TURN ON DARK SKIES

THE INFLUENCE OF FACADE GEOMETRY ON LIGHT POLLUTION

MASTER THESIS

IVANA MILIĆEVIĆ

Turn on Dark Skies

The Influence of Facade Geometry on Light Pollution

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Master's thesis

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When was the last time you counted the stars?

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ABSTRACT

The Andromeda Galaxy, the nearest major galaxy to our own (Milky Way, 200 billion stars) holds as many as 250 billion (2.5x1010) stars. Everything that we can see, without the visual aid, belongs to these two galaxies; yet, on a clear day, from a dark rural retreat, our eyes can see only between 2000 and 3000 stars (people with exceptional vision can see up to 7000 stars). On the other side, there are places on our planet from which nothing outside the Solar System is ever seen in the sky. This is directly influenced by the overuse of artificial lighting and is defined as light pollution.

This master's thesis is looking into the problem of Light pollution, understanding and presenting positive and negative aspects of artificial lighting, and proposing a new way architect can work to reduce it.

It is known that surface geometry has an impact on light reflection; however, very few research projects were based on the effect of geometry on light pollution. The main objective of this research is to identify how facade geometry could influence and control light reflection to reduce the overall problem of light pollution. This graduation project focuses on facade design in the form of vertical fins using a parking house in the centre of Gothenburg, Sweden, as a case study. Form of the individual element is defined to prevent waste light from spreading. Further, materialisation of the fins is proposed to illustrate how both, micro and macro scale of geometry can influence light reflection, therefore reduce or enhance light pollution.

1 RESEARCH DEFINITION

STATE OF THE ART

In today's world, one of the main discussion topics is how to be more sustainable, efficient, reduce the consumption and human's (negative) effect on the planet Earth. In the attempt to achieve this, many products were invented such as solar panels and wind turbines to gather energy from renewable sources, possibilities of natural materials such as straw, wool, seashells, etc. are explored to replace more toxic and inefficient materials. Architects are dealing with 'new' problems like overpopulation, global warming, climate change, air, water and light pollution. Focus is switching from designing the largest and most luxurious building to creating spaces for people, making them human and environment-friendly. This thesis will follow the same approach.

The UN Sustainable Development goals are blueprints, including 17 global goals for 2030 to get a step closer to a more sustainable future. This thesis is directly referring to Goal 11: Sustainable cities and communities by aiming to reduce light pollution in urban areas. The topic of this thesis also has an impact on Goal 3: Good health and well being.

Similar to UN Sustainability goals, Sweden has set 16 objectives with an intention to address the country's most significant environmental problems by 2020. Even though most of them will not be solved by 2020, it's showing an initiative to work on providing a better future. Objective 15: A good built environment is the most relevant for this thesis. Light pollution can also be perceived as toxic, and it's affecting , so objectives 4 and 16 are also relevant.

THE 16 SWEDISH ENVIRONMENTAL QUALITY OBJECTIVES (www.miljomal.se/Environmental-Objectives-Portal)

1. Reduced Climate Impact
2. Clean Air
3. Natural Acidification Only
4. A Non-Toxic Environment
5. A Protective Ozone Layer
6. A Safe Radiation Environment
7. Zero Eutrophication
8. Flourishing Lakes and Streams
9. Good-Quality Groundwater
10. A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
11. Thriving Wetlands
12. Sustainable Forests
13. A Varied Agricultural Landscape
14. A Magnificent Mountain Landscape
15. A Good Built Environment
16. A Rich Diversity of Plant and Animal Life

PROBLEM STATEMENT

Most common problems related to the light in cities are wrong positioning of luminaires, uneven illumination, glare, inappropriate intensity and/or position of signs and advertisements, waste light ending up in the atmosphere and inside the buildings. All of this can be considered a phenomenon of light pollution. Light pollution causes many problems affecting most of the population; from high energy losses that can be avoided by reducing waste light and using better design principles to disturbed biological cycle leading to health issues and mitigation of animals.

