cup," *Nature Reviews* 8 (2007): 960–75.
- 4 Temple Grandin, quoted in *Oliver Sacks: His Own Life* (2020), directed by Ric Burns.





# PERCEPTION

## Three Things Pertain to Good Lighting: Lighting, Space, Perception

Evolution + Interaction = Perception

Perception happens interactively in the eye-brain complex. Comparing experiences helps the individual to understand and categorize information. Perception does not objectively depict what we see, but integrates experience into the image seen. This knowledge is helpful when we design with light, to create certain atmospheres with light and give spaces the desired effect. Shade is essential because without it, there is no spatial perception.

- Light and shade in The Wave, Utah, creating the space.
- The Dutch Holocaust Memorial of Names, The Netherlands, Amsterdam, creates a varying sense of space.

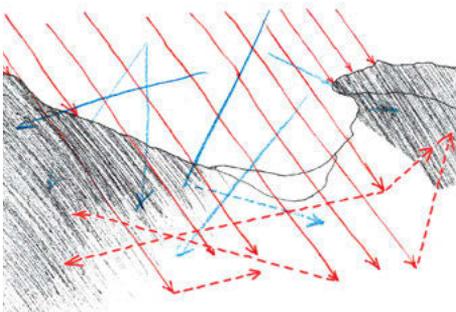
# How Are Shadows Formed?

## Opacity and Multiple Reflections

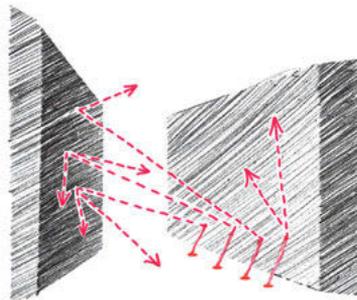
Opaque objects set in direct light cast shadows; the sharpness of the shadows' edges depends on the distance between the object and the projection plane and the size of the light source: the bigger it is, the softer the edge of the shadows. The depicted shade in *The Wave* on the left-hand side has a relatively soft edge. The sun produces almost parallel rays from its great distance. Luminaires that radiate their light not in a parallel but radial manner create less sharp-edged shadows. The illuminated side of *The Wave* reflects the light on the opposite rock face and lights it up. Photographers use transportable, folding reflectors in order to redirect sunlight in the exact same way.

## Diffuse Reflection

Each gap and each engraved letter of the Dutch Holocaust Memorial of Names casts a shadow when hit with light from the floor lamps. If they were illuminated directly from the front, this microtopography would be visually lost; the surface would then appear flat and less vivid.



- Absorption of the incoming parallel sun rays (red) and the incoming skylight from all directions (blue) and ray path in the case of several diffuse reflections.



- Beam path with several diffuse reflections between two opposite walls. This also brightens the wall that is not directly illuminated.

**“The soul is dyed with the color  
of one’s impressions.”<sup>1</sup> —  
Marcus Aurelius, 121 – 180 A.D.**

An insertion on my own behalf: I am face-blind. This means that I can see faces as faces; however, I cannot really recognize them. For a long time, I did not know such a condition existed and thought I was not paying enough attention when meeting people. Sometimes, I greeted strangers as a preventative measure or pretended to recognize people when meeting somebody I knew but did not recognize. I could tell many bizarre stories. So, if we ever meet, you could really help me if you simply told me who you were, especially if you got a new haircut or glasses. The many other face-blind people, about 2 percent of the German population, would also be grateful for this.

# The Interplay of Eye and Brain: Neurological and Psychological Aspects of Perception

Perception is based on a complex interaction between the eye and the brain. The previous chapter focused on the eye and its function as a sensor (see p. 28); this chapter is about its integration into the complex system of the body. Unlike a camera, the eye is controlled by the brain and its expectations and visual habits. The knowledge of this working method of the eye-brain complex allows us to plan lighting better.

The human eye and the areas of the brain responsible for vision have been functioning together in their development for a long time. The photoreceptors in the eye are specialized to capture certain visual objects, and the brain controls the visual process. In humans, the processing and accompaniment of visual stimuli take up 60 percent of the cerebral cortex in relation to the areas responsible for other senses. Humans are “eye animals” rather than “nose” or “ear animals.”

Already in the first step of seeing, the receptors of the ocular retina transmit the information received, preanalyzed and sorted, to the primary visual cortex in the cortex. Information processing is specialized: cortical reception occurs via the pathway to the parietal lobe, which is responsible for motion and position perception. It helps people to spatially orient themselves in the environment. Another pathway directs signals to the inferior temporal lobe, which is responsible for recognizing objects, colors, and shapes. This is followed by further selective processing of the received information. Here, the neurons in the cortex are specialized in images of hands, faces, and movement patterns.

## Interaction of Eye and Brain

The forward-looking expectation of the brain toward what is to be seen pertains to the interplay of specialized and expediently arranged neurons. It is both a curse and a blessing. It is a curse because we do not see an objective image of reality but rather what our brain prepares and filters for us based on its expectations. The blessing is the resulting speed, because the influence of experience on the image speeds up the processes in the brain and makes us react so quickly. Another manipulation that the brain makes to the image is that the blind spot is not perceived as a gap in the seen image.

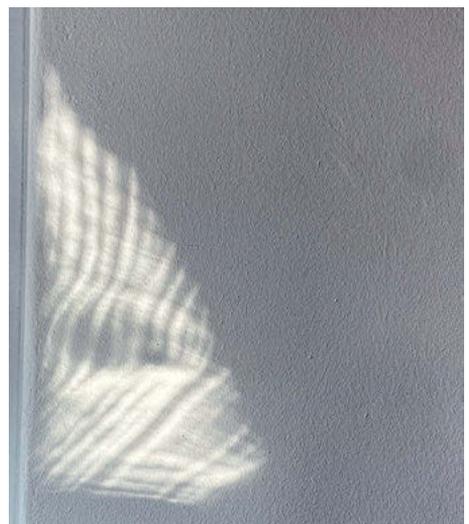
Knowledge of the factors that trick the perception of an objective reality helps lighting designers avoid the negative effects of a lighting environment and better understand the likes and dislikes of individuals: “My perception is a prediction of what ought to be out there in the world.”<sup>2</sup> The brain’s expectation of the image of a certain situation arises from the million-year-old basic cognitive equipment that every individual human being possesses and develops from birth. As with other learn-

ing processes, individual experiences flow into expectations of the world. This usually happens subconsciously.

## Evaluation of Brightness

In *Diary of a Baby*<sup>3</sup> by Daniel N. Stern, the fictitious six-week-old Joey is mesmerized by the reflection of a sun ray on the wall: “a space glows over there, A gentle magnet pulls to capture.”<sup>4</sup> At six weeks, eyesight is not yet perfect; however, a baby can already recognize different colors, shapes, and degrees of intensity. By the intensity of its emotions with regard to the impression of light, it already knows whether to approach it or to keep its distance. It can differentiate between wanting to seek shelter or to research curiously.

A weak stimulus—for instance, a lamp that is lit during the day—bears little fascination. However, a baby will avoid a stimulus that is too strong, such as, for example, one that is generated through direct sunlight. A moderately intensive stimulus created by sunlight, such as reflections of the sun as in the image below, enchants a baby and activates its attention. Moreover, the child can already distinguish between the near and far; the outstretched arm marks the boundary between them. This is also a building block in the wealth of experiences that already helps to shape perception by means of the brain’s expectations: “The space is growing warmer and coming to life. Inside it, forces start to turn around one another in a slow dance. The dance comes closer and closer.”<sup>5</sup> The baby stares steadfastly at the patch of light; it has found its visual point of fixation. When it gets bored with this point after a while, the focus of its attention wanders, although the eyes do not move.



— Reflections of the sun on the wall of a room.

## Optical Illusions

Optical illusions enlighten us as to how the brain presorts and evaluates. This accelerates the existentially important decision-making process of whether, in an encounter, approach or flight is the right course of action. The eye already transmits image information specifically to certain areas, such as that for orientation within a space. In this way the brain is not burdened with the spatial allocation of what is being seen: where the shadow is positioned on a surface with regard to the object and what this means about their position in relation to one another are clarified beforehand.

Experience teaches us that the shadow of people standing on the ground begins at their feet; if the shadow is detached from the foot, as is the case in the image below, the person appears to be floating.

### Perception of Time and Reflection in Dark and Bright Spaces

The stage designer Beatrix von Pilgrim studied the effect of light on spectators in the theater.<sup>6</sup> Under the title "Light reigns perception," she devised:

- » That perception of time and reflection of the viewer function completely differently in dark and light spaces. [...] So at the beginning of the play it gets dark; the viewer waits and is put into a different mode in the dark, the black magic box or the curtain disappears before his eyes, and the game in the viewer's head begins. [...] When you can't see anything because it's completely dark, the perception of time and the flow of the narrative jump.
- » In film, we know black fades, the gaps in the flow of the narrative [...] activate a notion in the viewer's mind of what has been skipped. [...] They enable space for thought for what could have happened or should have happened, a prompt for assumption.<sup>7</sup>

Dark spaces trigger fantasies and emotions, whereas in light spaces, people react rationally and sensibly due to its sobering, visible representationalism. These findings from the theater are equally applicable to architectural and urban environments.



— Optical illusions: a shadow suggests that a person is floating.

# The Art of Highlighting or Leaving in the Dark

Light very much influences how people perceive a space. The design of light and dark has a particularly strong effect. Is a bright room inviting or is there only light at the end of the tunnel? Do martial bright columns of light intimidate guests at an event, or do glittering points of light intrigue and attract people?

I will demonstrate the usefulness of the knowledge of perception for lighting design on two different types of buildings: museums and offices.

## Museum Lighting: Light or Dark?

Generally, there are two opposing lighting principles in museum buildings: in the nineteenth century, museum staff preferred the bright, daylight-oriented museum whose frosted skylights brought the soft light of the sky into the interior space. The objective was to show objects in a similar light to the one the artists saw them in when creating them. The daylight-oriented museum lighting stood in contrast to the conception of the museum of darkness, which allowed for dramatic presentations, almost like in the theater. Many museums feature both lighting concepts.

In museum and exhibition lighting, not only the psychological but also the physical effect of a dark space plays an important role: in a museum with dark rooms, exhibits are more prominent than in bright rooms, even if they are relatively dimly lit. The eyes adapt to the darkness and perceive the mandatory maximal illumination level for fragile objects of 50 lux as bright. Conversely, the pupils constrict when bright light sources dazzle, and vision fails in the dark. The dark environment helps to protect collection items from harmful light radiation.

## Office Lighting: Soft or Hard Light-Dark Gradients?

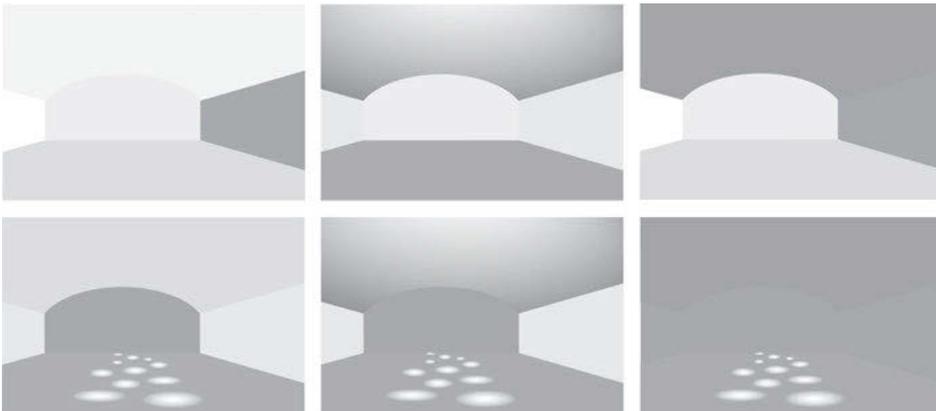
The knowledge of contrasts and glare shaped occupational medicine and ergonomic standards for the workplace in an effort to prevent eye strain. Under these regulations, low-contrast rooms can be created in which all surfaces appear equally bright. The reduction of glare ensures that there are no open light sources to look directly into, which is comfortable but unstimulating. Monotone, tiring lighting in offices can easily result when not even a small ray of direct sunlight is allowed over the course of a day.

With imaginative lighting design, offices can obtain diverse lighting. It can create islands of light to highlight certain areas, enable zones of shade, and furthermore adhere to the standards. Dynamic lighting systems allow for differences in light in the course of the day. Thus, light supports the transformation of office areas to workspaces that offer areas for concentrated work at the screen, for acoustically shielded telephone calls, and for communicative exchange between colleagues.

We perceive situations rich in contrast as interesting and exciting; they demand our attention. The sun dazzles, the shadows on the steps of the waterfront in the morning sun are rich in contrast. In an office situation, this spectrum would be too wide (opposite, top). At the waterfront in the fog, the sunlight is subdued: there are hardly any shadows (opposite, bottom). Admittedly, the eye is not exhausted by irritating contrasts; however, the soft envelope of light hardly gives any stimulus and tires the eye in the long run. An even balance between contrast-rich and soft light is important for interior spaces. The combination of soft, diffused light and direct radiant light creates a variant that corresponds to natural light.

## Perception of Space

Lighting variants of the same space change its proportions and atmosphere (below). A brightly lit ceiling makes it appear higher, fresher, and friendlier; walls stand out more in the light; whereas islands of light lend it something personal.



- Light on varying surfaces changes the perception of space: proportions and dimensions appear differently.



— Waterfront in the morning sun in Hamburg.



— Waterfront in the fog in Hamburg.

# Open Safe Havens: Light and Space at the Dutch Holocaust Memorial of Names, Amsterdam

The Dutch Holocaust Memorial of Names in Amsterdam is a memorial to the Dutch Jews, Sinti, and Roma who were murdered during the Holocaust and never received a gravesite. For each of the more than 102,000 people there is now a stone in the wall of the memorial. It is situated on a noisy road, lowered to street level in front of the entrance to the small park Hoftuin. In plan, the sculpture forms the letters of the Hebrew word for "in memory of." The two levels of the walk-in sculpture are slightly staggered. At the bottom, there is a 2-meter-tall brick wall with the engraved names; at the top, there are two suspended shiny elements that reflect the surroundings and appear immaterial.

The light defines the feeling of space by accompanying the alternation between expansiveness and density, between freedom and security. The image shows that the light from the individual floor lamps of the Dutch Holocaust Memorial of Names glow like candles. Normally, if the sky does not occupy most of our surroundings up to the horizon, then mountains, canyons of buildings, and interior and exterior walls do so. In our field of vision, it is the vertical surfaces which are the most important regarding the spatial effect. The light bouncing off between two walls at the Dutch Holocaust Memorial of Names defines the space. It feels relaxing and creates security: a space for seclusion and reflection.

— Dutch Holocaust Memorial of Names at dusk.

- 1 *The Essential Marcus Aurelius*, trans. John Piazza and Jacob Needleman (New York, 2008), 42.
- 2 Chris Frith, *Making Up the Mind: How the Brain Creates Our Mental World* (Malden, 2007), 132.
- 3 Daniel N. Stern, *Diary of a Baby* (New York, 1990), 17.
- 4 Stern, *Diary*, 17.
- 5 Stern, *Diary*, 17.
- 6 Beatrix von Pilgrim, "Belichtete Zeit: Über Bilder im inszenierten Raum," in *Raumverschiebung: Black Box – White Cube*, ed. Barbara Büscher, Verena Elisabeth Eitel, and Beatrix von Pilgrim (Hildesheim/Zurich/New York, 2014), 121.
- 7 Von Pilgrim, "Belichtete Zeit," 121.





# CULTURE

## Seeing the Light rather than the Luminaire

Perception + the Anthropogenic = Culture

Here, the term culture refers to visual habits that have developed culturally. In European culture, people tend to see the object-like, the measurable, and often overlook the "immaterial" light. In lighting design, many evaluate the beautiful luminaire first rather than the beautiful light prevailing in the room. Social customs shape the way we experience light. I have gotten to know the similarities and differences of various cultures in many parts of the world and to integrate this spectrum of possibilities into lighting design.

- Halo around the sun.
- The glass sphere luminaires in the Elbphilharmonie Hamburg create a halo on the ceiling of the plaza.

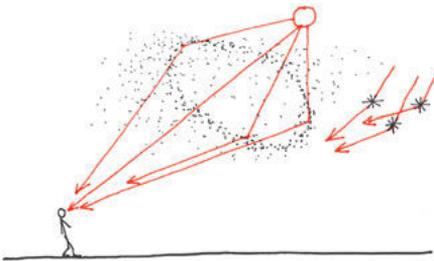
# What Is the Halo Effect?

## The Halo

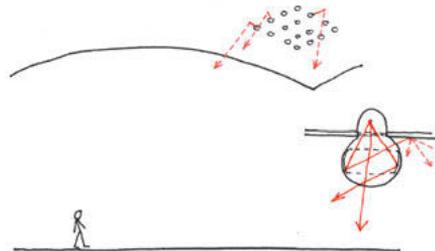
A halo is created by the refraction of light in the atmosphere. The halo we sometimes see around the moon against the dark sky, less often around the sun, is created in a similar way to a rainbow. Due to the fact that ice crystals in the air refract the path of light, a softly shimmering, sometimes colored, ring around the moon can be observed.

## Ring-Shaped Reflection

Ring-shaped reflections can be observed on the ceiling of the plaza of the Elbphilharmonie. These are reflections from the silver rings of the glass sphere luminaires. Some of the light rays falling into the glass sphere luminaires reflect upward before being thrown back down from the ceiling.



— Humans see a ring of light (halo) around the sun or moon due to the refraction of light in ice crystals in the atmosphere.



— The direct reflection in the ring-mirrored sphere casts a halo ring on the ceiling and protects the eye from glare.

**“Closeness to nature is highly important for us, we would like to save this relationship between man and his natural environment for future generations. [...] Self-sufficiency is an important part of the Finnish mentality. We like being alone—alone with nature.”<sup>2</sup> — Anu Puustinen, 2013.**

**“The beauty of the landscape—where sand, water, reeds, birds, buildings, and people all somehow flowed together—has never left me.”<sup>3</sup> — Zaha Hadid, 2006.**

# How Lighting Preferences Develop within Various Cultures

Where do light preferences and aversions in various cultures come from? Light creates orientation in time and space. Daylight is an essential part of nature that actually surrounds us as location-specific light. The four elements of early Greek philosophy were fire, water, earth, and air. Being a part of fire, light pertained to these elementary groups of materials or phenomena. All life was dependent on these four elements and adjusted to the quantities available in a given situation.

Humans began to adapt to the different daylight conditions during the course of their expansion over the planet, though their biological differentiation was insignificant. Their differentiation rather occurred culturally: under various climatic and geographic conditions, humans developed differing strategies with regard to building, protecting, and nourishing themselves. These in turn, in conjunction with geographic and climatic conditions, have shaped the reality of human life for generations.

## Preferences for and Aversions to Warm or Cold Light

How different cultures have developed their interaction with light manifests itself in ways of life, architecture, and urban development; culturally differing experiences lead to various preferences and aversions. The most obvious is the one for warm or cold light, depending on the latitude of the location of the respective culture. It is the different lengths of twilight phases in various places on Earth in particular that influence the visual habits of the inhabitants.

Dawn and dusk, with the transition from light to dark, are different everywhere. People living close to the Equator know the transition from bright daylight to dark night as a short time span of only a few minutes. The eyes cannot entirely adapt to the sudden darkness during this time. Therefore, they consider the transition to an immediately switched-on, bright daylight-white artificial light in the evening and at night to be reasonable and pleasant, even in restaurants. Visitors from the Northern Europe are surprised by this. Close to the poles, dusk takes longer and permits the eye to adapt during the slow darkening process. There is a long period of warm orange evening sky, so people of the north prefer a warm and subdued artificial light at night, especially in restaurants. This in turn surprises my clients in Malaysia, and they ask me not to include such "northern warm light" in my lighting design.