Current proposals on reducing waste light and light pollution are based on changing the luminaire's design and adjusting the light intensity. But is there more that can be done? The basic light principle says that light will be visible only when it hits the surface. Following this principle, surfaces in urban areas play an essential role in the lighting strategies, yet there is very little research on their role in the phenomenon of light pollution. This thesis aims to change that.

FOCUS AND RESTRICTIONS

This thesis is exploring possibilities of making "night friendly" facades with the idea of minimizing the reflection of artificial light and light trespass, therefore reducing the amount of wasted light. The main focus is on the form (macro scale) and texture (micro scale) of the facade panel, but also on the material and colour. Other aspects of making a sustainable building are also taken into concern.

Design is focused on the specific situation where interventions on the lights and luminaires will not suffice. The chosen case study is a parking garage in the centre of Gothenburg, Sweden, because of its location, design and working hours. Considering the need for the transparent facade, the idea of investigating the implementation of louvres was the main driving force of the project.

This research will mainly focus on light pollution created by artificial lighting in urbanized areas. It will briefly discuss other influencers but will not take them into concern in the design phase. Understanding that an immense contribution to the reduction of light pollution can be made by redesigning public lighting, this thesis will not focus on urban design but on the principles of the facade design that could be discussed during the design phase in a variety of other building projects. Moreover, recognizing the expansion of greenhouses and their effect on the light pollution, among other things, should be a topic of many discussions today, but it is not presented in this thesis, as it doesn't have a direct connection to the urban areas.

RESEARCH QUESTIONS

The light travels from the light source and bounces of all nearby surfaces until its diffused or there are no more surfaces and it ends up in the atmosphere. Therefore the hypothesis is that by redesigning the surfaces, or in this specific case, building skins, it would be possible to control light reflection. Design is focused on transparent facades, with louvres as the main concept, so the following research question is formulated:

How can the design of a facade, based on louvre elements, be geometrically morphed to reduce light pollution?

It is followed by sub-questions:

What kind of facade surface is appropriate for the reduction of light pollution?

What strategies can be adopted in architecture profession to improve the overall problem of light pollution?

AIMS AND OBJECTIVES

The general aim of this study is to advance the knowledge base of the light pollution problem in urbanized areas. This study could offer alternative options for reducing the waste artificial light ending up in the atmosphere and to contribute to the current efforts in sustainable design research. By providing knowledge of artificial light, materials and geometry, architects can implement such strategies to contribute to a more healthy and sustainable environment.

The main objective of this research is to identify how geometry could influence and increase the diffusion of artificial light to reduce the overall light pollution in a specific context. The facade is studied in two different scales, as an element and the entire form.

RELEVANCE

Academic and practical relevance

Light pollution is a side-effect of the modern, industrial civilization. It is triggered by the overuse of artificial light indoors but mainly outdoors (street lights, advertising, greenhouses, etc.). It had been recognized as a problem in the early years of the 20th century, but the efforts to address it hadn't started until the mid-'50s. Currently, there are many non-profit organizations around the world trying to spread awareness of the problem and find a solution to it.

Most of the known solutions are based on the urban design and better design of public lighting. All of them suggest lowering the intensity of the light and designing lamps to narrow the light scattering and prevent it from going directly to the atmosphere. Only a few pages were found that discuss the influence of the light reflecting off surfaces. It seems as important as the lamp design, yet very little research has been done on that topic.

This thesis extends the knowledge of the topic and intrigue others to think and research about it. It will also try to include architects in the discussion, in a way that we should think about the light reflection when designing a facade for the building or pavement around it.

Personal relevance

The idea for the thesis topic came from the experience I gained while doing an exchange semester in Delft, The Netherlands. Currently, this relatively small country in Europe is one of the biggest food producers in the world, and that is being possible by a large area covered by greenhouses. These greenhouses are using a significant amount of artificial light, and having all-glass facades, this light leaves the greenhouses and creates a problem of the bright orange sky during the night. During the sleepless nights, caused by this, I tried to understand how is it possible that one of the most developed countries can allow for such a thing and how can I, as an individual and architect influence this.

This thesis research is a small contribution to solving the problem of light pollution. Spending a full semester researching on this problem will give me a better insight into its complexity and guide me towards making more sustainable buildings in the future.

RESEACH OVERVIEW

The design-by-research methodology was adopted for this master's thesis project whereby design will play a central role to test the ideas and acquire new knowledge.

The research is divided into the following steps:

1. RESEARCH DEFINITION AND DESIGN IDEA - it all begins by a hypothesis, defining main research question and boundaries and the first idea of the design

2. KNOWLEDGE - this part presents the analysis of currently available literature on the topics of light pollution, artificial light and 24-hour society, different facade principles and materials.

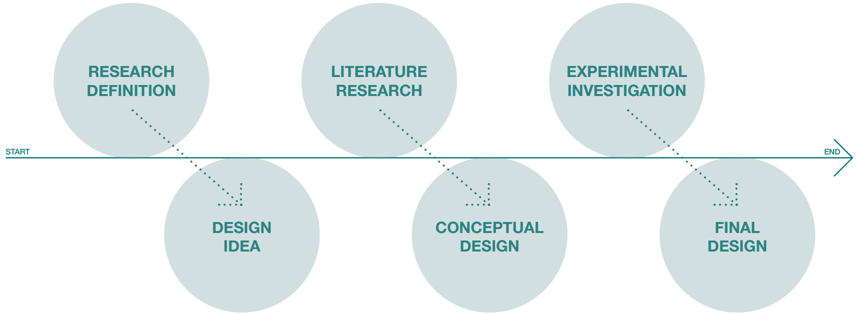
3. CONCEPTUAL DESIGN - after gaining valuable knowledge on the subject, initial design idea was to be re-evaluated and developed

into a conceptual design. In this part of the thesis, different parameters and requirements for project design were established according to the gained knowledge and context.

4. TESTING - making prototypes according to the conceptual design and using them to test the hypothesis and reach the final design.

5. FINAL DESIGN - deciding on one design after the experiments and doing final details

5. EVALUATION AND CONCLUSION - the last step was to reflect on the entire process of the research, understand and evaluate the results and conclude the thesis paper by answering the research questions.



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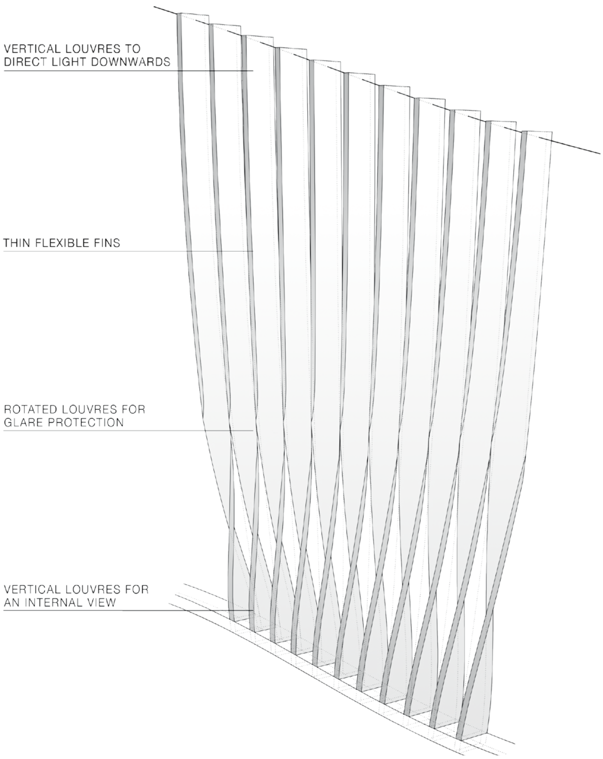
DESIGN PROPOSAL

The final design presents a modification of vertical fins to answer to the problem of light pollution while maintaining transparency of the facade. Surface of the fins is presented as two concepts, both with their pros and cons, allowing for further testing and exploration of the topic. They are reflecting the close context of the building, with park influencing the ‘green concept’ and the busy crossroad used as an inspiration to a more modern approach. This created a more dynamic and aesthetically pleasing facade. More about the final design is presented in Chapter 6 - Case study.