Not only the latitude, but also the colors of the landscape and its natural materials determine the light we are used to. They shape our affinity to a color and light atmosphere in geographically different ways. The colors of objects, the color of light, or the color temperature of white light are typical features of certain regions and times of day. They are rooted in the memory of the individual, arouse associations, and shape the perception of the light mood.

How various moods of light are not created by different light sources but rather by various materials, colors, and gloss levels upon which the light falls can be demonstrated in a practical trial. The photographs below show materiality and light moods with the constants of a test setup: the white room and the light sources in the color temperature of 2,700 Kelvin, always in the same position. The materials can be interchanged: matte yellow card, the golden glossy side of a rescue foil, and matte blue card, with the yellow card to its left. The impact on the space is visible on all surfaces, including the sloping ceiling and the dark-gray floor. A wooden bar reflects warmer, more pleasant light on the faces of people sitting at the bar than a glass or a blue-painted surface would do.

An unbiased view and the continuous observation of the illuminated world will build up a library of light in the memory. In literature, authors describe light situations in order to express different feelings of the protagonists caused by light.

### Orientation – Disorientation in Space and Time

The fact that daylight can provide emotional stability, reassurance about time, and orientation is shown in a scene of Juli Zeh's novel *New Year*, in which a boy misses his parents. The boy makes the threat of being left alone more bearable by using light for clues about the time of day. "The next morning Mama and Papa are gone. Henning



— Influence of materiality on lighting moods.<sup>4</sup>

gets up while Luna is still sleeping. He runs down the corridors, which have now shrunk down to their usual length and into the sun-drenched main hall. [...] He can guess how late it is by the color of the light. He looks at the sky, the sun, and the yard. It isn't sleeping time, it's already the colors of breakfast time. [...] The room grows ever darker. Henning knows that; he's often watched the darkness come, when he couldn't sleep. Shadows grow in the corners. Everything has a different face."<sup>5</sup>

The following text describes the pragmatic relationship between the people of Somalia and natural light, time, and the lifestyle habits resulting from it. The direct influence of daylight is self-evident: "A friend had warned me about daylight saving and the time change but I couldn't get it straight. [...] 'Why don't you just get up with the light?' In Somalia, nobody tells the sun what to do. Near the Equator daylight is pretty much the same all year round and I could tell how long until sunset by the length of the shadows. What did clocks have to do with the sun? In Western cities there are so many lights that it doesn't make much difference whether it's night or day and it's so cloudy and polluted you can't see the sun most of the time. In Somalia, the sun ruled our lives, when it was dark you slept; when it came up it drove you out of bed."<sup>6</sup>

### Location-Specific Light

Air can be enriched with light. The phenomenon only occurs in specific locations with favorable conditions. In the film *Dutch Light*, the authors raise the question as to why, during the Golden Age, painters of the Dutch School, such as, for example, Judith Leyster (1609–1660) in the painting *Young Flute Player* and Albert Jacobs Cuyp (1620–1691) in the painting *The Maas at Dordrecht*, painted scenes and landscapes in such overwhelmingly intense light. "There's an ancient myth that the light in Holland is different from anywhere else, but it has never been put to the test. It's the legendary light we see in paintings. The German artist Joseph Beuys, however, says that it lost its unique radiance in the 1950s, bringing an end to a visual culture that had lasted for centuries."<sup>7</sup>

Why did this light only exist there? It might be that the Dutch polder landscape with its large surfaces of water is responsible for this. The sunlight was reflected by the water. The sun rays were thrown against the underside of the clouds and reflected back down. A ray of light, which only spreads through the air once in other regions, here travels through the air four times, enriching it with light. The upper right photograph shows this phenomenon on the North Sea Coast of Schleswig-Holstein; in inland areas, I have never found it outside of Holland. A certain constellation of cloudiness, gaps between the clouds, and direction of sun must prevail in order to perceive this extraordinary rich light.



— Air enriched with light.



— Courtyard of Freudenstein Castle near Bolzano.

**“In the times that lie ahead of us—times of tremendous turmoil and huge upheavals—building with light will take on a whole new significance. The light of the warming, protective campfire has kept us safe through the night since the dawn of humanity: it’s a lighting atmosphere that resonates deep within us. Isn’t light about more than optimizing human performance in the workplace? Isn’t light also a sign of morning or evening, a signal of safety or imminent danger?”<sup>8</sup> — Werner Sobek, 2020**

# Heeding the Location and Listening to Its Users

The wealth of experience that builds up in experiments, small experimental setups, and during travels is incorporated in every project; it allows us to constantly refine our planning approach. The local natural light and the architectural traditions of handling light form the foundation of any lighting concept. As daylight teaches us, so do clients and architects if we pose enough questions. A further successful building block of the culture of lighting design is to consider it as a joint component of a building or urban space rather than a subsequent form of decoration. In this way, we can design our surroundings with light in a rich, sensitive manner close to the needs of the people.

When lighting designers attentively analyze and observe the architecture and location at the start of a project, a good concept can ensue. This includes:

## **The Traditional Construction Methods of the Respective Region and the Investigation of Their Approach to Daylight**

Japanese shōji (paper sliding walls) conjure a gentle light, casting soft gradients from the facade into a room. Mediterranean wooden shutters catch the light on the level of their inclined slats, and Mexican pergolas protect the outdoor space from too much sun and integrate light into a room. How were introversion, privacy, and seclusion at the project location expressed in traditions? The knowledge of local peculiarities enables us to include functionality, elaborate details, and depth into a project.

## **Defining the General Color Temperature of Light Early On**

Because the perception of pleasant light colors is culturally different, it is helpful to the design process to define a direction together with those involved early on. Some have a clear view on things, others have never consciously considered color temperature. Warm and cool light may well interact in a space—it is not prohibited. A ceiling illuminated in neutral white can harmonize with a cozy island of light of a focused warm light cone.

An example for this is the courtyard of Freudenstein Castle in the evening (see p. 55, bottom). When the daylight shines in the blue hour with between 9,000 and 12,000 Kelvin, the masonry appears cool in the upper area, which enhances the impression of coziness in the arcades, which are illuminated with a warmer light of 2,700 Kelvin.

## **Responding to Architecture: Integrating Rather Than Decorating**

Architects designed with a clear idea of what the building should provide, how life is organized in it, what is comfortable for people, and what forms of expression and materials correspond to all this. They decide on the rhythm and the proportions of spaces. Lighting design can exaggerate or level these decisions out. Indirect light can elongate spaces in height when the ceiling height is relatively low. In the Grande Galerie of the National Museum of Natural History in Paris, architects and lighting

designers used the alternation of various ceiling heights dramaturgically: visitors go from the bright, glazed entrance hall through to the low intermediate area, which is intentionally kept dark, into the impressive high-ceilinged hall with its galleries, the heart of the exhibition.

To integrate light sometimes also means to build in luminaires in ceilings and walls so that the luminaires are invisible. In other lighting projects, integrating light means to bring into effect visible sources of light in an unobtrusive manner in order to let them illuminate spaces self-evidently and naturally.

### **Listening to Clients and Users**

They know the everyday routines and life in their professional practice or their living environment and are pursuing a particular goal with the new build or refurbishment. Bad experiences with light and lighting controls in earlier buildings are a clear hint as to what should be improved in the design. Lighting designers cannot know all processes in specific buildings; that is why it is helpful to visit clients in their previous premises. In order to prevent misunderstandings during this discourse, it is sensible to keep a written record of the planning requirements and to have it signed off prior to design planning. The checklist Client Requirements, Planning Prerequisites routinely tracks the arising questions. It is adjusted as needed, accompanies the entire course of the project, and thus helps to consciously make possibly divergent decisions while at the same time perusing superior objectives in a structured manner.

In order to record them during meetings, it is advisable to check through the requirements room by room. Shown here is an example for an office building.

### **Creating Free Spaces with a Clear Planning Culture**

In practice, other successful aspects are often the focus of lighting design. Each project in which clients and their planning team want more than simply a functioning lighting system harbors a chance for something new. Unfortunately, we often think that we lack the time for a detailed conception; economic and social presettings appear to press us. The performance profiles of lighting designers and other planners have also strongly changed in the course of the last decades—due to increasingly complex requirements for buildings and their light, due to more elaborate planning and coordination processes, larger planning teams, and the digitalization of planning tools. Light calculation programs offer high precision, but the efficiency method also, consisting of a formula, various factors, and a few constants, is a relatively simple procedure for the calculation of good results. Mastering these skills strengthens the competence of young lighting designers in their daily work.

## ➤ Client Requirements, Planning Prerequisites

- Illumination level
- Lighting control in individual rooms / areas
- Type of control system: should the luminaires be dimmable? Are lighting scenarios possible?
- Environmental certificates / energy certificates: if so, which ones?
- Does the company have a design manual?
- Further norms and other standards of the clients
- Fire safety requirements
- Which sustainability and quality standards do I recommend to the proprietors above and beyond the usual technical regulations?

## ➤ Office building planning requirements

Room name	Average lighting level in lux		Uniformity	UGR	Special requirements / note
	acc. to specification DIN EN	recommendation UBL			
<b>Ground Floor</b>					
Entrance hall / foyer	100	200–300	0.4	22	
Reception desk	300	300	0.6	22	
Canteen	200	200	0.4	22	
Lift vestibule	200	200	0.4	25	
<b>1st to 6th floors</b>					
Office	500	500	0.6	19	Single / double office / open space workstation 500 lux, surroundings 300 lux
Conference room	500	500	0.6	19	
Break room	100	200–300	0.4	22	
Hallways	100	100	0.4	25	
Staircases	100	100	0.4	25	

# Differentiated Lighting Intentions on the Elbphilharmonie Plaza, Hamburg

The Plaza of the Elbphilharmonie is a public space in Hamburg that is not just for concertgoers. First and foremost, it is an observation platform with a strong connection to the sky, the river Elbe, and the city. We cite Hamburg's overcast sky when a group of luminaires—on the ceiling of the plaza—appears as clouds of light in the sky. A vibrant town square is created from which the view of Hamburg can be enjoyed.

The spherical lights on the plaza differ substantially from those in the great hall, even if they are formally similar at first glance. The light also is different. To consider the light first and then the luminaires is always helpful to the specialist: the luminaires of the plaza direct the light differently; they are differently dimmed from the glass sphere luminaires in the great hall and have different light distribution curves. They consist of well-disguised, densely bundled downlights behind the sphere, which transport the light in a focused manner over the great height down onto the brick floor. Islands of light are created in doing so instead of an even pool of light on the floor. The now reddish light reflected back from the floor would color the ceiling of the plaza an undesirable pink. However, this effect is softened by the halo around the glass sphere luminaires. The vapor-deposited mirror ring on the sphere reflects the light from the LED and shields it at the same time so that no one is dazzled. A clearly visible halo surrounds each sphere on the ceiling.

Some people understand lighting design as the design of a ceiling plan, as if it were primarily about a nice pattern on the ceiling. This is only of secondary importance; the primary focus of any lighting design is the light itself.

— There are clouds and islands of light  
on the plaza of the Elbphilharmonie.

- 1 Herzog & de Meuron hold the copyright for the luminaires.
- 2 Puustinen, Anu. Lecture: "Avanto: architecture and silence," St. Petersburg, May 24, 2013.
- 3 Hadid, Zaha, "I don't do nice". Interview with Jonathan Glancey, [www.theguardian.com](http://www.theguardian.com), October 9, 2006
- 4 Space by Studio Spazio in the exhibition *Dialogue Japan: Europa im AIT Architektursalon 2021*.
- 5 Juli Zeh, *New Year*, trans. Alta L. Price (New York, 2021), 81–82, 102.
- 6 Waris Dirie, *Desert Dawn* (London, 2002), 30–31.
- 7 Website of the film *Dutch Light*: <https://www.dutchlight.nl/the-myth-the-reality-the-film/> (accessed February 21, 2022).
- 8 Werner Sobek, "Thesis 14," in 17 Theses. Zumtobel Group Geschäftsbericht 2019/2020; <https://www.wernersobek.com/news/17-theses-on-sustainability/> (accessed August 8, 2022).





# SUSTAINABILITY

## The Art of Choosing the Right Light Source

Culture + Consideration = Sustainability

Sustainability takes place when culture goes hand in hand with consideration. What is sustainable lighting design? It comprises ecological, economic, and social aspects and begins with the generous and ideal application of daylight.

- Red glowing lava at the Fagradalsfjall in Iceland.
- The theater bar of the Oldenburg State Theater shines out into the city.

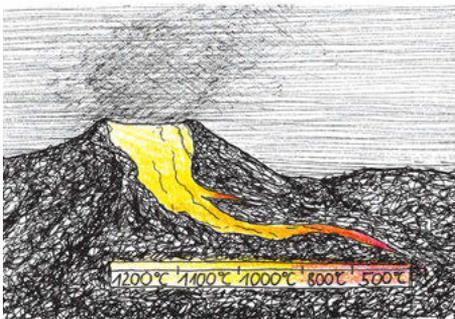
# How Artificial Light Is Created: Thermal Radiators, Discharge Lamps, Chemical Light Generation

## Lava as a Thermal Radiator

The Fagradalsfjall in Iceland draws a luminous line on the landscape with fiery lava (see p. 62). The hotter the lava, the brighter and whiter it shines; the cooler it is, the less bright and reddish warm the flow of lava glows. Thermal radiators work the same way. With incandescent lightbulbs and halogen incandescent lamps, the tungsten wire glows in temperatures of 2,600 to 3,200 Kelvin; if we dim them, the wire cools down and therefore glows warmer.

## The Gas Discharge in Neon Light

Neon lights were the predecessors of fluorescent lights. In contrast to the incandescent lamp, in a neon light gas plasma emits light as a light column between the two electrodes. With a filling of argon, a pink light occurs; helium within a yellow-tinted tube lets the light column appear yellow. Upon taking a closer look, you will see that not the entire glass tube is filled with light, but only the center.



- Like the tungsten wire of an incandescent lamp, lava emits light rays because the material glows due to the generation of heat.



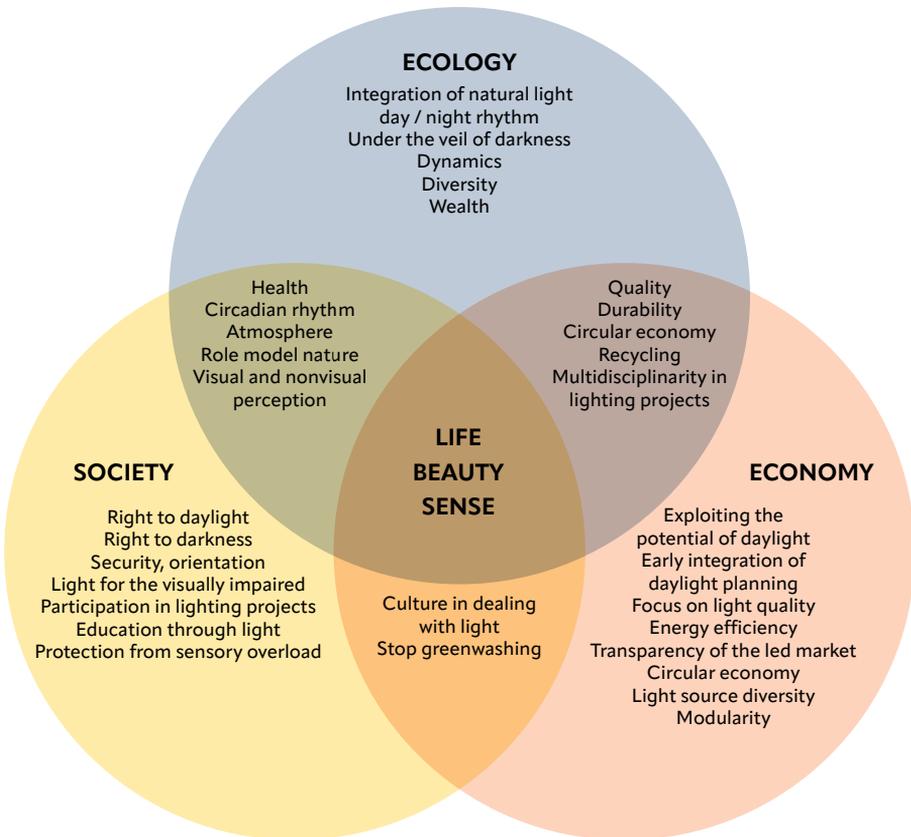
- In the gas plasma of the neon tube, electrons, excited by an electrical current, jump from one orbit around the atomic nucleus to the other, releasing energy in the form of light.

**“I [...] observe how difficult we find it to even understand that things like climate, environment, work, social justice, that it’s all connected [...]. At the same time, I demonstrate how much strength is contained in participation and self-empowerment, that is, in commitment and knowledge, in simply celebrating the beauty of life with others, also in order to reassure oneself again and again of what needs to be protected and defended.”<sup>1</sup> — Antje Boetius, 2021**

# Sustainability Comprises Ecological, Economic, and Social Aspects

Sustainable light under ecological, economic, and social aspects.

In times of the inflationary usage of the word *sustainability*, I have developed a definition referring to light and lighting design as shown in the illustration. The three thematic fields of ecology, economy, and society overlap; life, beauty, and sense are central aspects.



## The Ecology of Light

It was astronomers and environmentalists who launched the discourse on the ecological repercussions of omnipresent light—in other words, on light pollution. Medical practitioners and chronobiologists are now researching the effects of too much nocturnal light on health, as well as the aspect of a lack of light during the day. Nature and human beings need the rhythm of light and darkness on Earth.

Truly sustainable lighting design takes daylight into consideration as far as possible, as it is available without consuming any resources, without emitting any CO<sub>2</sub> during production or usage. This is an approach that is not taken into consideration enough in the construction sector. This is partly due to the fact that energy-efficient LEDs bring good, sufficient, and cheap light into interior spaces.

In the endeavor to build energy-efficient light sources, scientists and industry have reached a milestone with the invention of the blue (white light-emitting) LED. However, the anticipated positive ecological effect, a reduction in overall energy consumption, has failed to materialize. Instead of securing energy savings, our growth-based economy continuously launches ever bigger and brighter products onto the market. We consume more and more electrical energy for light. The world is becoming brighter than ever, day and night: we are observing a drastic rebound effect, similar to the one in the car market with its more efficient but more powerful engines.

### Economy: The Consequences of the LED on the Lighting Market

There are numerous sources that study various aspects of LED production and its disposal, which cannot be immediately compared, however. Some of the relevant information is as follows:

Worldwide, humankind produced 53.6 million metric tons of e-waste in 2019, according to [globalewaste.org](http://globalewaste.org): that was 21 percent more than in 2014. In 2019 only 17.4 percent of this was collected and recycled. For 2030, [globalwaste.org](http://globalwaste.org) is expecting 74 million metric tons of e-waste.<sup>2</sup>

Each German produces 19.4 kilos of e-waste per year. The percentage of lamps and luminaires and the amounts of different types of illuminants (compact fluorescent lamps, discharge lamps, LEDs) cannot be stringently derived from the statistics. Based on the lamps sold, we can only see how large the quantities of e-waste will be in subsequent years. Germany's Federal Environment Agency cites 39,659 metric tons of illuminants of all types sold in 2019, of which 10,384 metric tons were LED; in the same year, 7,952 metric tons of illuminants of all types were collected. The quantity of e-waste is increasing, but hardly any is recycled.

The 2009 EU regulation banning incandescent lightbulbs only promoted lighting systems in terms of luminous efficacy during operation, but ignored resource consumption for production and recycling. The illuminants industry benefited from the ban on incandescent lightbulbs: discontinued and environmentally harmful technologies such as the compact fluorescent lamp, misleadingly called "energy-saving lamp," were still being sold off. Only two to three years later did the massive sale of LED lamps commence.