GÖTAPLATSEN

3 THEORY OF LIGHT

Ever since the humans discovered fire, they were aware of the possibility to "make" light and use it to see in the dark. For a long time, a fire was mainly used as a place to socialize, make food and get warm. It was only around 200 years ago when the first artificial lighting was installed in London and lit the city. But the full potential of extending the day with all its activities was understood with the invention of electric light by Thomas Edison in 1878. Giving the possibility of working longer hours and being more productive, application of electric lights was on the rise. It has extended so much that now, most of the developed world, cannot imagine life without artificial light.

Currently, we live in a 24-hour society - a phenomenon of the 21st century. It means that we have an opportunity to work, go out and shop during the entire 24 hours of the day, not depending on the sunlight. This wouldn't be possible without artificial light. Our streets are lit so we feel safer, our roads are full of light to avoid accidents, shops have luminescent signs to let people know they are open, buildings are lit to improve their night appearance, etc.. But this also has negative aspects. People are sleeping on average 2 hours less than 50 years ago, fighting depression and anxiety, but also developing heart problems and diabetes. The artificial light also influences animals as many of them rely on the day/night shift, which is lost in the big cities. Even though light is not the only thing causing these problems, it has been proven that it has a significant influence on our biological clocks.

The problem of light pollution is often mentioned. Quoting the International Dark-Sky Association: "Light pollution is excessive and inappropriate artificial light." It is widely spread throughout the developed world and presents one of the most significant problems of today. The overuse of artificial lighting and it's bad design and placement result in around 30% of wasted light that goes directly into the atmosphere and creates the problem of light pollution. In a world where we try to reduce our energy consumption to the bare minimum, this is unacceptable. Furthermore, this is not a localized problem; it affects a large area, substantially reducing the number of visible objects on the sky, distancing us from the rest of the Universe. To understand how we can change this, we need to get to the core of the problem.

LIGHT IN THE CITY

From the 15th century, when the first street lights were installed, people have understood their potential and today it is almost impossible to imagine a city without lights. They are necessary for orientation as they allow users to differentiate buildings, streets, parks, but also to see other users of the public space. Street lights are often connected to the feeling of safety. They allow pedestrians and drivers to perceive the surrounding and possible obstacles ahead of them. Businesses use them to attract people and highlight some products in the windows even when the shops are closed. Use of public space would be nearly impossible without public lighting, and the city economy would be much lower.

Public lights highly influence the night image of the city. During the day the city is seen as a whole as it's equally illuminated by the sun, but during the night this changes, and by changing the intensity and type of lights it's possible to control the cityscape. The light can come from various sources like public street lights, traffic, advertisements, intentional light from inside the shops, cafes, restaurants but also emergency light and "forgotten" light from offices. Central areas of the city usually have more light as they have more night activities that attract people compared to the more residential neighbourhoods. The function of the public space, or even entire area, can be imposed by choice of luminaires and their placement, light intensity and colour.

Brief history of street lighting

- **ANCIENT ROME** — Wealthy citizens used **vegetable oil lamps** to light the front of their homes
- **1417** — Mayor of London ordered that all homes must hang **lanterns outdoors** after nightfall during the winter months
- **1802** — Invention of **coal-fueled gas lights** by William Murdoch
- **1878** — Paris installed **first electric streetlights**
- **1879** — Tomas Edison invented the **light bulb**
- **1930** — **Low-pressure sodium lamps** were introduced in Europe
- **1962** — **Light-emitting diode (LED)** was developed by Nick Holonyak, Jr
- **1965** — **High-pressure sodium (HID) lamps** brought superior colour and efficiency
- **TODAY 2019** — **HID lamps** are the most widespread type of streetlights on the planet. Use of **LED** is growing

Figure 1. Effect of water on light reflection - Brunnsparken, 2019

Figure 2. Illuminated store windows and advertisement signs - Brunnsparken, 2019

Figure 3. Illuminated store fronts outside the opening hours - Linnegatan, 2019

Figure 4. Uneven street illumination and skyglow in the background - Forsta Langgatan, 2019

Figure 5. Light coming from inside the buildings and hanging street light - Andra Langgatan, 2019

Figure 6. Light coming from inside the parking garage - Sodra Vagen, 2019

Principles of light design

One year has 8760 hours, and the public light is on for approximately half of it (around 4380 hours), which makes it one of the biggest energy consumers in the city. Therefore the lights should be optimized for every scenario individually to reduce the energy consumption and avoid unnecessary losses. Moreover, public lighting highly influences the feeling of space, so one of the most important goals is to achieve a pleasant atmosphere.

> *"The character of the town must not be lost through the use of artificial light."* *(Van Santen, 2006)*

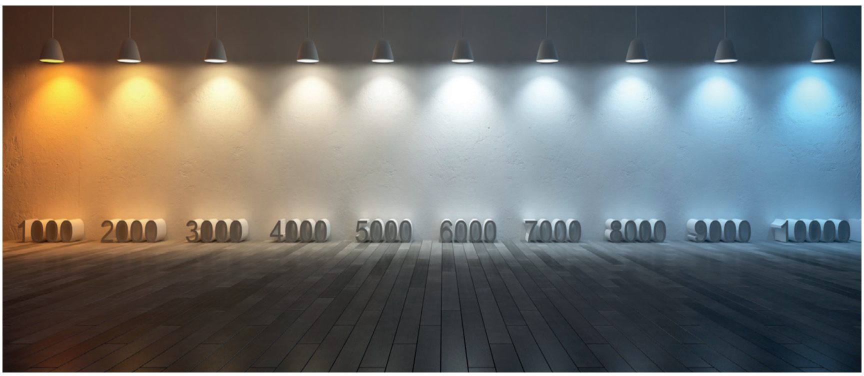
Starting points for designing the public lighting are to determine if the amount of existing light is sufficient, is it evenly distributed and are there any disturbances to the users and the surroundings. This can be broken down into the considerations of whether the light is necessary, what type of light and what intensity, should it be direct or indirect, evenly or unevenly distributed, where should it be placed. When it comes to choosing the right light source, essential factors are the type of the light source, its durability and energy consumption, but also light colour, colour rendering and light yield. The material and shape of the luminaire, shielding of the lamp, distance between the light sources, height and position of the light source are central factors in light emission as well as the appearance of the city.

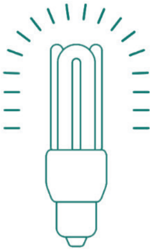
The surfaces surrounding the space are as important because of their reflectivity that can affect the amount of planned light. This involves pavement (asphalt, stone, grass) and facades (brick, stone, wood, concrete, glass, metals, plants) with dominant factors such as surface, colour and form. The main principle is that the light can be reflected or diffused depending on the surface, and that is determined by the material luminance. More about this is presented later in the booklet.

"The requirements for the lighting are:
1. Visibility of objects, to ensure safety and orientation,
2. Recognition of people,
3. Comfort and well being
4. The ability to create three-dimensional shapes (plasticity): not only for the recognition of people and objects but also for general comfort,
5. It is important to prevent glare - the brightness of the light must be limited or shielded in (almost) horizontal directions,
6. Light colour: the visible colour of the light must suit the surroundings,
7. Colour rendering: doing justice to colour plays a role in social interaction. The colour of clothing, for example, must be clearly identifiable in pedestrian areas. From a security point of view, the recognition of colours is also important, for example, in witness statements to the police,
8. The light source should generally not be visible."
(Van Santen, 2006)

Types of light

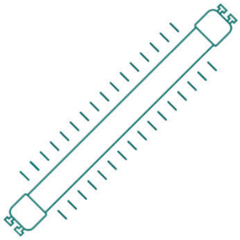
Outdoor lighting uses more industrial sources of light, compared to the incandescent or compact fluorescent bulbs used indoors. Most commonly used are low-pressure sodium - LPS, high-pressure sodium - HPS, metal halide and light emitting diodes - LED. These lights have different colour temperatures, meaning that they appear more blue (higher temperature) or yellow (lower temperatures). IDA rates colors bellow 3000K as dark sky friendly because they don't impair dark sky view.