Focusing on energy efficiency, designers first developed cool white LEDs with 6,000 Kelvin and more because LEDs with a higher color temperature have a 1 to 2 percent higher luminous efficacy than LEDs with a lower color temperature. However, cool white LEDs are mostly unsuitable for private and commercial use. We remember the cold fairy lights in gardens and on balconies with which residents wanted to make outdoor spaces cozy and friendly. The important quality of light lost out to energy efficiency, which eclipsed all other properties of light sources. However, the quality issue now puts other disadvantages of LEDs, such as their costly production and disposal, on the agenda.

## Life Cycle Management

The market for LEDs is growing. In 2019 more than 100 billion LED units were sold worldwide, 50 percent of which were for illumination in buildings. A growth rate of 12.5 percent per annum is predicted,<sup>3</sup> and the International Energy Agency reckons that LED lamps will have forced all other illuminants out of the market by 2025.<sup>4</sup> This, however, means that the quantity of LED waste will increase rapidly.

Besides the control gear, LEDs consist of rare earths and metals, such as lutetium, cerium, europium, gallium, indium, gold, and silver as well as plastics, ceramics, glass, organic casting compounds, adhesives, and other electronic components. Some of these raw materials are rare, and resources will be completely exhausted in the near future. Nevertheless, LED lamps are still not recycled so far; the valuable components are not reintroduced into the production process. It has long been documented how riskily old illuminants, especially fluorescent lamps containing mercury, have been disposed of in the global South under conditions that are hazardous to health.<sup>5</sup> Although LEDs fall under a different category to toxic fluorescent lamps according to the WEEE guidelines, they are collected together and are thus also contaminated with mercury. If LED illuminants were collected separately, they could be dismantled in an elaborate manual testing and recycling process, and a large percentage of the materials could be separated for production.

Proportionately these are:

- » Heat sink: 42.3 percent
- » Housing and connecting parts: 21.3 percent
- » Electronics in the driver: 16 percent
- » Glass: 15 percent
- » LED module: 3.5 percent
- » Base and contact plate: 1.9 percent.<sup>6</sup>

Since LEDs have become widespread as illuminants, the previously common separation of luminaire (housing and control gear, cable, plug) and illuminant is becoming increasingly rare; almost all components are thrown away together instead of being repaired separately.

In France, the French Repairability Index now makes the right of repairability measurable. The Ecodesign Directive, the Green Deal of the EU, and the action plan

for Circular Economy of the EU Commission are to implement the right of repair and repairable products on a national level in the future.<sup>7</sup>

Luminaire manufacturers are slowly beginning to move their production and recycling systems closer to a circular economy. Only then will this illuminant fulfill sustainability requirements.

## Hi-Tech – Low-Tech

Can a society that uses high-tech systems and manufacturing methods parallel to manual and analogue systems act in a successful way fit for the future? Striving for diversity with regard to products and techniques leaves less room for being susceptible to breakdowns. Large-scale power cuts show that being dependent on a single form of energy—electricity—for light, warmth, communication technology, and the work environment massively restricts the people affected. SARS-CoV-2 has also taught us how quickly supply chains reach the limits of their resilience.

So if working conditions were to be more humane, inventions more widely spread, and recycling and repairs more self-evident with consideration for nature, would economic and financial systems cease to drive minor units or enterprises into economic niches? In order to include scientific findings directly into concrete planning, an increased proximity of research and application will in any case be an exciting task for scientists, lighting planners, and architects. Allerd Stikker defines the integration of these nonmaterial aspects that are difficult to measure as essential:

“These factors, combined with the population explosion of the twentieth century, have led to a situation where we have occupied ourselves virtually exclusively and at great speed with the material and measurable aspects of innovations and not with the aspects that are nonmaterial and not as easy to measure but at least as important. The latter aspects are considerations of an ecological, social, ethical, or cultural nature or relate to a person’s own worldview.”<sup>8</sup>

# How to Plan with Sustainable Light

In order to explain the sustainability of their lighting systems and its benefits to clients, we need comparable data on various aspects of sustainability that must be measurable. There are several certificates regarding the energy efficiency of buildings in which lighting, however, is only one aspect among many. Focused on the industrial products of lamps and luminaires, special certificates are developing only slowly and inconsistently.

## Certificates for Sustainability in Building

Common environmental certificates for buildings are BREEAM, LEED, DGNB, DNB, and the WELL Building Standard. They give ratings for lighting designs, lamps, and luminaires with a view to lowering operating energy consumption and contain only few criteria regarding exposure and lighting:

LEED: The LEED (Leadership in Energy and Environmental Design) certificate developed in the USA deals with lighting design under the category "energy and atmosphere" and gives points in the order of their evaluation for:

1. A low energy consumption of the lighting system;
2. The controllability of the lighting;
3. The minimization of light pollution (also regarding the light that radiates out of buildings).

DGNB: The DGNB (German Sustainable Building Council) evaluates light under the criteria "health, comfort, and user satisfaction" regarding visual comfort and evaluates daylight availability, line of sight to the outside, glare-free daylight and artificial light, color rendering, and sun exposure.

## Assessment Criteria for Illuminants and Luminaires

The choice of the right light source contributes to sustainable lighting projects fit for the future. Next to the brief description of exemplary light sources I place the additional criteria:

1. Health and well-being
2. Recycling
3. Aesthetics and quality of light such as nonglaring, color reproduction, and color temperature

4. Durability
5. Transparency with regard to production and logistics
6. Lighting technology adapted to human vision
7. Energy efficiency in production, operation, and recycling
8. The climate-relevant CO<sub>2</sub> emissions in all product phases during manufacturing.

These are the criteria we query with luminaire manufacturers whose products we plan to use in our projects.

## **The Sustainability Aspect of Health and Well-Being: The Light Source of the Sun is Unequaled**

Spaces that are generously provided with daylight are healthy. We notice especially in the dark season how comfortable we feel in a space that is lit from two or more sides. More influence of daylight means more sustainability in any type of building. A healthy room in the full spectrum of natural light, upon which our body is dependent, makes for resilient as well as active people. Added to this are the advantages of lower energy consumption through electric lighting and, in the best case, fewer built-in luminaires.

In the many slums on Earth, the sheet metal huts often do not have windows. It is so dark during daytime that one can hardly see anything, let alone read. But old PET bottles filled with water and a little bleach, attached to suitably cut holes in the hut roofs, act as a light source. Thus, the sunlight is directed into the space and is well distributed.<sup>9</sup>

## **Recycling of Electric Illuminants: Comparison Incandescent Lamp – LED Retrofit**

From a recycling point of view, incandescent lightbulbs are best. They only consist of one glass bulb in which a tungsten wire is made to glow in an inert gas (nitrogen-argon, krypton, or xenon). The base is made of metal; the glass bulb is sealed in it. The image of the incandescent lamp shows the minimalist setup of materials (see p. 73). Together, that's about 30 grams of easily recyclable material.

The LED retrofit bulb replaced the incandescent bulb in existing luminaires, even in classic designs, following the incandescent ban. In order to be able to fit an LED retrofit bulb to any luminaire that previously housed an incandescent bulb, it needs a standardized socket such as the E27 or E14 socket and an integrated electronic drive which reduces the household voltage from 240V to 12V or 24V operating voltage. Therefore, it is often larger and heavier than an incandescent bulb and consists largely of plastics and composites, electronic scrap with bonded circuit boards, and other rare earth materials. The LED retrofits are hazardous waste; recycling is elaborate and expensive and happens only in the rarest of cases.

## **Aesthetics and Quality of Light Make Sources of Light Sustainable: Comparison Neon Light – Linear LED**

The more precisely the lighting concept is defined by a certain light quality, the more beautiful and timeless its value. The orange-red wall and ceiling lights by Verner Panton in the canteen of the Spiegel publishing house are design icons and have also moved into the new building. However, the aesthetic of neon lights is inimitable as they produce a colorful light pillar in a gas plasma. When the glass tube is clear, you can see the gas discharge if you look closely—a fascinating spectacle. The tube acquires depth and that fine appearance that lends great works of art of the twentieth century a special aura (see right). An LED line, packed into a plastic tube, on the other hand, is banal and no adequate substitute for a neon tube. For a while it seemed that the vibrant LED lines had entirely replaced neon lights and only a few glassblowers specialized in artistic lettering and signs mastered the craft. Since 2016, a renaissance of neon signs is now taking place. In operation, the neon tube consumes more energy to produce light (lumens/watt) than the LED, but it is easy to repair.

### **Durability of Lighting Concepts**

A durable lighting concept does not need to be replaced often. Essential for a durable lighting concept are high aesthetic quality, high-quality luminaires, and the orientation toward the users of the building. If the concept foresees modular or flexibly usable lighting elements, one can even enter into changes of use without having to exchange luminaires. If a concept allows for such additions and changes well, the lighting system will be long-lasting.

### **Durability of Luminaires**

Luminaires of high quality are sustainable because they function for a long time and are easily repaired. When manufacturers repair their luminaires even decades after they have been bought, then that is sustainable.

A timeless luminaire design and a high aesthetic quality result in luminaires' not being replaced every time there is a change in trend. Design classics show that sustainability can also mean fun and pleasure.

### **Transparency of Production and Logistics**

In production, transport routes between suppliers, manufacturers, and consumers play an important role. The knowledge of the origin of used components is helpful in evaluating working conditions and human rights during the production of these parts. Added to this are the electrical energy required for production (produced with low CO<sub>2</sub> emissions), the recyclability of the materials used, and the use of replaceable LED modules. Those who fulfill these criteria conscientiously pay more. For individual manufacturers, such criteria of sustainability are more easily established if planners and users have a preference for sustainable luminaires and lamps. Therefore, we urgently



- Incandescent lamps are made of few, well reusable materials.



- Historical neon writing.

need good legislation, and as long as this does not exist, each request put forward by the lighting designer to the manufacturer and each clarification to the property owner helps to introduce sustainable lighting.

### **A Lighting Technology Geared to Perceptual Physiology Does Not Overexpose and Is Economical**

The precise and holistic observation of luminous efficacy leads to more future viability. The luminous efficacy is measured in lumen per watt. A free-radiating luminaire has a higher luminous efficacy than one that is equipped with reflectors or lenses. What is important is that the light reaches the spot where it is needed. In addition to the technically described luminous efficacy, this approach includes the factor of usefulness and user practice. The limitation of glare ensures that people will not be dazzled and will need less light to be able to see: it's that easy!

## **Bioluminescence**

Learning from nature is a central part of lighting design fit for the future: exploring bioluminescence and experimenting with it opens up access to the most efficient existing light generation method. The image on the right shows the bioluminescence of fireflies flying over a meadow. Fireflies, glowing mushrooms, and jellyfish produce no heat when producing light due to a chemical reaction.

## **Recognizing Greenwashing**

As in other industries, greenwashing occurs in the lighting sector. The profession and their expertise oblige lighting designers to examine information critically and to know the interests of the stakeholders. In practice, this also means assessing new products for their properties, their suitability as a tool, and their side effects and evaluating them with a view to their usefulness and appropriateness as well as the circular economy.

## **Certificates of the Lighting Industry**

Luminaire manufacturers can have their companies certified with ISO 14001 and their products certified with the Product Life Cycle Accounting and Reporting Standard. As long as there are no uniformly agreed standards for the field of lighting, the players make do with defining their own standards for sustainability in an exchange between lighting designers, scientists, and luminaire manufacturers. The dialogue within the lighting sector and during projects between clients, architects, and the industry is increasingly raising awareness of sustainable lighting design.

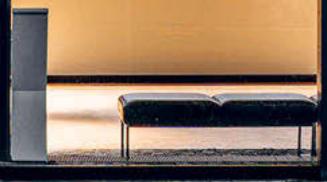


# The Shop Window Facing Outward: Oldenburg State Theater

In the Oldenburg State Theater, with the theater people's shared enthusiasm for neon lettering, we designed a 16-meter-long neon sign in red. For many citizens in Oldenburg, the theater is a central place, and in return the theater invites everyone in. The cozy and festive light shining through the large windows into the city now attracts people into the theater world regardless of performances. The foyer and bar have become a meeting place and a stage whose set design transforms again and again in the changing light scenes of the spotlights in front of the dark walls. The theater does not advertise by brightly illuminating its facade from the outside, but with atmospheric light from the inside.

— The foyer of the Oldenburg State Theater shines out like a shop window.

- 1 Interview with Antje Boetius, "Kein Grund zur Panik?" *Süddeutsche Zeitung*, June 20, 2021.
- 2 [Globalewaste.org](https://www.globalewaste.org); see also V. Forti, C. P. Baldé, R. Kuehr, and G. Bel, *The Global E-waste Monitor 2020: Quantities, Flows, and the Circular Economy Potential* (Bonn, 2020).
- 3 [www.grandviewresearch.com/industrie-analysis/led-lighting-market](https://www.grandviewresearch.com/industrie-analysis/led-lighting-market) (Accessed January 8, 2022).
- 4 [www.iea.org/reports/lighting](https://www.iea.org/reports/lighting).
- 5 *Bulb Fiction* (2011), dir. Christoph Mayr.
- 6 "LED Lamps Recycling Technology for a Circular Economy," *LED Professional*, August 25, 2016; <https://www.led-professional.com/resources-1/articles/led-lamps-recycling-technology-for-a-circular-economy> (accessed February 21, 2022).
- 7 The Sustainable Products Initiative (SPI) by the EU defines connecting factors in order to drive forward the production of durable, more easily repairable, recyclable, and energy-efficient products.
- 8 Allerd Stikker, *Code Orange for Life on Earth* (Rotterdam, 2019).
- 9 The organization *Liter of Light* successfully implements the project: <https://literoflight.org/>.





# HEALTH

## The Biological Effect of Light

Sustainability + Medicine = Health

The WHO defines health as a “state of complete physical, mental, and social well-being and not merely the absence of illness or infirmity.”<sup>1</sup> In this chapter, we will explore the visual and nonvisual effects of light on the health of people. We will explain the circadian rhythm and the natural and technical possibilities to support it. I use the example of the Cooperative Regional Control Center, Elmshorn, to show the positive effect architects and lighting designers can achieve with a space and lighting design of balanced amounts of daylight and artificial light.

— *Komorebi* is the Japanese word for sunlight shining through leaves.  
— The Cooperative Regional Control Center, Elmshorn, is bathed in light. Trapez Architekten, Hamburg.

# Semitransparency and Opacity: A Ping Pong of Light

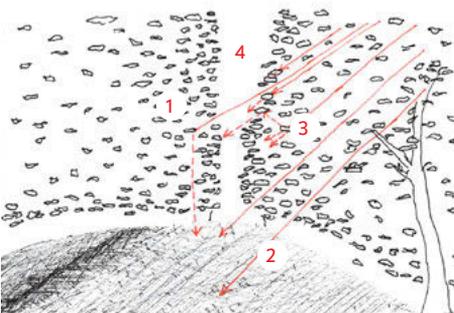
## Diffused Reflection and Transmission on Leaves

Light penetrates the foliage and the trees above and beside the forest path. Some of the rays of light are reflected by the leaves, they are thrown back and forth, others break through directly, are transmitted, and fill the space with light.

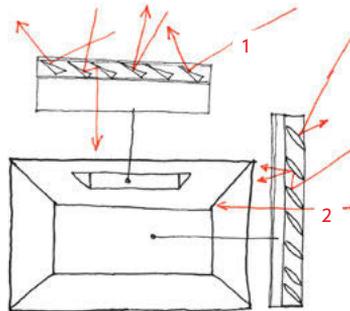
Opalescence and opacity complement each other. In this manner, this combination, neither produces a soup of light, nor a sharp contrast of light but rather a balanced, friendly, and stimulating light.

## Regular (Mirrored) Reflections in the Sun Protection Louver

The light-directing louvers in the space between the glazing of the skylight and the convex louvers of the south window throw back the direct sunlight while allowing diffused light from the sky to pass through. The space is thus supplied with daylight without being heated up by direct sunlight or dazzling employees at certain times.



- (1) reflection on surface
- (2) unobstructed beam path
- (3) filter (yellow leaf) and diffuser
- (4) multiple reflection allows permeability of certain light directions



- The mirror louver in the skylight reflects light back into the sky (1) by means of specular reflection and directs other rays inward (2). Both principles work on the louvers of the south facade.

**“A polka-dot has the form of the sun, which is a symbol of the energy of the whole world and our living life, and also the form of the moon, which is calm. Round, soft, colorful, senseless and unknown. Polka-dots can’t stay alone; like the communicative life of people, two or three polka-dots become movement... Polka-dots are a way to infinity.”<sup>2</sup> — Yayoi Kusama, 1978**

# How Does Inner Clock Work?

Sun and moon, day and night, these transitions and human society are the sources of our health. This cheerful quote also stands for light and its influence on our lives.

## Visual and Nonvisual Effects of Light

While the chapter “Evolution” discusses the visual functionality of the eye, here I will also explain the nonvisual aspects for healthy light and its consequences. Findings in medicine and ergonomics lead to definitions of correct lighting environments for workplaces considering visual aspects. They describe requirements for light with regard to brightness, glare, and contrast, in order for the human eye to effortlessly fulfill its various tasks. The resulting norms and standards are recommendations, not applicable law. In practice, however, they are binding where employers’ liability insurance associations prescribe them for the health care and insurance protection of employees.

The installation in the photo reflects sunlight onto the shady side of a passageway in Basel’s old town. Fortunately, “the sun shines for us,” and keeps us healthy and cheerful. That was not always and everywhere the case. Since industrialization, air pollution temporarily darkened the sun at times to such an extent that people, particularly in cramped slums and poor neighborhoods, suffered from rickets due to the resulting vitamin D deficiency.

The nonvisual effects of light on the circadian rhythm and the function of the ganglion cells in the retina of the eye have only been known since about 2002. Researchers realized that blue spectral components in white light have the strongest influence on the sleep-wake rhythm. In the meantime, these insights often flow into lighting design, sometimes well-founded, but sometimes with exaggerated expectations of technical solutions.

All living beings on Earth have adjusted to the rhythm of day and night. All biological processes have adjusted to this rhythm. These differ during day and night: in sleep phases, not only cell regeneration and detoxification but also information processing and the anchoring of memories take place in the brain. As soon as the processes are disturbed due to too much artificial light at night, we become ill.

The suprachiasmatic nucleus in the brain, consisting of approximately 50,000 cells with internal clocks, generates the rhythm in the exchange between these internal clock genes and their protein products. By the way, the individual differences of early risers, also called “early birds,” and nocturnal revelers, also called “night owls,” depend on these circadian genes.

In addition to the master clock of the suprachiasmatic nucleus, there are internal oscillating clocks in almost all organs and fibers of the body—a joint network that does not, however, keep the 24-hour rhythm precisely, because this takes about 10 minutes longer in humans. Here, like a metronome, the natural light of sunrise and sunset ensures the daily adaptation. The receptors for this process are the photosensitive gan-

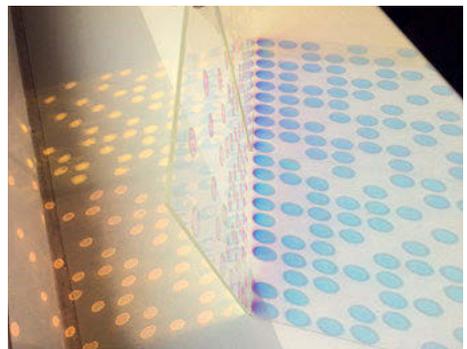
glion cells that were discovered in the frontal layer of the retina of the eye during the 1990s (see p. 28). They react to the wavelength of approximately 430–550 nanometers, which the sky intensely radiates above the glow of dawn and sunset on the horizon. Moreover, the retinal ganglion cells control the dilation of the pupils, alertness, and mood through their luminance sensitivity.