LOW-PRESSURE SODIUM

LPS is very energy efficient but emits only a narrow spectrum of pumpkin-colored light that some find to be undesirable. Yet, LPS is an excellent choice for lighting near astronomical observatories and in some environmentally sensitive areas.



HIGH-PRESSURE SODIUM

HPS is commonly used for street lighting in many cities. Although it still emits an orange-colored light, its coloring is more “true to life” than that of LPS.

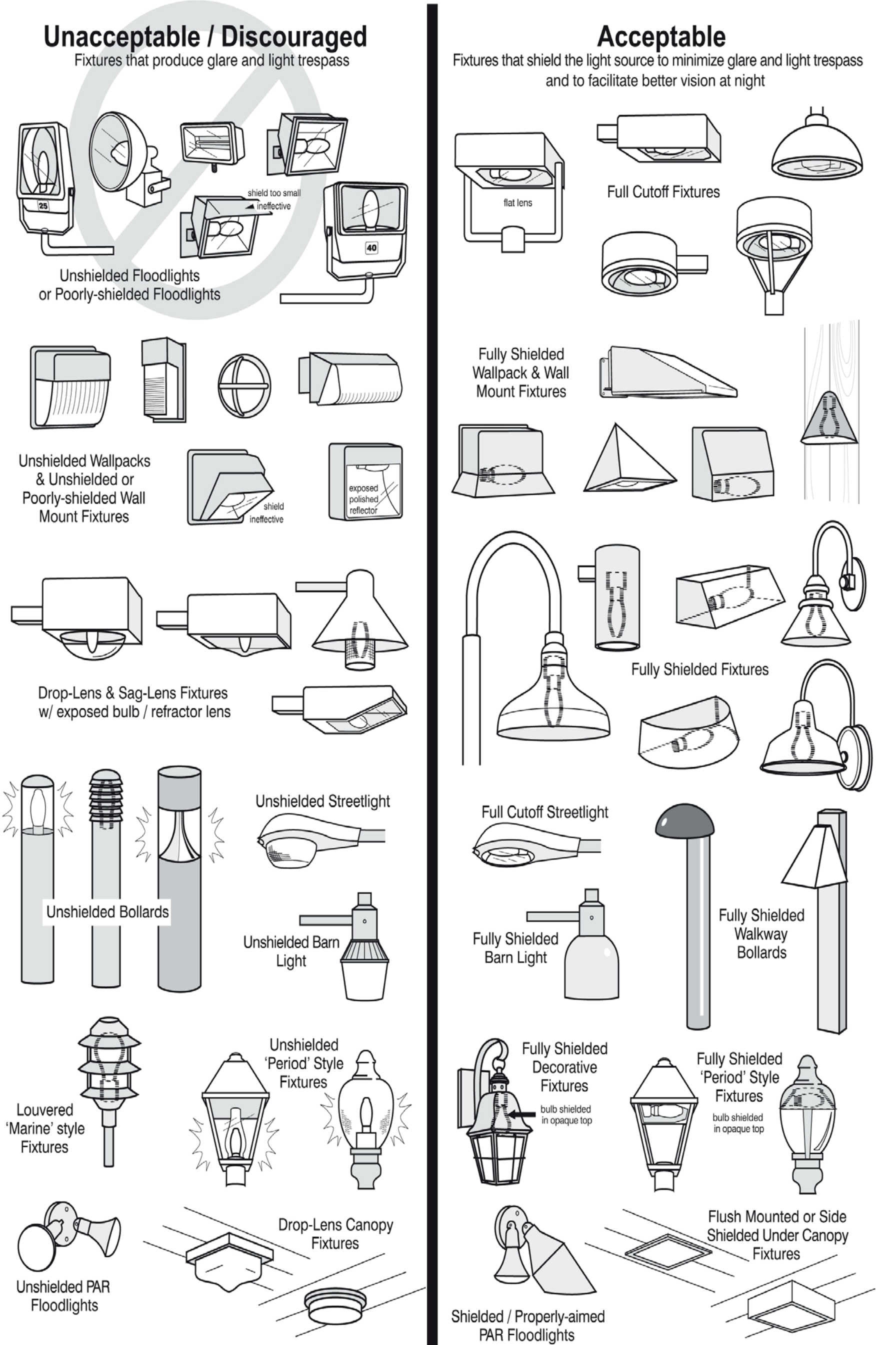
LIGHT EMITTING DIODE

LED lamps produce white light and can be dimmed. Because of their reported long life and energy efficiency, LEDs are rapidly coming into widespread use, replacing the existing lighting in many cities.

METAL HALIDE

Metal halide lamps emitt white light. Both LED and metal halide fixtures contain large amounts of blue light in their spectrum. Because blue light brightens the night sky more than any other color of light, it's important to minimize the amount emitted.

Examples of Acceptable / Unacceptable Lighting Fixtures



Illustrations by Bob Crelin © 2005. Rendered for the Town of Southampton, NY. Used with permission.

ILLUMINATION OF BUILDINGS

The way the city is experienced during the night is directly influenced by artificial lighting. Many cities are being redeveloped and reorganized to appear more attractive and lure more people, therefore increasing the economy. This is known as the 'beautification of the city'.

One of the main principles of the city beautification is the illumination of buildings. When done correctly, this can lead to a pleasant yet attractive atmosphere, which is agreeing with the surrounding but subtly drawing attention to a specific object. The illumination of buildings is not a new concept; it has been used even before the invention of artificial light. It was done during the special events when the buildings were lit up by candles, oil pots or torches. From the beginning of the 20th century, buildings were mainly lit up for advertising purposes, and that method of informing is still used. Other applications of building illumination include functional illumination and architectural illumination, where architectural can be historical (building and structures of important historical value), contemporary (modern and industrial premises) or ambience (parks, water features).