While youths have a high photosensitivity, it decreases significantly with age. So it is good for the elderly to be exposed to higher light quantities. This realization is increasingly gaining acceptance in the lighting design of retirement and nursing homes. Neurologists recommend illumination levels of 1,000–2,000 lux in the common rooms of retirement and nursing homes.

- *“... you should be happy that the sun still shines for you.”*  
Dieter Roth, 1975.



- Polka-dots are suitable as partial sun screening. Made of dichroic material, they function color-selectively.



## The Indoor Generation, Light Exposure, and Sleep-Wake Rhythm

Light quantities of approximately 5,000 lux are necessary in order to trigger the circadian rhythm, but such quantities of light only exist outdoors, not indoors. Nevertheless, "We spend up to 90 percent of our time in buildings, without daylight or fresh air: we are the 'indoor generation.'"<sup>3</sup>

"In a digital age that runs 24/7, daylight is an antidote to our increasing alienation from nature."<sup>4</sup>

The tendency of people to fall asleep late and to be tired in the morning arises through evening exposure to light; morning exposure to light leads to early waking. Researchers discovered this correlation in students who spent several weeks either indoors or in tents and outdoor spaces. For the influence of the sleep-wake rhythm, the intensity as well as the timing of exposure to light play a role. The wavelength of 480 nm is always effective in connection with other wavelengths. A monochrome wavelength of 480 nm alone would not suffice to trigger the circadian rhythm. The receptors for the other wavelengths, the cones and rods, must be stimulated simultaneously for the process to take place. However, the influence of various parameters is not yet fully explored so that in practice, we have to work with assumptions. The widespread opinion that elements of blue wavelengths in mobile phones and e-books would negatively influence the sleep-wake rhythm when reading before going to bed, however, is not true. The amounts of light emitted here are too small to have a harmful effect on the body.<sup>5</sup>



- People who spend a lot of time outdoors get the best protection against many physical and mental illnesses: all the wavelengths of daylight, but also enough darkness to sleep.

# Healthy Light for Living and Working

The emphasis for a lighting design depends on the health aspects on the uses, the users, and the location, the architecture, and its surroundings. For an office building, protection from glare is a more serious aspect than for a residential building. For a retirement home, generous natural lighting is extremely important, whereas people with impaired vision are irritated by strong contrasts especially in circulation areas and on stairs.

## Healthy light:

- » Is so balanced that it does not irritate the eyes (visually)
- » Is bright enough during daytime and dark enough during nighttime that it enhances our circadian rhythm and does not disturb it (nonvisually)
- » Has a beneficial effect on our psyche, stimulates us, makes us cheerful, or makes us calm.

We perceive the psychological effects of light particularly clearly in the change of seasons. Sara Teasdale (1884–1933) describes this aptly in the poem “May Night”:

The spring is fresh and fearless  
And every leaf is new,  
The world is brimmed with moonlight,  
The lilac brimmed with dew.  
Here in the moving shadows  
I catch my breath and sing—  
My heart is fresh and fearless  
And over-brimmed with spring.<sup>6</sup>

Sara Teasdale, 1884—1933

## Significant Visual Aspects: Required Minimum Light Intensity, Uniformity, and Glare Limitation

The illumination level necessary to enable sight is determined by the activity (see checklist of Client Requirements, Planning Prerequisites on p. 58). Different illumination levels are required for reading, sewing, drawing, chopping wood, when using high-speed machines, and for computer monitors; these are mostly measured on a horizontal surface at table height. A homogenous illumination of the immediate working space and the uniformity of the illumination level in the immediate surroundings create good visual conditions. These requirements not only apply to working surfaces but also to vertical surfaces such as walls, for this way, the eye does not need to constantly adapt to different brightnesses. However, if you illuminate the whole room too evenly, you create a boring and tiring atmosphere. In addition to brightness and its uniformity, glare limitation—measured in the Unified Glare Rating (UGR)—is helpful in planning a comfortable lighting situation. It sets the luminance of a light source in relation to the luminance of its surroundings or background, for example the room ceiling, and describes a recommended maximum contrast. The UGR method does not always determine the actual perceived glare emitted by a luminaire, particularly with LED luminaires (and their small points of light of a very high luminance).

Physiological glare is the demonstrable and calculable reduction of visual function, while psychological glare must be evaluated by a sufficiently large number of observers. In addition, short-wave rays (cooler light with a higher proportion of blue) cause a higher glare sensation than long-wave rays (warmer light with a higher proportion of red).<sup>7</sup>

## Significant Nonvisual Aspects: Human-Centered Light and Lighting Atmosphere

Research on circadian rhythm has made ground-breaking discoveries during the last fifteen years. We now know that living predominantly indoors is harmful to health, but also that light can be used specifically in therapies. When architects, urban planners, and lighting designers include these findings in their considerations early on, daylight can be drawn into buildings in the best possible way.

The healthiest light is unfiltered, spectrally rich daylight. Double- and multiple-glazed window panes absorb important wavelengths and decrease the amounts of light considerably: their implementation should be reconsidered. Doctors recommend spending enough time outdoors every day. How long that should actually be is dependent on the time of year, weather, and latitudes of the respective location. Morning walks are probably more effective than afternoon walks; the exposure to light acts as a wake-up impulse. General office lighting, even the so-called true light or full-spectrum lamps with a high proportion of blue, does not emit enough light to replace real daylight. In comparison, so-called daylight lights or light showers help better against depression and fatigue as they are placed directly in front of a person and therefore much more luminous flux reaches the eye than from the distant ceiling luminaire in the office.

Patients spend twenty-four hours a day in their hospital rooms. The fact that surroundings are helpful to the healing process is particularly true with regard to light: people recover from many diseases faster and need less medication when light supports their circadian rhythm. In test series and in practical situations, artificial light surfaces on the ceilings above beds simulate the course of natural light in brightness sequences and color temperatures. This not only promotes faster recovery, but also better orientation regarding hospital processes and, last but not least, well-being.

- 1 Preamble of the Constitution of the WHO, July 22, 1946.
- 2 Kusama, Yayoi, quoted in Laura Hoptman, Akira Tatehata, and Udo Kultermann, eds., (London, 2000), 112.
- 3 "The Indoor Generation by VELUX," May 15, 2018, YouGov study for VELUX, <https://press.velux.ch/yougov-studie-fur-velux-bringt-gefahren-fur-die-indoor-generation-ans-tageslicht/> (accessed February 22, 2022).
- 4 Mary Guzowski, *The Art of Architectural Daylighting* (London, 2018), 6.
- 5 See Russell Foster, "Light Regulation of Circadian Rhythms: Fact and Fiction and Design Implications," in *Architectural Design* 90, no. 6 (2020): 66–71; and Ian Ritchie, *Neuro Architecture: Designing with the Mind in Mind* (Chichester, 2020), 66ff.
- 6 Sara Teasdale, "May Night," [https://www.yourdaily-poem.com/listpoem.jsp?poem\\_id=3375](https://www.yourdaily-poem.com/listpoem.jsp?poem_id=3375) (accessed February 22, 2022).
- 7 Mathias Niedling, "Zum Einfluss des Spektrums auf die Blendung: Untersuchungen zur Wirkung des kurzwelligen Strahlungsanteils auf die physiologische und psychologische Blendung," diss., Technische Universität Berlin, 2018, 16.

# How Good Lighting Helps Staying Healthy: Continuous Operation and Shift Duty at Elmshorn Control Center

Policemen and firemen work day and night at the Cooperative Regional Control Center, Elmshorn, and must stay wide awake. They take emergency calls, decide how serious a situation is, and organize the rescue team. They constantly have four to five screens and an additional joint big screen in view. Occupational physicians and lighting designers call this a “demanding visual task.” In order to avoid reflective glare and high contrast, daylight was mostly shut out in control centers to date. Here, the clients and the team of planners risked exactly the opposite: to let in as much daylight as possible. This can only be achieved with well-planned screening elements against direct sunlight in the skylights and in front of the room-height windows. The combination of skylight and window is—similar to windows on two sides of a room—a gift; the daylight factor is outstandingly uniform and a pleasure. In such spaces, it is possible to breathe freely and to take part in the natural light-dark rhythm of the day, even when working shifts.

Just as the forest filters light during the day, the sophisticated geometry of the skylight glare protection of the Cooperative Regional Control Center, Elmshorn, filters the light. In addition to the screens, the skylight, the glass facade, and luminaires distributed like clouds create an atmosphere of light. The lighting comfort is high because the pendants not only shine directly downward, but also indirectly light up the ceiling. Similar luminance levels are produced by the ceiling and the round luminaires: direct glare and reflective glare via the screens are thus avoided; contrast and brightness are balanced. Control rooms should create a lighting environment that provides an uninterrupted focused view of the screen while offering visual rest through views out the window.

- Skylight, glass facade, and luminaires distributed like clouds.





# DARKNESS

## How Much Light Is Too Much?

Health + Rhythm = Dark Sky

The transition from intensive brightness during the day to adequate darkness during the night is important for human health. This is also true for plants and animals in their respective ways. From outer space, we see the massive amounts of light that we humans produce. What looks so beautiful from afar prevents our view into space. We produce light in order to see more, but we continually see less: we are losing one of the most beautiful phenomena of nature, the starlit sky.

I will demonstrate which lighting principles help and how to walk the tightrope between the need for orientation and public safety on the one hand and the need for darkness on the other.

- The aurora borealis over Tromsø, Norway, subtly changes.
- The facade of the Westfield Mall of the Netherlands in Leidschendam appears like a scarf billowing in the wind.

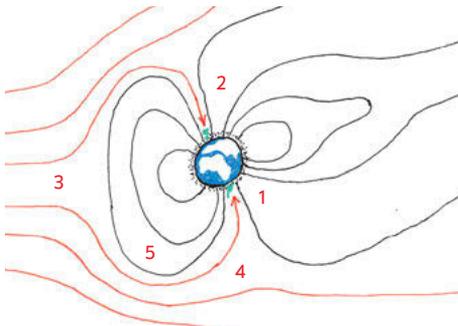
# How Does the Aurora Borealis Occur?

## Fluorescent Aurora Borealis

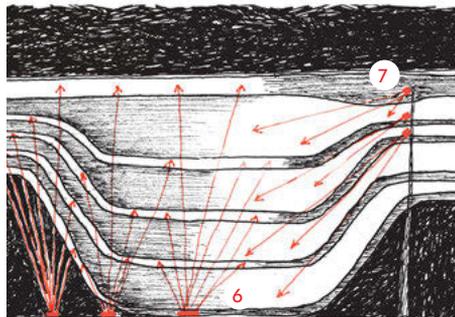
An aurora develops where solar wind particles meet oxygen and nitrogen atoms in the atmosphere and induce them to glow. The reactions with oxygen particles produce green; those with nitrogen particles, violet and blue wavelengths of light. Earth's magnetic field shown in the image creates a funnel-shaped protective shield above the poles; therefore, auroras are most frequent and strongest here. The changing intensity of the solar wind causes the constant movement of the aurora borealis.

## Opacity and Shadow from Various Directions of Light

The changing directions of light and the permanently mounted luminaires which are dimmed alternately let the white facade of the Mall of the Netherlands appear to move.



- Solar wind particles interact with atoms of the atmosphere and create light.
- 1 aurora
- 2 magnetic field lines
- 3 solar wind
- 4 solar wind particles
- 5 plasma



- The opaque facade reliefs cast changing shadows in alternating directions of light: light from below close to the facade (6), and light from the front and sides at a distance from the facade (7), alternating.

**“Stand in the evening light until you become transparent or until you fall asleep.”<sup>1</sup> — Yoko Ono, 1970**

**“You say light, I think shadow”<sup>2</sup> — Sandra Praun, Aleksandra Stratimirovic, 2017**

# We Need Shade during the Day and Darkness at Night

From nature, we also learn how to play with shadows. The apparent path of the sun makes all objects cast wandering shadows. The flickering fire in the caves of early humans threw dramatically twitching shadows on the walls. Without shadow, light would only be half as beautiful. The playful handling of shadow and darkness creates impressive atmospheres and touching works of art.

## The Right to Shade

Urban layout plans should not only allow for enough space in between buildings in order to achieve good daylight factors within interior spaces, but should also meet the need to provide shade in public spaces. The geographical location and its climate determine the degree respectively. We can only use exterior spaces where temperatures are bearable and where there is shade, such as, for example, in Hamburg (see right). In many areas of the world, cities have heated up to such an extent that hardly anyone walks even the shortest distances voluntarily. In formerly milder climate zones, many people die in major cities during summer heatwaves. The journalist Sam Bloch investigated the lack of shade in Los Angeles and called for the recognition of shade as a common resource and thus as an integral part of urban planning. In Los Angeles, a lot of shade exists only in wealthy neighborhoods. In poor residential areas, there are almost no trees in playgrounds, parking lots, and streets.<sup>3</sup> As I have also previously observed in Kuala Lumpur, people prefer to move around by car: the lack of shade increases the volume of motorized traffic.

## Darkness: Protection and Fear

The darkness of the night provides protection and can be frightening at the same time. There is historical, religious, and neurological-psychological evidence for this. Rather than understanding the night as the shadow of the Earth in the sunlight, until the Middle Ages, people in Europe interpreted the night as a punishment for sin, among other things. It was also believed that the night was God's proof that Hell existed. Witches and demons were assigned to darkness as the power of evil. The occupation of night-watchman, with the task of protecting sleeping citizens from fire and other dangers, already existed in the Roman Empire. In the sixteenth to eighteenth centuries in Europe, crimes committed at night were punished more severely than crimes committed during the day.<sup>4</sup>

The intense darkness of cities was lit sparsely by the light from the windows of houses and from the hand lanterns of the night watchmen so that people preferred to stay home at night. The term *nightlife* stems from the seventeenth century, as an active public life began to extend into the dark.

The neurological and psychological side of darkness was already mentioned in the chapter "Perception" under "Perception of Time and Reflections in Dark and Bright Spaces." Bright surroundings address the rational, dark surroundings the emotional and imaginative areas of our brain. Demons and scenarios of fear can develop unhindered in our imagination, rational control is reduced. However, the night also creates a sense of security: in evolutionary terms, darkness provides sleeping humans and animals with basic protection from observation and from attacking enemies. In the novel *American Dirt* by Jeanine Cummins, which is set in our contemporary world, refugees from Mexico experience both sides of darkness, namely fear and protection: "The sun sinks in front of them [...] and the colors are slow to deepen, slow to slip into blackness, but when at last they are gone, the darkness is deeper and more vast than anything Luca has ever seen. [...] The sky is clear and there are stars overhead, but the moon is new, so even when it rises, it offers no light to their path. Ideal conditions for crossing [...]."<sup>5</sup>

### Health: Light Nuisance and and Nighttime Disturbance

All humans and many animals need the rhythm of day and night, and therefore darkness, in order to sleep and stay healthy. In the wake phase, the organs of living beings prepare for the intake and processing of food. Digestive processes are more intensive during sleep. Energy resources are distributed in the body while, at the same time, vital activities such as cell repair or detoxification of the body take place. In the brain, memories consolidate and information processes are structured. Our daily functioning is thus dependent upon the quality of our sleep. The neurobiologist Russell Foster writes, "Our occupation of the night has been possible as a result of the widespread commercialization of electric light. This extraordinary resource has allowed us to declare war upon the night; our sleep and circadian organization have been the luckless victims, and the consequences to our performance and health can be serious."<sup>6</sup>



- In the heat of summer, the sign advertises shade, which is new in Hamburg.

## Species Protection

The systematic reduction of nocturnal brightness and targeted qualities of light (light pointing downward, good glare reduction, low quantities of light, and a tendency toward warm colors of light) contribute to the protection of flora and fauna. Many plants alter their growth and reproduction patterns when exposed to artificial light at night. As a result of this, the flowering time of plants can set in earlier or later. The fact that foliage stays on trees longer can be easily observed where street lights disappear into the crowns of trees. The branches closest to the luminaire are still leafy when all other branches are already bare. Many plant seeds need sufficiently long periods of darkness to germinate. Plants that reproduce via runners or rhizomes are thus favored over seed-producing plants in their propagation.

On land, amphibians mostly move around at night so that their skin does not dry out; the darkness also protects them from enemies. Even weak light sources limit their sense of orientation and disturb them in their search for food and breeding partners. Carnivorous animals lose their hunting grounds due to light barriers. Insects are attracted to light and die of exhaustion if they incessantly circle artificial light sources. The females of the large firefly use bioluminescence to attract males over distances of up to 45 meters. They thus compete with artificial light and have become noticeably rarer over the last 50 years. Migratory birds that orient themselves by stars or the Earth's magnetic field are misguided by the light of cities and cannot find their flight paths or fly detours. Birds that feed exclusively on night insects find less food in their usual foraging places, and many of their former habitats are lost due to light emissions.

Without biodiversity, the balance of the ecosystem is destroyed. The food chain no longer functions and we deprive ourselves of our fundamental basis of existence if light pollution is not curbed and decreased.<sup>7</sup>

## Dark Sky

There are various initiatives, policies, and laws aiming to protect and reclaim darkness so that we can cast an unclouded glance into space.

The UNESCO, the CIE (International Commission on Illumination) and the IAU (International Astronomical Union) have developed a package of measures to reduce light pollution caused by public illumination and private lighting.

## ↗ Measures to Prevent Light Pollution According to CIE and IAU

- Limit lighting times
- Restrict advertising at night
- Reduce unnecessary lighting
- Avoid directions of light from below and against the horizon
- Forgo luminaires that radiate upward, like recessed floor luminaires
- Use only well-shielded luminaires

More information is published by the following organizations:

- The “Guide to the Lighting of Urban Areas (CIE-136-2000)” (<https://cie.co.at/publications/guide-lighting-urban-areas>) and the “Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations (CIE 150-2003)” (<https://cie.co.at/publications/guide-limitation-effects-obtrusive-light-outdoor-lighting-installations-2nd-edition>) provide further recommendations for protection against light pollution.
- The International Dark-Sky Association (IDA, <https://www.darksky.org/>) collects information, educates, and awards seals of approval for luminaires that cast little stray light into the sky.
- The IUCN Dark Skies Advisory Group (DSAG, <https://darkskyparks.splet.arnes.si/2009/12/18/dsag/>), a working group of the International Union for Conservation of Nature and Natural Resources (IUCN), classifies light-protected areas under assessment with various criteria.

## Stellar Parks

The UNESCO has designated nocturnal darkness as a cultural property worthy of protection: the visible starlit sky is a natural resource. Astronomy and sea travel could only develop with the help of the dark, starlit sky. The Bortle scale categorizes the sky luminosity over the quantity of stars that are still perceptible to the naked eye. The International Dark Sky Association (IDA) awards star parks with the help of this scale in the categories gold, silver, and bronze. Bortle-scale maps visualize how light pollution has increased massively decade to decade.

## Laws and Regulations to Protect against Light Pollution

In 1988 in the Canary Islands, the first law worldwide was passed to reduce light pollution with the Ley del Cielo. In 1999 Chile was the first country to create nationwide laws (Norma de la Contaminación Lumínica) to limit light pollution in order to preserve observatory sites. In Europe, the Czech Republic was the first state that passed a law to dim street lighting around 2010. Today, various statutory provisions and regulations against light pollution exist worldwide. The Austrian organization Helle Not (bright plight), which is striving to contribute to the prevention of light smog, lists multiple European regulations.<sup>8</sup> The laws applicable in different European regions are predominantly the responsibility of the federal states and regions and, to the detriment of uniform procedures, can vary quite widely. The Federal Emission Control Act in Germany refers to inner-city residential areas and regulates the light emissions that could disturb the neighborhood through windows or exterior lighting. Since around 2010 planning practitioners are increasingly asked to verify compliance with the maximum permissible values in lighting design.

# Light Pollution and Lurking Dangers: Designing Darkness Using Lighting Master Plans

How much artificial light do we need during the night? Good parties only work in the (relative) dark. An urban space that is too bright, on the other hand, dispels the special nocturnal mood. That is not necessary as more light does not imply more safety.

From a distance, the constantly increasing light pollution shows over Hamburg's night sky. Hamburg Harbor as an outdoor workplace as well as the public lighting of the transport routes contribute to this. Good workplace lighting and good public lighting have to find a balance between an environmentally friendly, sensitive light and sufficient lighting that provides a sense of security. Purposefully placed, uniform, non-dazzling light does not need to be particularly bright in order to provide good visual conditions.

Private and public lighting shine ever brighter every year. This view from a spaceship onto the Gulf of Mexico shows the enormous global light emission. From an airplane, you can see very well where there are new LED light installations and where there are old, dimmer light sources. Rather than using the advantage of energy efficiency and less electricity consumption, we make the world brighter to its detriment and to all of ours.



— The night sky above Hamburg.



— View from a spaceship onto the Gulf of Mexico.

## Lighting Master Plans for Cities

The first lighting master plans for cities emerged in the 1990s. First, they were motivated by making cities more interesting and livable at night by highlighting special features in the cityscape and by implementing lighting fixtures for aesthetic, maintenance, and cost reasons. In the beginning, the cities as the contracting authority separated the lighting of streets, the so-called functional lighting, from the lighting of facades and monuments, the so-called decorative lighting, and assigned separate planning competences to both. A coherent atmosphere without any light duplication can, however, only be realized in a holistic lighting concept. In the lighting master plan for the Expo 2000 in Hannover, we retained the darkness in the spacious parks that stretched across the pavilion grounds in order to enable recuperation from the sensory overload of the exhibition. What was still a pioneering achievement in 1997 is now more self-evident. Thus, the desire for vivid light and a glare-free view over dark surfaces of water and into the night sky finds a good balance in the lighting master plan for Rotterdam.<sup>9</sup>

## Lighting Councils and Committees

Master plans and lighting concepts for cities can limit and “reverse” the worldwide overload of light. Their lighting principles, systematically applied, are classified as rules in the respective cities and boroughs. Master plans that are continuously renewed and perpetuated by committees and lighting councils are tools for good lighting in the public space. A lively exchange of experiences between experts and citizens of various cities encourages the conscious handling of light and darkness. Another great supraregional example is the LUCIA Project, a cooperation of cities of the Baltic Sea Region, which fosters the exchange of knowledge between city administrations and planners on sustainable public lighting and implements it in concrete pilot projects.<sup>10</sup>

## Safety

In the debate on safety through lighting in the public space, terms such as *objective safety*, *sense of safety*, *fear of crime*, and *space of fear* are compounded. A distinction is made between objective safety and subjective safety, in which the person does not feel any fear of danger. A correlation between crime and lighting has not yet been proven in studies.<sup>11</sup> Rather, improvements in subjective safety result only from a higher quality of light and not, as is often implied, from higher luminance and illuminance levels. The EN 13201-2 for pavements that are exclusively for pedestrians, for example, recommends a horizontal illumination level of 5 lux for a normal crime risk, but 10 lux for a higher crime risk. For safety and the environment, however, an increase in glare limitation with a constant illuminance of 5 lux would make far more sense.

What actually leads to more subjective safety for different population groups is best demonstrated by projects with citizen participation. When different disciplines work closely together, they can specifically address the needs of the local population.

Subways are scary when there is a strong light contrast at the exit of the tunnel. Signals of social disorder, a lack of social control perspective, pollution and neglect, lack of clarity, and the solitude of certain locations influence the subjective feeling of safety more than their illumination. That is why we need to illuminate the public space in such a way that it adopts the perspective of pedestrians and cyclists.

## Participation, Equality

Initiatives of participation come from NGOs or EU projects: Plan International and UN-Habitat jointly organize so-called Safety Walks in the context of Urban Programme – Sichere Städte für Mädchen (Safe Cities for Girls) in which project participants record places with photos and texts within their neighborhoods that they have experienced or perceived as dangerous. "Subsequently, they create maps on which they mark the places potentially dangerous for girls. With this, they approach authorities such as the police, city councilors, or government representatives to demand improvements. [...] Girls and also boys are actively involved in the shaping and development of their neighborhood. Currently, the program is carried out in 12 countries, among others in Egypt, India, Peru, Vietnam, Australia, and Spain."<sup>12</sup>



— Light point heights near the shore in the Rotterdam lighting concept.

## Guidelines for Master Plans

During the course of our lighting master plans for various cities, we have developed the following guidelines for adequate, atmospheric, and considerate lighting:

### **Good glare reduction/glare limitation. (A)**

An even better glare reduction than the one requested in the EN 13201 standard, especially for street lighting, relieves the eyes, which can see better without glare, even with less brightness. In the illustration, the beam angle of the luminaire is less than 180 degrees.

### **Low-glare individual spotlights, directed downward. (B)**

The lighting technique of spotlights that are affixed to multifunctional masts allows for precise glare reduction as well as differentiated direction of light.

### **Low light point heights from bollards and low masts. (C)**

Low light point heights from bollards and low masts distract birds and insects less than great light point heights. They are partially below their flight path and usually create smaller and more precisely defined light cones with similar illuminance.

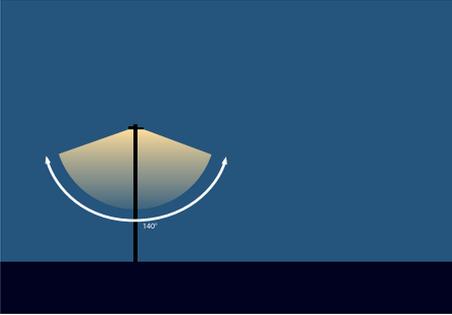
### **Light on demand for pedestrians. (D)**

The image shows how lighting on streets can be controlled for pedestrians, cyclists, and motorists to be brighter or darker as needed. When there is less traffic, the luminaires in a particular section can be dimmed via motion and other sensors.

### **Avoid upward light in the open air. (E)**

When upward light in exterior spaces is applied only under canopies and avoided in the open air, the sky remains darker. To light up trees from below became fashionable in the 1990s because the luminaires disappear so beautifully into the ground and are rather invisible during the day. However, it is better to find other ways of accentuating trees or to rely on the stray light that may be present. For the illumination of buildings, we can direct luminaires with a narrow half chaff angle—meaning a sharply defined light cone—diagonally and not vertically onto the facade.

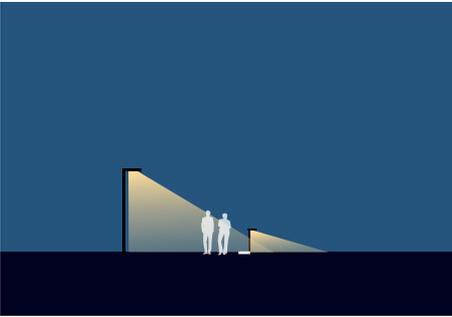
A



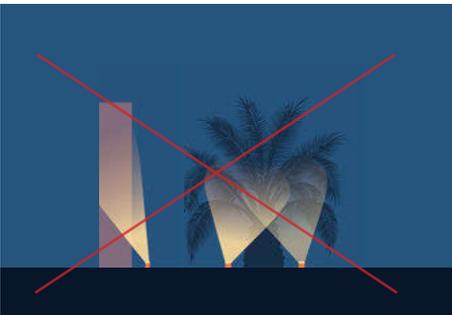
B



C



E



D

# Low Light Emission as a Concept: Mall of the Netherlands, Leidschendam

The Mall of the Netherlands was redeveloped from an existing shopping mall with open-air shopping streets. The architects show the transformation on the outside with a gigantic "scarf" that is looped around the entire building complex and that appears to move in the light. With the soft dimming levels between light and shadow, the facade shows presence and glows in a peacefully reserved way without disturbing residents. It helps people to find their way around the district at night and to feel safe.

— Nighttime view of the Westfield Mall of the Netherlands.

- 1 Ono, Yoko: *Grapefruit: A Book of Instructions and Drawings by Yoko Ono*. New York City 1970, S. 246.
- 2 Praun, Sandra, Stratimirovic, Aleksandra: *You Say Light – I Think Shadow*. Stockholm 2015.
- 3 Sam Bloch, "Shade," *Places Journal* (April 2019); <https://doi.org/10.22269/190423> (accessed March 31, 2022).
- 4 Ernst Peter Fischer, *Durch die Nacht: Eine Naturgeschichte der Dunkelheit* (Munich, 2015), 65ff.
- 5 Jeanine Cummins, *American Dirt* (New York, 2020), 317, 323.
- 6 Russell Foster, "Light Regulation of Circadian Rhythms: Fact and Fiction and Design Implications," in *Neuro Architecture: Designing with the Mind in Mind*, ed. Ian Ritchie (Chichester, 2020), 67.
- 7 Antoine Sierro, *Hell leuchtet die Nacht! Wie Lichtverschmutzung die Natur belastet* (Sion, 2019).
- 8 See: <https://hellenot.org/themen/gesetz-norm-und-leitfaden/#c1018> am (accessed May 1, 2022).
- 9 Ulrike Brandi Licht and Gemeente Rotterdam, eds., *Rotterdamse Stijl: Lichtplan Rotterdam* (Rotterdam, 2011).
- 10 See: <https://lucia-project.eu/resources-for-you> (accessed March 30, 2022).
- 11 LiTG – Fachgebiet Physiologie und Wahrnehmung, *Beleuchtung und Kriminalität*, no. 45 (2021).
- 12 Dunja Storp, "Von einer, die auszog, das Fürchten zu lernen: Licht und Sicherheit im Kontext der Planung," *Licht* (January 2022): 50ff.
- 13 Plan Redaktion, *Sichere Städte für Mädchen*; <https://www.plan.de/aktuelles/kampagnen-und-aktionen/safer-cities-sichere-staedte-fuer-maedchen.html> (accessed March 31, 2022). Nowadays there are also Safer City Maps for many German cities: <https://www.plan.de/safer-cities-map/#/>.





# DYNAMICS

## Controlling and Dimming Light Scenes

Dark Sky + Time = Dynamics

Control systems afford the possibility to adjust lighting situations according to need. This is convenient and saves energy in comparison to inflexible lighting systems. We have been able to dim electrical light for a long time; this is more complex with digital illuminants such as LEDs than with incandescent lamps. The advantage: control systems interact with the luminaires. They are being further developed and the industry is gradually establishing common standards. After having established a good knowledge of the clients' and users' requirements, lighting designers, electrical engineers, and media engineers make specific recommendations on an appropriate lighting control system.

- The Berlin sky.
- The ceilings of the ICE 4 cite the light of the sky during the course of the day.

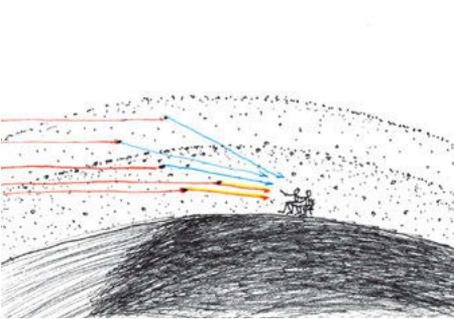
# The Vibrant Sky: Wavelengths in White Sunlight

## The Rayleigh Scattering in the Sky

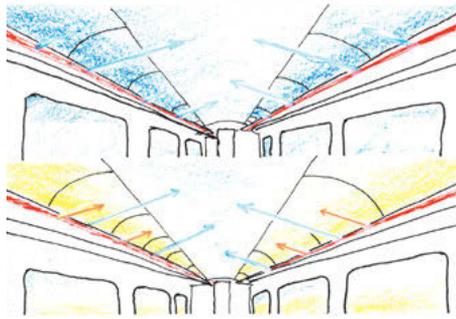
The Rayleigh scattering explains the blue of the sky and the red of the morning and evening sky. High in the sky, sunlight covers a short distance through the atmosphere, whose molecules only scatter few blue radiation components in other directions. Low in the sky, in the morning and evening, sunlight covers a much longer distance through the atmosphere, and far more high-frequency blue light waves are scattered to the side. Thus, more red long wavelengths reach the observer. The sun and the area of the sky around it appear in a reddish orange.

## Accent Lighting on the ICE 4: Controlled RGB-W LED Light Up the Ceiling

With LEDs, various temperatures of color are created differently: either the monochrome light is mixed with a red, green, and blue LED—which are often combined with one or two white LEDs on one circuit board (RGB-W and RGB-WW)—or two white LEDs (one warm white and one cool white) are combined.



- Scattering of sunlight: from flat angles with a long path through the atmosphere (red-orange rays) and from wide angles with a short path through the atmosphere (blue rays).



- RGB-W light-emitting diodes produce more blue light when red and green components are used less (top); and a warmer white light when red and green components are used more (bottom).

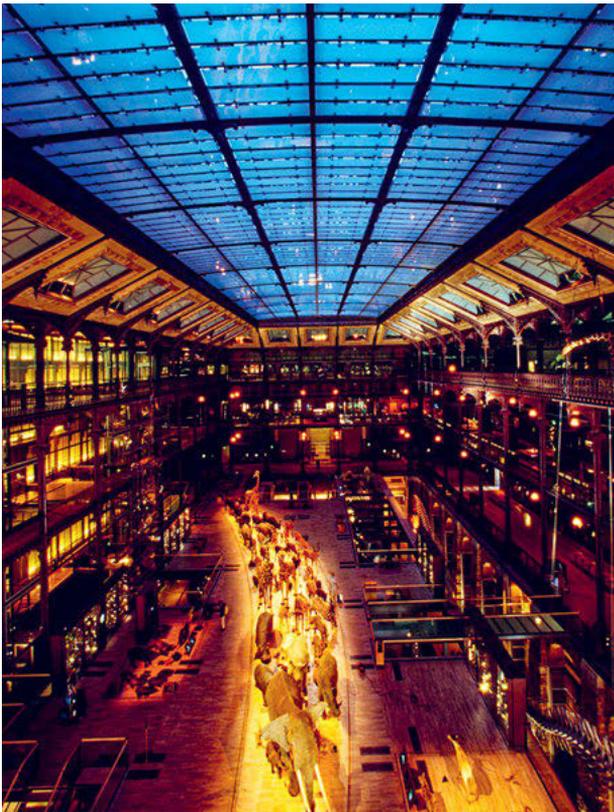
**“At times I think of the way the sun would set on the farmland around our small house in the autumn. [...] the sun setting behind you, the sky in front shimmering in a hasty pink and soft, then slightly blue again, as though it could not stop going on in its beauty, then the land closest to the setting sun would get dark, almost black against the orange line of horizon [...] and the sky lingering, lingering, then finally dark. As though the soul can be quiet for those moments. All life amazes me.”<sup>1</sup> — Elizabeth Strout, 2019**

# Why Control Light?

One of the reasons to apply lighting control systems is that the acceptance for color temperatures and brightness of electrical light changes in the course of the day. Bright light in cooler colors, which we find pleasant during the day, appears to us at night as glaring, fridge-cold, and unfriendly. The warm, subdued light that we like in the evening appears dull, dark, and yellowed during daytime.

In the theater, light has been controlled for a long time as it is used as an essential dramaturgical stylistic device. In 1994 we realized the first lighting control system in architecture that runs through a daily routine of lighting scenes at the Grande Galerie des Musée d'Histoire Naturelle in Paris. It uses a theater control system adapted for the museum installation. Over the course of the day, the sky (the glazed ceiling) and the spotlights illuminating the procession of animals into Noah's Ark gradually change.

Today, intelligent light management in architecture and exterior lighting are a matter of course. The chart (see right) shows the advantages and new aspects of light management for our profession.



— Continuously controlled light at the Grande Galerie des Musée d'Histoire Naturelle, Paris.

# ↗ Reasons for using lighting control systems.

Reasons	How	Where	Example
<b>Primary</b>			
Flexibility	<ul style="list-style-type: none"> <li>» Daily use</li> <li>» Openness for variable requirements</li> </ul>		
<b>Ergonomics</b>			
Health	<ul style="list-style-type: none"> <li>» Adherence to norms</li> <li>» Human-centered light</li> </ul>	<ul style="list-style-type: none"> <li>» Office</li> <li>» Hospital</li> </ul>	<ul style="list-style-type: none"> <li>» Adaptation of light colors to circadian rhythms</li> <li>» Support of the healing process through light intensity / colors</li> </ul>
Security	<ul style="list-style-type: none"> <li>» Adaptation of brightness to the environment</li> </ul>	<ul style="list-style-type: none"> <li>» Street lighting</li> </ul>	<ul style="list-style-type: none"> <li>» Adaptation of light to frequency of use</li> </ul>
<b>Psychology</b>			
Harmonious atmosphere	<ul style="list-style-type: none"> <li>» Changing brightness and color of light</li> </ul>	<ul style="list-style-type: none"> <li>» Domestic, office, restaurant</li> </ul>	<ul style="list-style-type: none"> <li>» Bright / fresh during the day, warm / dimmed in the evening</li> </ul>
Attention	<ul style="list-style-type: none"> <li>» Changes in brightness</li> </ul>	<ul style="list-style-type: none"> <li>» Theater / cinema</li> <li>» Sales, advertising</li> </ul>	<ul style="list-style-type: none"> <li>» Light goes off: the show begins.</li> <li>» Draw the eye</li> </ul>
Self-determination	<ul style="list-style-type: none"> <li>» Individual influence</li> </ul>	<ul style="list-style-type: none"> <li>» Offices</li> </ul>	<ul style="list-style-type: none"> <li>» Control system for individual work stations</li> </ul>
<b>Economy/Ecology</b>			
Reduction of energy consumption	<ul style="list-style-type: none"> <li>» Brightness according to requirements</li> </ul>	<ul style="list-style-type: none"> <li>» Offices</li> </ul>	<ul style="list-style-type: none"> <li>» Lights off in absence</li> <li>» Reduction of electric light according to daylight</li> </ul>
Reduction of light pollution		<ul style="list-style-type: none"> <li>» Public lighting</li> <li>» Outdoor sports facilities</li> </ul>	<ul style="list-style-type: none"> <li>» Adaption of light according to traffic density</li> <li>» Manual switch on, timer switch off</li> </ul>

# Light Scenes, Integrated Circuits, and Control Charts: A Playground for Technophiles

For concrete planning, the first step is to inquire about and focus on the expectations of the group of users and clients. Between the statement, "Actually, we don't want a control system; it's too complicated and expensive. A simple lightswitch will do for us," and the wish to be able to control each luminaire individually in brightness and color from everywhere, it is necessary to design a practical system. The handling must be tailored to the users and their working environment; the control system should run smoothly and consistently.

Lighting tests during the planning stage help in formulating the users' wishes (see right). This is particularly important in museums. Once these parameters are clarified, lighting designers can set up light scenes, integrated circuits, and control system charts.

## Sequences and Light Scenes

There are two fundamentally different applications for control systems in architecture.

- » Preprogrammed scenes: a sequence is programmed when the artificial light is to be adapted to daylight or a certain time of day is to be re-created. Sequences can be repeated in a loop, be called up when required, or driven automatically at predetermined times or other impulses. This is what we find in museums, offices, hospitals, and hotels.
- » Preprogrammed static light scenes: a different way to deploy control systems is to preprogram static light scenes whose control groups are assigned specific dimming and / or color temperature values. Users call up the respective desired light scenes. This is sensible in lecture halls, multifunctional rooms, individual offices, and private homes.

## Dimming and Changing of Color Temperatures

The dimming of LEDs requires more technical modules than that of incandescent lamps and halogen incandescent lamps. There are two methods: pulse width modulation and current dimming.

- » With pulse width modulation, the LED is switched on and off in rapid succession. People perceive the temporal mean value—with the same switch-on and switch-off time of 50 percent, a 50 percent light intensity appears. The dimming frequency should number more than 400 Hz so that stroboscopic effects that may generally cause headaches and that are a danger for people with epilepsy can be avoided.
- » Current dimming makes use of the fact that the intensity of the LED light is relatively proportional to the current flowing through the LED. When using this method, flickering or the pearlescent effect cannot occur as is the case with the pulse-width modulation; however, the intensity and color temperature of two adjacent LEDs may be strikingly different.

“Dim-to-warm” LEDs can imitate the typical (and preferred) change in color temperature into the warm spectrum (from 2,700 Kelvin to 2,200 Kelvin) that occurs during the dimming process.



— Lighting test.

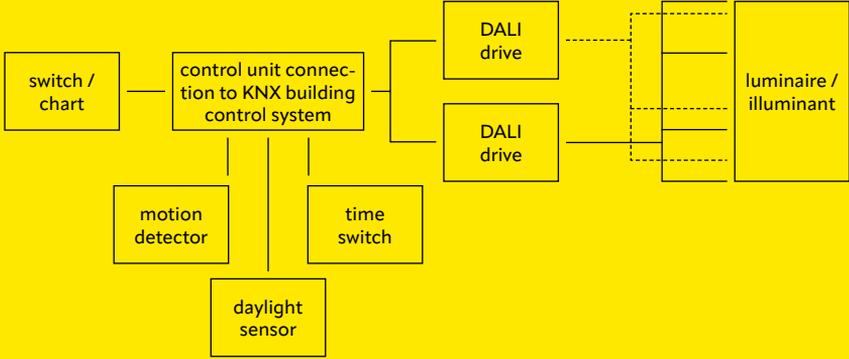
## Systems for Lighting Control Systems and Light Management

Modern control systems are evolving, are becoming smaller, more complex, and more user-friendly, but not easier to install. Smart home, smart building, and smart city raise high expectations in many projects that not every system can fulfill. This makes it all the more important to provide clarity during the planning process regarding the objectives. Standardization is only taking place gradually due to a multitude of products of various manufacturers (hardware and software). The KNX System has prevailed as a standard for building and home control. DALI (Digital Addressable Lighting Interface) is a special protocol for digital lighting control systems that enables an easy installation of robust, scalable, and flexible lighting networks. The upper scheme shows a DALI control system and its components. DALI is an industry-wide standardized protocol in the international standard IEC 62386. In buildings, the DALI lighting control system is integrated into the general KNX control.

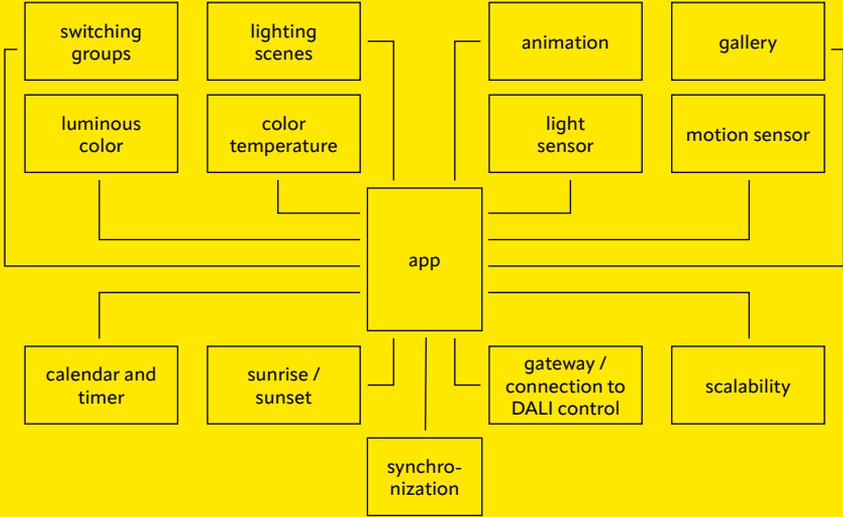
Wireless mesh networks enable an intelligent lighting control system on the basis of Bluetooth low energy. The bottom scheme shows a Bluetooth control system via an app. The light can be directly programmed and controlled via the app. This is convenient for spatial situations that often change, such as temporary exhibitions in museums; it saves time and is fun.

Lighting control systems can support principles of the circular economy, such as cradle to cradle, and contribute their share to durable architecture and urban development with high flexibility of infrastructure. Electrical engineers, lighting designers, and specialists for building automation prefer open and convenient systems. The intelligent implementation of control systems in the interest of the user follows the principle of less is more. At the same time, one must not dispense with so-called fallback scenarios, which one can use when complex control systems fail.

### DALI control scheme



### Bluetooth control scheme



# The Sky Is Aboard: Daylight Moods on the ICE 4 Train

Passengers of the Deutsche Bahn are on the move during the day and at night. The large windows on both sides of the ICE 4 let in a lot of daylight; the carriages have a high daylight factor (when they are not going through a tunnel). We designed the light scenes that accompany the daily schedule and their respective control system based on the existing linear LED luminaires. Daylight changes its color from bluish-white to the warm white of the red evening sky. The image on the right shows the warm-white interior lighting at 6 pm in the ICE 4 as the train passes through the evening in Hamburg. In the interior of the train, the artificial light simulates the changes in the light of the sky. The direct component of the main light varies between 3,000 Kelvin and 4,000 Kelvin, while the indirect accent light offsets the ceiling in a corresponding pastel light. The light colors are based on perceptual-psychological principles, and the passengers on the train find the experience of controlled light to be pleasant, as it follows the natural rhythm of the day.

— The ICE 4 travels through the evening.





# COMPOSITION

## It's All in the Mix

Dynamics + Connection of the Building  
Blocks = Composition

Whether daylight or artificial lighting design: lighting projects begin with an analysis of the available daylight in the building or in the outside space. We develop our concept for artificial light – that can indeed create similar moods to that of daylight – from this analysis and from the specifics of the architecture, location, and uses. Light gives orientation in space and time, it divides areas into sections, it refreshes, rouses, calms down, and accentuates when the various light elements are combined well with one another.

- Morning sky in Sankt Pauli.
- The train shed of Rotterdam Centraal Station has a bright atmosphere.

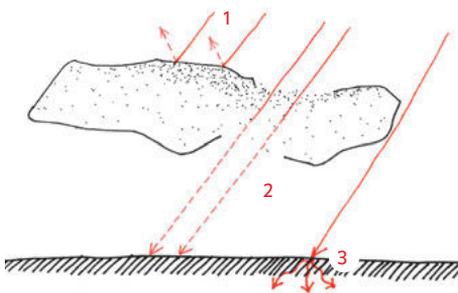
# Absorption, Reflection, and Transmission

## Absorption, Reflection, Transmission on the Ground and in the Clouds

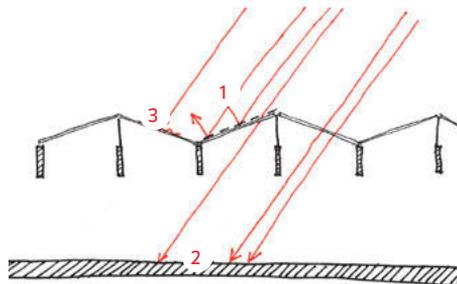
Morning sky in Saint Pauli: The concrete flooring in the foreground shows the phenomenon of absorption of light. The gray surface reflects only little radiance and absorbs it; thus, a large part of the visible light is converted into heat. The upper side of the white clouds reflects a proportion of the sunlight back into space. The cloud mass transmits a different part of the radiation in its differently dense layers, so that only a little light hits the ground and water. Where there are holes in the cloud cover, these allow direct sunlight and skylight to shine through, and there is an almost unhindered transmission of light rays through the air.

## Absorption, Reflection, Transmission

The same physical phenomena of absorption, reflection, and transmission are observable with other materials in the case of the roof of the train shed of Rotterdam Central Station. It absorbs visible light with its opaque photovoltaic surfaces and transforms it into electrical energy. The grid points in the glass ceiling reflect a defined proportion of light rays while the gaps in the grid are clear, transmitting the remaining part of the solar radiation accumulating here into the train shed. A third of the glass roof over the shed is completely clear and transmits direct sunlight into the shed.



- Reflection (1) takes place on the cloud, transmission (2), within it, and absorption (3), on the ground.



- The photovoltaic elements absorb the sunlight (3), the printed glasses reflect (1), and the clear glasses transmit the light rays (2).

**“Let me tell you now, child  
That morning sun is here  
to greet us  
With a loving light, so warm  
That morning sun is here  
to meet us  
Waiting on the waking up  
of everyone  
She ain’t gonna quit  
‘Til you’re smiling now.”<sup>1</sup> —  
Melody Gardot, 2015**

# Variation Stimulates Light Preferences

The knowledge of the psychological effect of light on people helps us to plan light adequately and to actively support certain uses and groups of users. We know that darker lighting situations appeal to the imaginative, emotional side of the brain, while brighter spaces rather appeal to the rational, reason-driven side.

## **Psychological Basic Needs of People in Relation to Their Living Environment**

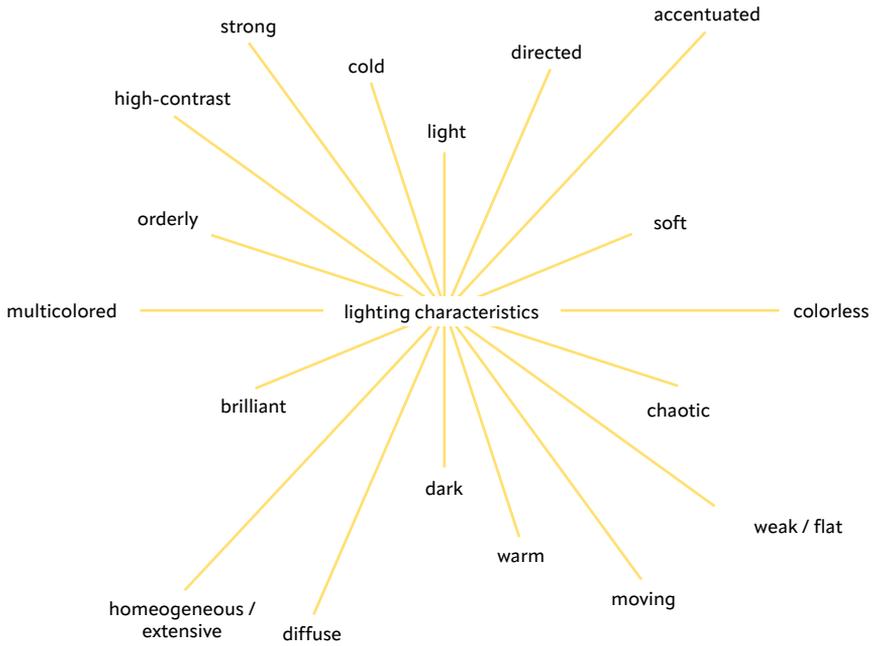
Psychological and atmospheric effects of light are not easy to measure; further research is needed. Ingrid Gehl's systematics of the basic psychological needs of people in relation to their living environment refers to architecture and urban planning and offers a practical approach. She defines eight building blocks of psychological well-being:

1. Contact with other people
2. Privacy
3. Space for diverse experiences
4. Meaningfulness
5. Play
6. Structure and orientation
7. Personal influence enabling identification
8. Aesthetics and beauty

Not only the built space, but also the prevailing light within it creates the right environment to fulfill these basic needs. On the right I will name options for corresponding lighting for some of the above-mentioned building blocks. A mind map, (next page, top) shows a word field of adjectives that are available to us to characterize light.

### **Light That Supports Communication (re. 1)**

A friendly and welcoming atmosphere of light encourages contact with other people. Bright, fresh light works well in common rooms of day-care centers and schools, while subdued, cozy light in a pub can help overcome possible shyness.



— Mind map of various characteristics of light.



— Lighting creates different orders and moods within the same space.

### **Privacy through Light (re. 2)**

Privacy occurs in soft islands of light, gently modulated light differences, and also in darker areas behind or in between lighter areas. Large spaces do not have to be partitioned by walls; areas accentuated with light in different ways also create places of retreat. A space can distribute different moods through different lighting.

### **Differentiated, Vivid Light (re. 3)**

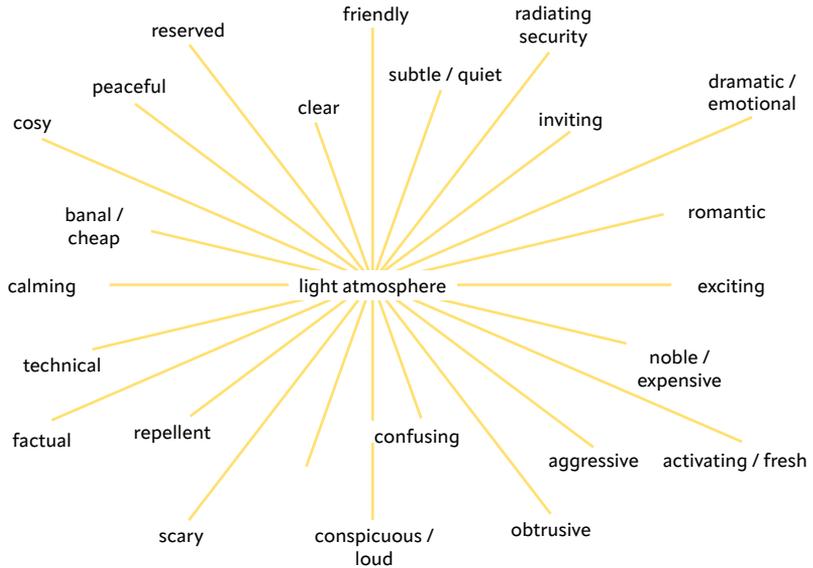
In contrast to spaces of retreat, the space for diverse experiences is created when light turns surfaces of a space into unmediated stages for those who feel more comfortable, particularly in bright light. In addition, islands of light liven up spaces. When people alternately move through the cones of light and then back into darker areas, their movement is perceived more strongly than when they always move in the same brightness. Islands of light also define areas of function: a sitting area, a work table, an entrance, or an illuminated sculpture.

### **Light Hierarchy (re. 6)**

Structure and orientation: in the public space, a light hierarchy of light points of differing heights distinguishes through-roads from neighborhood streets and internal routes. High light points appear more anonymous or more generic, while lower light points appear more cozy and homely. Both support orientation within the quarter as well as in buildings. The light points in a stadium, which are often over 30 meters high, and in street lighting on crossings with a height between 16 and 18 meters emit an even, rather uncomfortable light. Heavily trafficked roads have light point heights of six to twelve meters. Neighborhood streets and pedestrian zones have light point heights of three to five meters; these light sources are closer to human scale: they produce a more private light that offers sojourn quality.

### **Involving People (re. 7)**

Personal influence enables identity: in large office spaces, the sense of being able to play a part in one's own lighting environment can help with settling in and taking possession of one's place. One's own table lamp that can be switched on according to personal needs can achieve this. Also, when the outdoor lighting of housing estates is planned in a participatory process with residents, a sense of self-efficacy and integration is created.



- Lighting atmosphere in individual compositions coordinated with the space.

### Aesthetics, Harmony of Light (re. 8)

The beauty of light is dependent on how much interaction takes place between light, space, and materials. This holds true for daylight, artificial light, and the combination of the two. Registering one's own observations and expanding one's own knowledge is helpful; but research and application can also connect even more in this field. Good lighting design is sensitive, usually restrained, and respectful. Each location and building poses a lighting task that needs to be recognized anew. A harmonic lighting atmosphere is created in individual compositions coordinated with the space. With these, we create moods of light that send certain signals, evoking a sense of comfort.

# Choice of Lighting Instruments

After finalizing the concept of which areas of a space should appear brightly lit over a large area or accentuated like a spotlight, light distribution curves help to choose adequate luminaires. They differ in that reflectors and lenses spatially transform or model the light from a light source. The various techniques, the classic macro-optics, the miniaturized and micro-optics affect the size and shape of the luminaires.

## Characteristics of Light, Optics, and Applications of Luminaires

Methods of directing light in a luminaire are:

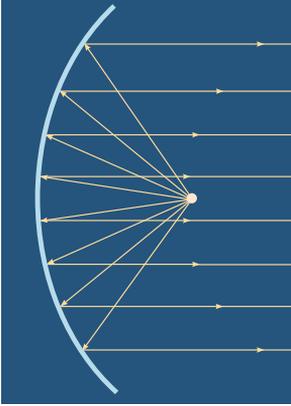
- » Regular (mirroring) reflection
- » Regular (visually clear) transmission (refraction)
- » Wave-optical principles (interference and deflection, diffraction)
- » Light scattering in reflection and transmission.

Reflectors and refractors complement each other in luminaires. Reflectors function sideways and in the background of the light source and shape the main direction of the light distribution curve of a luminaire. Refractors such as lenses, Fresnel lenses, longitudinal prisms, and prismatic cells act in front of the light source and specify the desired light distribution curve. The upper illustration on the right schematically demonstrates which physical phenomena, which can be observed in nature, function in reflectors. Classic light technology combines a light source with a reflector and / or a refractor / a lens in a luminaire. Lenses that are strung together and lens arrays work well in linear and flat LED luminaires. The lower illustration on the right shows typical light-intensity distribution curves that are modulated and that give fast information on the effect of a luminaire. These are provided for light calculations as digital files by manufacturers.

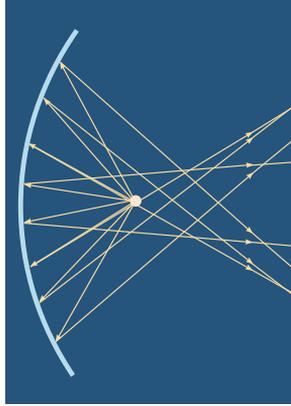
Diffusors make light gentler and distribute the luminance density at the light outlet onto a larger surface; however, they do not prevent glare, as is often wrongly assumed. They are particularly well suited when combining a high transmittance (avoiding great loss of luminous flux) with a good light-scattering factor (avoiding the depiction of individual points of light).

There is a rule of thumb for backlit light ceilings: the spacing between the individual LEDs must be no more than twice as large as the distance between the diffuser pane and the LED plane.

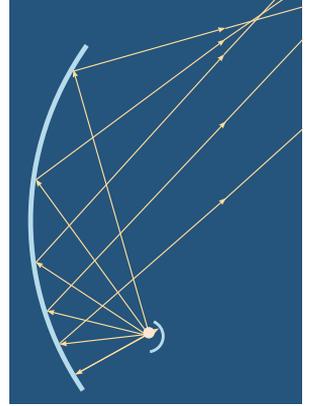
### Schematic illustration of the light path in reflectors.



— tightly focused

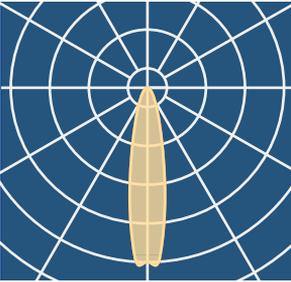


— wallwasher

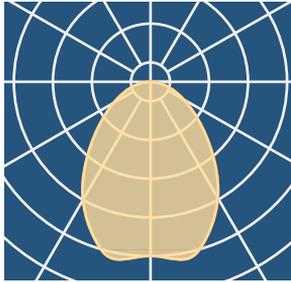


— batwing

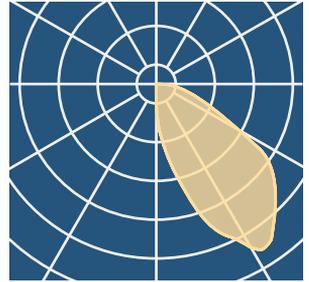
### Typical light distribution curves in architectural lighting.



— LDC tightly focused



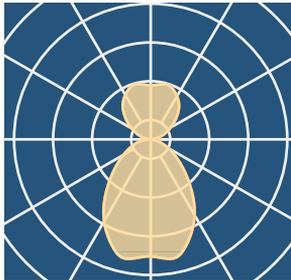
— LDC wide-beam



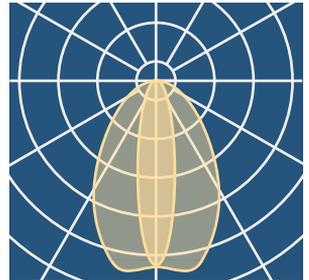
— LDC wallwasher



— LDC batwing



— LDC direct-indirect radiant



— LDC ribbon-shaped

# Multifunctional as if in a Living Room: The Light at Centraal Station, Rotterdam

In relation to its floor area, the train shed of Rotterdam Centraal Station is low; however, this effect is canceled out visually by the bright, translucent roof: the hall appears to be tall, almost like an outside space: passengers can breathe freely and experience the weather and the seasons. The train shed gives a view into the tent-shaped entrance hall leading to the city.

The Rotterdam Centraal train station is an example of many functional requirements for light that are associated with a pleasant and lively atmosphere. Below the wooden ceiling – different from the train shed – there is a homely atmosphere. There are light slots in the roof that supplement the generous amount of daylight from the sides. At their ends are narrow beam spotlights that cast brilliant and varied light downward over the height of the room. There are islands of light, a structuring of the hall, and clearly identifiable accesses between the long-distance railway, the underground, and the bicycle parking spaces. The architects and I received a remarkable compliment from a passerby who approached me when I was taking photographs: “The station is beautiful, isn’t it? Rotterdam now has a living room.”

— The train shed in Rotterdam unites various atmospheres.

1 Melody Gardot, “Morning Sun,” 2015.

2 Terri Peters, *Social Sustainability in Context: Rediscovering Ingrid Gehl’s Bo-miljø* (Cambridge, 2017), 371.



APL

STATION

M

Service  
WVG  
Delftsplein  
Lijnbaan

Metro  
Stationsplein

Conradstraat



# ATMOSPHERE, MAGIC

## Making the Immaterial Tangible

Composition + Dreams = Atmosphere, Magic

The collaboration between clients, architects, designers, and craftspeople is not only resilient against demanding external influences, but especially animated and successful when the team follows a joint vision. Lighting design for its part adds facility and the freedom of an immaterial design object into the project. Light has a great influence on the beauty of the design. Mutual curiosity, amazement, the realization of dreams, and thinking the seemingly impossible—that is how new, unique spaces are created.

- Starlit sky over the desert of Utah.
- Instead of a chandelier, an extensive star-studded sky shines at the Susie Sainsbury Theatre at the Royal Academy of Music, London.

# Expansion of Light in Time and Space

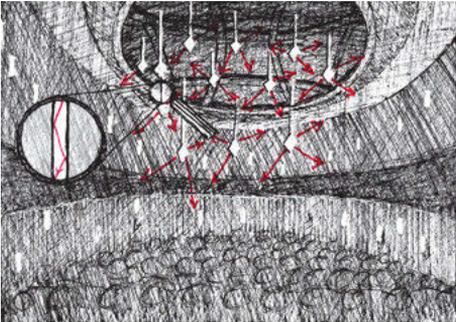
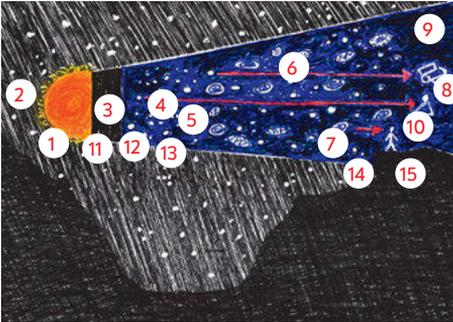
## Speed of Light

When we see stars, we are looking at the past: the speed of light is 299,792 kilometers per second. The farthest celestial object that we can see with the naked eye is the Andromeda Nebula. The spiral galaxy, which is 2.5 million light-years away from us, comprises approximately a trillion stars. What we can see is the past: the Andromeda Nebula emitted this light 2.5 million years ago.

Small light points, small quantities of light need darkness; we can only perceive them against a sufficiently dark background. We do not see stars during the day as it is too bright all around. However, there are only a few places in the world where artificial light does not prevent us from seeing the stars even at night. One of the most impressive places is The Wave in Utah, devoid of people, the atmosphere is free of light pollution.

## Total Reflection

Total reflection occurs at the interface between an optically denser and a thinner medium when the angle of incidence of the light beam (measured at the perpendicular to the interface) is relatively wide; in other words, it strikes the material at a flat angle to the interface. Glass facades can prove to be obscure mirrors when we look at them at a flat angle. We use this phenomenon in light guides made of glass or acrylic, which are manufactured as thin individual fibers, tubes, or solid rods. In large cross sections, even daylight can be directed into lower stories of a building: total reflection directs light around corners and bends into the light crystals of the concert hall of the Royal Academy of Music, London.



— The spread of light allows us to look back into the past. With the naked eye, we can see as far as the Andromeda Nebula, but now we see it as it was 2.5 million years ago.

— Under the magnifying glass, you can see the total reflection within an optical fiber that guides the light into the crystals.

- 1 Big Bang
- 2 background radiation
- 3 Dark Ages
- 4 first stars
- 5 protogalaxies
- 6 spiral galaxies
- 7 Andromeda
- 8 James Webb telescope
- 9 Hubble telescope
- 10 human eye
- 11 0.38 m years
- 12 300 m years
- 13 400 m years
- 14 11,300 m years
- 15 13,800 m years

**“When elders passed in our village, the community would gather in a courtyard lit by a much larger lamp [than a small petroleum lamp], which illuminated those dancing in it and elongated the shadows until they merged with the spectators looking on from the darkness beyond the light. These beautiful moving patterns decorated the festivities held for the souls just departed.”<sup>1</sup> — Francis Kéré, 2021**

# Magic: When Space, Light, and Emotions Are in Balance

## Festivals of Light

The fact that people are fascinated by self-generated lights in the dark night manifests itself in the many thousand-year-old festivals of light. The Chinese Lantern Festival, which concludes the New Year's festival; the Thai Loi Krathong with its flying lanterns; Diwali in Hinduism; Obon in Japan, with its floating lanterns; Hanukkah with the branched candelabrum; the crown of candles of Santa Lucia in Sweden; the Nowruz festival; Christmas; bonfires; or Saint Martin's Day, with its children's lantern processions have all been celebrated for millennia and remain emotionally charged for good reason.

Light festivals show people's closeness and bond with nature, no matter whether they are celebrating the winter solstice or the equinox. The daily change between light and darkness and the seasonal changes still shape human life, although our perception of these has been undermined by electric light since the end of the nineteenth century.

With public gas lighting in the streets at the beginning of the nineteenth century, night life began to take place in cities. "Its peculiar atmosphere comes from the light that shines from the shops and entertainment venues—cafes, restaurants—onto the pavement and the street. This light is meant to attract potential buyers, it is advertising light or commercialized festive lighting, in contrast to the official regulation lighting of the street lamps. The sphere of commercial light relates to that of regulation lighting like the bourgeois society does to the state."<sup>2</sup> The effect of the concerted light advertisement at Times Square in New York is described by Ernst May in 1928: "Here, the eye no longer reads any writing, here, it no longer distinguishes any form, here, it is only dazzled by an overabundance of flashing light, by an excess of light elements that cancel each other out in their effect."<sup>3</sup>



— Loi Krathong light festival in Thailand.

## Light in Movement and Superimpositions, Illusions

I have fond memories of our grandfather performing magic tricks to amaze us when we stayed at our grandparents'. Before going to sleep, we were already in bed, he conjured rings of light and figures in the air of the dark room with his glowing cigar. Some might know photographs of Picasso painting with light. The magical effect underlying this trick arises from a certain speed in the movement of the cigar. In long exposures, the same amount of moments overlap and show the path of running people or of the stars.

The painting by this unknown artist shows a landscape in the blue hour while the warm light colors of the sky are changing into cooler ones. Through the window of a ruin one can see a pale pink cloud. For me, for a long time, this ruin was an intact castle. The castle is not behind, but in the tree: it is a treehouse from which warm candlelight shines. The illusion is so strong because the experience of warm light from the windows implies an interior space behind it. However, the magic of the light not only appears in the darkness of the blue hour. We marvel at a rainbow in broad daylight, even more so when it appears as a double rainbow, and the sky is of a different darkness inside and outside the rainbow's arc. Gradients and overlays of colors and brightness appear soft and fascinating.



— The illusion of the castle in the tree.

# Security, Curiosity, Tranquility: Light Concepts and Collective Emotional Fundamental Experiences

The light point height, the color temperature of the white light, and the light distribution of luminaires have a decisive influence on the sense of security or expansiveness in an interior or exterior space. It is understandable that we humans have become accustomed to perceiving the high-standing sun in a bright sky as a general, generous, and activating light. The opposite is the case with the low evening sun and the campfire, which already conveyed a sense of security and shared identity in the age of the cavemen.

## A Sense of Security and Festivity at Sanssouci Palace in Potsdam

At Sanssouci Palace in Potsdam, visitors can comprehend the phenomenon of the various light point heights. For the use of private rooms, Frederick II and his servants carried candlesticks around with them and put them down on low wall consoles. For audiences, the medium-high wall lights illuminated the palace, and for grand state occasions and concerts, the chandeliers shone high up in the center of the room for representational purposes and to impress visitors.

Lighting design first of all addresses the light in a room and only in a second step the luminaire and its design. Luminaires of varying light-distribution curves create very different atmospheres and even small differences cause large variations in the actual space.



— Chandelier and candlesticks at Sanssouci Palace.

## The Magic of Slowness

We can also create magic with slowness, as Moniek Toboesch has done in her installation *Waiting for Buses and Birds* at the Stationseiland Amsterdam Centraal. She shows projections of birds that transform into flocks of birds and then into formations of clouds. In the process, they move slowly across the glass roof. The waiting passengers do not notice their presence immediately when waiting there, and that is precisely where the magic lies. The many commuters repeatedly experience new aspects of the artwork; it never gets boring.

## The Play of the Sun, Reflections, Superimpositions

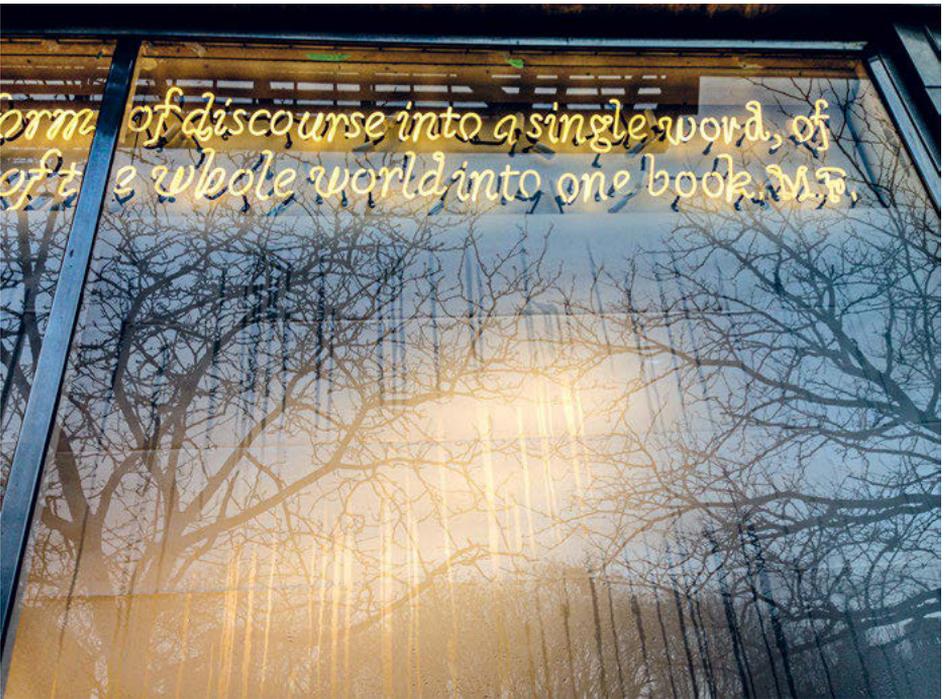
In order to let sunlight flood his buildings from another direction, Richard Neutra constructed small lakes, which he referred to as "reflecting pools." In my offices, we see this effect when the sun's rays reflect the surface of the water of the adjacent upper harbor onto the ceiling. The ceiling looks like a second sky with changing light phenomena.

The glass of the shop window in Brooklyn reflects the blue-white sky and the sharp contours of the trees; the neon letters shine through the clear part of the glass pane. They have the same warm light-color as the light of the room. The lower part of the glass pane is frosted from the inside so that the space is only blurredly visible. A clear view only exists where the condensed water drips down the glass pane thus "removing" the frosting.

Upon closer inspection, the accidental interplay of reflecting and translucent transitions is full of fine superimpositions and poetry, and we can perceptually recreate it. Printed or vaporized glass, perforated materials with grids, progressions, and fine patterns offer lighting designers and architects countless aesthetic possibilities of creating soft contrasts of light and dark for relaxed vision. Consciously created reflections give space more depth. We use various reflective properties of materials between matte and shiny, opaque, semitransparent and color-permeable in multiple layers in order to redirect and shield bright light from windows and from luminaires.



— Light installation *Waiting for Buses and Birds* at Stationseiland Amsterdam Centraal.



— A shop window in Brooklyn.

# Two Poles of the Atmosphere: The Royal Academy of Music, London

The Royal Academy of Music shows two opposite poles of light: bright and soft in the Ela Burgess Recital Hall; dark and sparkling in the Susie Sainsbury Theatre. In both, students and visitors experience light and music in harmony: both spread unhindered and fill entire rooms together.

The Angela Burgess Recital Hall appears bright; the daylight shines in from above and from the side. For rehearsals, artificial light is usually not necessary during the day. At the angle between ceiling and wall, where the stage spotlights are located, is the horizon light. It brushes the ceiling and is only imperceptibly and gradually visible as daylight fades.

We chose expanding star clusters as an image instead of the classic chandelier for the Susie Sainsbury Theatre. The light from these crystals fills the entire room and spreads out—like music.

— Angela Burgess Recital Hall, the  
Royal Academy of Music, London.

1 Francis Kéré, "Memories, Illuminated," in *Momentum of Light: Zumtobel Group AG Geschäftsbericht 2020/2021* (Dornbirn, 2021).

2 Wolfgang Schivelbusch, *Lichtblicke: Zur Geschichte der künstlichen Helligkeit in 19. Jahrhundert* (Frankfurt am Main, 2004), 138.

3 Schivelbusch, *Lichtblicke*, 148.



## Acknowledgement

“Which is more important,” asked Big Panda, “the journey or the destination?”  
“The company,” said Tiny Dragon.<sup>1</sup>— James Norbury

My thanks to: Malina Angermeier

Kristina Bacht; Christine Brandi; Elisabeth Brandi; Johannes Brandi; Dorothee Brandi-Effenberg; Yunjoung Cho; Béla Dizdar; Jemma, Lili, and Thorsten Eppert; Lukas Esser; Ursel Etzel; Doris Heidhoff; Eva Henschkowski; Irmela Hijiya-Kirschner; Flora König; Katharina Kulke; Angela Lai; Tobias Langguth; Jeffrey I. Miller; Uta Oettel; Mark Raymond; Vanessa Reuwsaat; Johanna Rieckhoff; Sibylle Rieckhoff; Ian Ritchie; Ulrike Ruh; Luca Salas; Uli Schmidt; Lisbeth Skindbjerg-Kristensen; Malina, Sebastian, and Susanna Stelljes; Baharak Tajbakhsh; Marina Wachs; and Malte Zimmermann.

<sup>1</sup> James Norbury, *Big Panda and Tiny Dragon*.



## Glossary

### A

#### **accommodation**

The adaptation of the shape of the lens in the eye to focus on objects at different distances.

#### **adaptation**

The adaptation of the eye to various luminance in the field of vision by means of the pupillary light reflex.

#### **additive color mixing**

The even mixing of the three primary colors red, green, and blue create white light.

#### **architecture**

According to Vitruvius, architecture is the mother of all arts, based on stability, usefulness, and beauty.

#### **atmosphere / mood**

Perceived subjectively, atmosphere or mood occurs in the process of objectifiable design: the way in which elements are put together in an environment. This pertains to light in particular.

#### **aurora borealis**

A phenomenon that occurs when electrically charged electrons and protons of the solar wind meet oxygen and nitrogen atoms in the upper layers of Earth's atmosphere and ionize them. Due to the energy transfer, the electrons reach a higher energy level, but then decrease again and produce fluorescence. Four different types of aurorae occur: corona, curtains, arcs, and rays.

#### **azimuth**

The horizontal angle between the north point and a celestial object; in the case of daylight this is the sun, from the perspective of the observer. Together with the elevation angle, the azimuth describes the position of the sun.

### B

#### **bioluminescence**

An enzyme reaction by which organisms (fireflies, luminescent fungi) emit visible light. It is one of the most efficient light sources.

**blackest black**

This color reflects about 0.05 percent of incident light, observed in the feathers of birds of paradise in nature. The blackest synthetic material achieves a reflectivity of 0.045 percent through nanocapillary tubes that absorb light.

**Bortle scale**

A worldwide cartography that describes the level of light pollution in a location.

**brilliance**

This occurs through the reflection of directional light onto glossy surfaces or by the refraction of light in transparent materials.

**C****candle**

Was invented 5,000 years ago. The light intensity unit of a candle is 1 candela (1cd).

**circadian rhythm**

The biological rhythm within about 24 hours that organizes sleep, food intake, and the reproduction of living beings in a temporal sequence.

**circular economy**

A regenerative system that returns goods to production cycles after consumption. The principles of an environmentally compatible economy are durable construction, maintenance, repair, reuse, and recycling. The opposite of the circular economy is the linear or throwaway economy.

**color adaptation**

The adaptation of the eye to the light color of an environment. It creates a natural color perception with differing light temperatures of white light.

**Color Rendering Index (CRI)**

The color rendering index Ra (CRI) quantifies a quality characteristic of artificial versus natural light. When artificial light contains all spectral colors of sunlight, the illuminated objects appear natural. The index-a stands for the general color rendering index, which only includes the values of the first eight test colors according to DIN 6169. Re includes 14–15 test colors and is much more accurate.

**color spaces**

A system for the numerical recording of light colors and body colors as a diagram showing the color locations of all colors and color mixtures in saturation levels from pure color to white. Its different color temperatures are located on the Planck curve.

**color temperature / light color**

Kelvin (K) describes how warm or cold light appears. The warmer (incandescent lamp: 2,700 K) the light is, the lower the color temperature; the cooler it is (daylight / skylight: over 5,300 K), the higher the color temperature value.

**D****DALI**

Digital Addressable Lighting Interface is a standard for the control of lighting systems.

**Dark-Sky**

The International Dark-Sky Association (IDA) is an initiative against light pollution.

**dawn / dusk**

The smooth transition of skylight in the alternation between day and night, which occurs through the position of the sun and the scattering of light in the atmosphere.

**daylight autonomy**

The proportion of hours of use per year in which a room achieves the necessary illuminance levels exclusively with daylight. No artificial light needs to be switched on during these hours.

**daylight factor**

This describes the ratio of the illuminance at a point on a given plane indoors to the simultaneously existing horizontal illuminance outdoors, which results from direct and indirect skylight (without sunlight) in an unobstructed sky hemisphere.

**downlight**

Type of luminaire that is mostly pointed downward onto a horizontal plane.

## E

### **efficiency**

The efficiency factor ( $\eta$ ) indicates what proportion of the supplied energy is converted into light. It captures the efficiency of a luminaire without considering its application and the question of where the light is needed.

### **efficiency method / efficiency procedure**

A method for calculating the average illuminance of rooms with the aid of the luminaire efficiency factor, the room efficiency factor, and the lamp luminous flux, which shows the interrelationships of the light distribution and their effect in the room.

$$n = \frac{E \cdot A}{z \cdot \Phi \cdot \eta_B \cdot WF}$$

- n = numbers of luminaires
- E = illumination level
- A = surface area
- z = quantity of lamps per luminaire
- $\Phi$  = luminous flux of a lamp / an illuminant
- $\eta_B$  = lighting efficiency  
(= luminaire operating efficiency [=  $\eta_{LB}$ ] × room efficiency [=  $\eta_R$ ])
- MF = maintenance factor

The photometric values can be found in the manufacturers' data sheets; the room efficiency ratio depends on the luminous flux distribution of the luminaire, the room geometry, and the degrees of reflection in the room, and it is read from the room light output ratio table with the aid of the respective room index (k) and the degree of reflection combination of ceiling (C), wall (W), and floor (F).

### **Eulumat**

European data file format used for lumen and to describe intensity distributions of luminaires. Eulum or LDT files comprise the photometric characteristics of a luminaire in a standardized file format for light calculation.

## F

### **fading**

The crossfading of light scenes. Fade-in is the start of the light scene; fade-out is the end of the light scene.

**filter**

A filter selectively transmits part of the incident radiation as colored light or filters out ultraviolet and infrared radiation components.

**fireflies**

Insects that glow due to the luciferase luminescent substance and oxygen. The process of this self-sufficient generation of light is called *bioluminescence*.

**G****glare**

Glare can stem from a light source and occur through reflections on glossy materials. Glare rings, shutters, louvers, and slats protect against a direct view into a lamp or the sun. Car headlights and street lights can be dangerously dazzling.

**global radiation**

The sum of solar radiation and surrounding sky radiation.

**gloss level**

Describes the reflectance property of surfaces with a scale from dull matte (0–3 glossy) to glossy-high gloss (over 100 glossy).

**gobo projector**

A type of luminaire with lenses that can be adjusted toward one another in order to sharply project light images onto surfaces of a certain size and distance. In museums, surface contours can be specifically emphasized; when illuminating facades, windows and entrance areas can be left out so that the light does not disturb the rooms behind them.

**H****half beam angle**

The angle between two points of a light intensity distribution curve whereby the luminous intensity drops to 50 percent of the value measured in the main radiation direction. The beam angle is the basis for specifying light cone diameters.

**heliodon**

A device to simulate the angles of solar radiation on a building at a specified latitude at any time of day or year in a model.

**I****IES files**

Use the standardized photometric format of the IES (Illuminating Engineering Society) and represent luminous intensity distribution curves based on light measurements in such a way that they can be loaded into lighting calculations.

**illumination level**

Unit: lux (lx). The quantity of luminous flux that falls onto one point from all directions.

**inverse square law (ISL)**

Also known as the photometric distance law: illuminance as a function of distance from a light source decreases with the square of the distance.

**isolux diagram**

Depicts illuminance distributions on a reference plane (measurement surface) with lines of equal illuminance.

**K****KNX**

A digital standardized system for building control in the areas of lighting, heating, and ventilation.

**L****light exposure and illumination**

The supply of light in a place. Exposure occurs with daylight; illumination, with artificial light.

**light intensity**

Unit: candela (cd); luminous flux per solid angle (lm/sr).

**light intensity distribution curve / light distribution curve**

The lighting effect of a luminaire. It depends on the luminous flux, the positioning of the lamp in the housing, reflectors, and optics. The light distribution curve of luminaires is integrated into the software for light calculation.

**light islands**

Bright areas on horizontal surfaces that structure a space and bring it to life, possibly marking different uses or facilitating orientation—in contrast to a uniformly illuminated floor.

**light pollution**

A phenomenon of light sent uncontrolled into space, especially by outdoor lighting. Satellite images show the brightness of populated areas and the increase in light pollution on Earth.

**light protection**

The limitation of maximum light intensity of ultraviolet and infrared radiation to protect exhibits in museums.

**light speed**

The propagation velocity of light in a vacuum. It is 299,792,458 m/s. The unit of length meter is defined by the speed of light and its fixed value.

**lighting book**

This contains all technical data of planned luminaires. It comprises data sheets which, in addition to the luminaire codes, list information on luminous flux, wattage, light distribution curve, color temperature, product image, and accessories of the respective luminaire. The preparation of the luminaire book is part of the design planning and must always be used in combination with the lighting list and lighting plan.

**lighting design process**

As in architecture, the lighting design process is divided into the planning phases of basic evaluation, preliminary planning, design planning, approval planning, implementation planning, preparation for awarding the contract, participation in awarding the contract, site supervision, and documentation.

**lighting list**

A table of the planned luminaires and their costs or cost estimates. It contains details such as the luminaire code, luminaire type and manufacturer, power consumption, number of units, and luminaire price.

**lighting plan**

Layout of the positions of the planned luminaires. Lighting designers draw the lighting positions and respective luminaire codes onto the ceiling plan; a legend explains the individual types of luminaires. The lighting plan is the basis upon which the light book and the lighting list are compiled.

**luminance**

Light flux emitted by a surface. This can be the surface of a light source, a translucent material, or also a reflective material. Colloquially, we speak of "brightness" or the "impression of brightness." The unit of measurement is candela per square meter ( $\text{cd}/\text{m}^2$ ).

**luminous efficacy**

The luminous flux emission in ratio to the electrical power expended by a lamp: lumen / watt ( $\text{lm} / \text{W}$ ).

**luminous flux**

The total light output emitted by a light source. It is calculated from the spectral radiant power by evaluating it with the spectral luminous sensitivity of the eye. Unit: lumen ( $\text{lm}$ ).

**M****melatonin**

A sleep-promoting hormone produced in the pineal gland and released into the bloodstream in the evening and at night. Excessively bright artificial light suppresses melatonin levels during the night and can cause sleep disorders.

**mesopic vision**

The transition from photopic vision during the day with the cones of the retina to scotopic night vision with the help of rods in the luminance range from  $3 \text{ cd}/\text{m}^2$  to  $0.01 \text{ cd}/\text{m}^2$ . Color perception and visual acuity decrease (at night) compared to daytime.

**mud light or light mud**

Diffuse light that sticks to the ceiling and makes the room appear indifferent and gray. Mud light is created under luminous ceilings or matte-covered luminaires and requires supplementation with brilliant, directional light.

## N

### **night mayor**

An official responsible for organizing the nightlife and cultural scene of a city, mediating between restaurateurs, event organizers, residents, politicians, and the municipal administration.

## O

### **OLED, organic light-emitting diode**

A flat, luminous, thin-film component made of organic semiconducting material whose electrical current density and luminance are lower than those of LEDs. Since their market maturity around the year 2000, they have not yet established a significant presence in the lighting of buildings.

## P

### **phosphorescence**

A property of substances to glow in the dark after exposure to light. These substances are called *luminophores*. The term phosphorescence is derived from the chemical element phosphorus, "light carrier."

### **photopic vision**

Daytime vision when adapting to luminance levels above 3 cd/m<sup>2</sup> occurs with the cones of the retina. Visual acuity is high, and colors can be perceived.

### **pirate's eye patch**

An eye patch helps a pirate to have one eye prepared for light adaptation and the other for dark adaptation at the same time. This is an advantage when having to move between deck and hold, not only in the case of attacks.

### **purple line / purple straight**

The line connecting the two outermost points on the CIE chromaticity diagram in such a way that the image of the chromaticity coordinates is closed. It combines the short-wave violet with the long-wave red. The purple line is a theoretical construction originating from the mathematical description of human color perception based on the three color receptors for day vision.

## Q

### **quantum leap**

The change in the energy level of an electron in an atom, a molecule, or a solid. During this transition, a photon is emitted (excitation) or absorbed (absorption).

## R

### **rebound effect**

Describes the effect in the energy industry that more efficient devices such as luminaires do not generate energy savings, but rather devices of higher power are operated, leading to more brightness, for example.

### **reflectance**

Relates incident and reflected light intensity and depends on the brightness and color of a surface.

## S

### **scotopic vision**

Night vision when adapting to luminance levels below  $0.01 \text{ cd/m}^2$ . Scotopic vision occurs with the rods mainly in the periphery of the retina. Visual acuity is low, and color perception is not possible, but perception of movement is high.

### **shadow of the Earth**

A cone of shade that planet Earth throws into space, which we experience as night.

### **shielding angle / cut-off angle**

The angle between a horizontal and a straight that runs from the edge of the sunscreen louver toward the sun or from the edge of a luminaire to the edge of the light source. A good shielding angle decreases glare as well as unwanted light spill.

### **stars**

According to current knowledge, there are 70 quadrillion stars in the universe. In cities and populated areas, we see about 100 to 200 of them; in areas without light pollution we see up to 3,000 stars with the naked eye. The Bortle scale classifies areas of Earth according to the number of stars visible there.

**star park**

Maps based on the Bortle scale are continuously updated to show the rapid increase in light pollution. Nowadays, star parks are being set up: similar to nature parks, they limit the influence of too much light. The view into the starry sky remains open and the reduction of biodiversity on Earth is slowed down as a result.

**sustainability / future viability**

In a holistic sense, respectful conduct in relation to social, ecological, and economic conditions.

**T****transmittance**

A measure of the transmittance of a medium for light waves, defined, for example, as the proportion of external light transmitted through a window pane.

**twilight**

Derived from the Low German *twelecht*, it initially meant "dawn" and "dusk." At the end of the eighteenth century, "indeterminacy" and "ambiguity" were added as definitions, and then in the first half of the twentieth century, the denotation "mixed light" was added, from the combination of daylight and artificial light.

**U****unified glare rating (UGR)**

A method for calculating and comparing glare caused by excessive brightness in relation to the surroundings.

**V****visual comfort**

A quality of a lighting system in terms of illuminance, absence of glare, and color rendering.

**W****wallwasher**

A recessed luminaire or spotlight that evenly illuminates an entire wall. The walls of a room are often more important for the impression of brightness than the floor because they occupy a larger area of the visual field.

**WEEE Directive 2012/19/EU (Waste Electrical and Electronic Equipment)**

Regulates the handling of electrical and electronic waste and defines minimum requirements for the reuse and recycling of equipment.

**whitest white**

A wall paint based on barium sulphate that reflects more than 98 percent of the incident light. The temperature of its surface remains below the ambient temperature.

**Y****yakamoz**

Turkish: marine phosphorescence was declared the most beautiful word in the world in 2007 with the meaning, "reflection of the moon on the water."

## Ulrike Brandi

### Biography

Ulrike Brandi, Executive Director Ulrike Brandi Licht GmbH  
Designer, Dipl. Des.

Date of Birth 1957

Bad Bevensen, Germany; lives in Hamburg.

1984–1988

Studies in Industrial Design at Hochschule für bildende Künste  
in Hamburg, degree under Dieter Rams.

1987

Foundation: Ulrike Brandi Licht Lichtplanung und  
Leuchtenentwicklung.

1995–1996

Lectureship FH Düsseldorf, architecture-interior design  
department.

1996

Transformation of the company into a GmbH, owner  
and sole managing director.

1998–1999

Guest professorship at the Hochschule für bildende Künste  
Braunschweig in the industrial design department.

2013

Foundation: Brandi Institute for Light and Design

### **Books by Ulrike Brandi Licht:**

Ulrike Brandi and Christoph Geissmar-Brandi, *Licht für Städte – Ein Leitfaden zur Lichtplanung im urbanen Raum* (Basel, 2006).

Ulrike Brandi DETAIL light edition, *Tageslicht – Kunstlicht, Grundlagen, Ausführung, Beispiele* (2005).

Ulrike Brandi et al. for German Architecture Museum, *Das Geheimnis des Schattens – Licht und Schatten in der Architektur*, exh. cat. (2002).

Ulrike Brandi and Christoph Geissmar-Brandi, *Lichtbuch, Handbuch der Lichtplanung* (Basel, 2001).

### **Memberships:**

Since 2022  
IALD College of Fellows (FIALD)

Since 2007  
Lichtbeirat Hamburg

Since 1994  
Lighting Detectives, Transnational Tanteidan  
(founding member together with Kaoru Mende, Tokyo)  
International Association of Lighting Designers (IALD)

Since 1988  
Deutsche Lichttechnische Gesellschaft (LiTG)  
Deutscher Werkbund (DWB)

## Ulrike Brandi Catalogue Raisonné, Extract from more than 1,300 Projects:

### **Trident Park, Malta, 2022**

Client: Trident Park, Malta  
Architect: ritchie\*studio, London  
Ill. pp. 10, 23

### **Elbphilharmonie, Hamburg, 2017**

Clients: ARGE Generalplaner Elbphilharmonie, Herzog & de Meuron, Höhler+Partner  
Architect: Herzog & de Meuron, Basel, Höhler+Partner  
Herzog & de Meuron have the copyright for the glass sphere luminaires.  
Ill. pp. 24, 35, 48, 61

### **Dutch Holocaust Memorial of Names, Amsterdam, 2021**

Client: Nederlands Auschwitz Comité  
Designer: Studio Libeskind  
Architect: Rijnboutt  
Landscape architect: Rijnboutt  
Ill. pp. 36, 47

### **Oldenburg State Theater, 2018**

Client: Oldenburg State Theater  
Architect: Droste Droste & Urban, Oldenburg  
Ill. pp. 62, 77

### **Cooperative Regional Control Center, Elmshorn, 2018**

Client: District of Pinneberg  
Architect: Trapez Architektur  
Ill. pp. 78, 89

### **Westfield Mall of the Netherlands, Leidschendam, 2017**

Client: Unibail-Rodamco Nederland Winkels bv, Schiphol, Netherlands  
Architect: MVSA Architects BV, Amsterdam  
Ill. pp. 90, 105

### **ICE 4 Lighting Control, 2018**

Client Deutsche Bahn AG  
Ill. pp. 106, 117

### **Rotterdam Centraal Train Station, 2014**

Client: ProRail, Amsterdam  
Architect: Benthem Crouwel, Amsterdam  
Ill. pp. 118, 129

### **Royal Academy of Music, London, 2018**

Client: Royal Academy of Music, London  
Architect: Ian Ritchie Architects, London  
Ill. pp. 130, 141

### **La Grande Galerie de l'Evolution, Paris, 1994**

Client: Mission Interministerielle des Grands Travaux  
Architect: Chemetov & Huidobro, Paris  
Ill. p. 110

### **Sanssouci Palace, Potsdam, 2013**

Client: Stiftung Preussischer Gärten und Schlösser, Potsdam  
Ill. p. 137

### **Lighting Masterplan, Rotterdam, 2008–2011**

Client: Bureau Project Management DSV, Gemeente Rotterdam  
Ill. p. 101

### **Amsterdam Centraal Train Station, 2015**

Client: ProRail, Amsterdam  
Architect: Benthem Crouwel, Amsterdam

### **Mercedes-Benz-Museum, Stuttgart, 2006**

Client: DaimlerChrysler Immobilien (DCI) GmbH  
Architect: UNStudio, Amsterdam

### **Munich Airport Terminal II, 2003; satellite terminal, 2010**

Client: Flughafen München Baugesellschaft mbH  
Architect: Koch+Partner Architekten, Munich

### **EXPO 2000 Hanover, Lighting Master Plan, 2000**

Client: EXPO 2000 Hannover GmbH  
Architect: A. Speer + Partner, Frankfurt/Hannover; K. Louafi, Berlin; Kienast Vogt Partner, Zurich

### **International Airport Pudong, Phase II, Shanghai, 2008**

Client: German Newway GmbH, Shanghai, China  
Architect: ECADI, East China Architectural Design & Research Institute Co. Ltd., Shanghai

## Further Reading

Brandi, Ulrike, and Christoph Geissmar-Brandi. *Licht Für Städte: Ein Leitfaden zur Lichtplanung im urbanen Raum*. Basel, 2006.

Ulrike Brandi *Licht*, ed. *Tageslicht – Kunstlicht: Grundlagen, Ausführung, Beispiele*. Munich, 2005.

Büscher, Barbara, Eitel, Verena Elisabet, and Beatrix von Pilgrim, eds. *Raumverschiebung: Black Box – White Cube*. Hildesheim/Zurich/New York, 2014.

Fischer, Ernst Peter. *Durch die Nacht: Eine Naturgeschichte der Dunkelheit*. Munich, 2015.

Guzowski, Mary. *The Art of Architectural Daylighting*. London, 2018.

Jun'ichirō, Tanizaki. *Lob des Schattens: Entwurf einer japanischen Ästhetik*. Zurich, 1987.

Leschziner, Guy. *The Nocturnal Brain: Nightmares, Neuroscience, and the Secret World of Sleep*. London, 2019.

Picard, Anna. *Musical Architects: Creating Tomorrow's Royal Academy of Music*. London, 2021.

Posch, Thomas, Anja Freyhoff, and Thomas Uhlmann, eds. *Das Ende der Nacht*. Weinheim, 2010.

Richter, Peter G., ed. *Architekturpsychologie: Eine Einführung*. Dresden, 2013.

Ritchie, Ian, ed. *Neuroarchitecture: Designing with the Mind in Mind*. Chichester, 2020.

Schivelbusch, Wolfgang. *Lichtblicke: Zur Geschichte der künstlichen Helligkeit in 19. Jahrhundert*. Frankfurt am Main, 2004.

Torres Tur, Elías. *Zenithal Light*. Barcelona, 2006.

## Picture credits

### Photographs:

Artist unknown (private ownership, Ulrike Brandi): pp. 136

Johannes Brandi and Johanna Rieckhoff: pp. 36 top, 78 top, 84, 90 top, 130 top

Dorothee Brandi-Effenberg: pp. 31

Marco Cops: pp. 139 top

Thorsten Eppert: pp. 48 top

Jörn Hustedt Network, for Ulrike Brandi Licht: pp. 48 bottom, 62 bottom, 78 bottom (detail)

Jannes Linders, for Benthem Crouwel Architekten BV bna: pp. 118 bottom, 129

Martina Orsaka, for C.I.R.E.C.A Domaine de

Boisbuchet: p. 33 top

ritchie\*studio: p. 33 top (visualization)

Ian Ritchie, ritchie\*studio: p. 23

Adam Scott, for ritchie\*studio: p. 130 bottom, 141

Ulrike Brandi Licht: pp. 55 bottom, 61,

101 (visualization), 113, 137

Unsplash: pp. 62 top, 73 left, 75, 99 right, 110, 135

Stephan Walzl, for Oldenburg State Theater: p. 77

Michael Zapf, for Elbphilharmonie Hamburg: p. 24 bottom

### Graphics:

Ulrike Brandi Licht: pp. 17, 28, 66, 103, 115, 123, 125, 127

All other unlisted photographs and graphics are by Ulrike Brandi.

**Translation from German into English:** Lisa Goost  
**Copy editing:** Keonaona Peterson  
**Project management:** Baharak Tajbakhsh  
**Production:** Anja Haering  
**Layout, cover design and typesetting:** Uta Oettel  
**Paper:** Magno Natural, 120 g/m<sup>2</sup>  
**Printing:** Grafisches Centrum Cuno GmbH & Co. KG, Calbe  
**Image Editing:** Repromayer GmbH, Reutlingen

**Library of Congress Control Number: 2022949696**

Bibliographic information published by the German National Library The German National Library lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.dnb.de>. This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, re-use of illustrations, recitation, broadcasting, reproduction on microfilms or in other ways, and storage in databases. For any kind of use, permission of the copyright owner must be obtained.

**ISBN** 978-3-0356-2415-1  
**e-ISBN (PDF)** 978-3-0356-2428-1  
German Print-ISBN 978-3-0356-2408-3

© 2023 Birkhäuser Verlag GmbH, Basel  
P.O. Box 44, 4009 Basel, Switzerland  
Part of Walter de Gruyter GmbH, Berlin/Boston

**9 8 7 6 5 4 3 2 1**

[www.birkhauser.com](http://www.birkhauser.com)