Every building is different and tells its own story; therefore the illumination must be adjusted to enhance it. The buildings should be in harmony with the environment during the day and night. This can be achieved by understanding the properties of building surfaces (materials, textures, colours) and designing light to be evenly distributed with some play of light and shadow to draw attention. Placement and the intensity of the light sources must not pose a problem for the users of the space and building.

> *"Balance and harmony are connected with the volume of light and colour that is aimed at a building or an object, with the direction, colour and the colour rendering of the light source; and with the reflection and the colour of the illuminated surface."* (Van Santen, 2006)

Illumination of the building can also come from within the building, whether it’s intentional and planned or accidental. It can create a feeling of used space and enrich the ‘livable’ appearance of the city. It is often used by offices and retail to draw attention to their brand. Depending on the surroundings, this way of illumination can be very successful or very violent for the environment.

Figure 7. Gothia towers (Gothia towers)

Figure 8. Götaplatsen with Poseidon at night (W.carter, 2016)

Figure 9. Draken cinema

Figure 10. Stora Teatern Gothenburg (Andréasson, 2007)

24-HOUR SOCIETY

The use of artificial light at night has changed the lifestyle of people all over the world. From the lighting in the form of fire, which was used to lit the environment but also warm people and makes them feel safe, to the invention of the electric light bulb and later LED lights, people have found a way to make use of night. Today, artificial light is one of the vital elements of everyday life. Application of street lighting has blurred the line between day and night activities and changed the urban life in the cities. It makes public space feel safer, allows for a span of social and economic activities during the night, influences the way people, economy and towns are organised. This change has lead to the phenomenon of the '24-hour society'.

> *'Economic and social activities were extended into the night hours, streets and parks became safer, commercial goods, historic buildings and whole cities were lit up for adulation'*
> *(Henckel and Moss, 2010).*

The 24-hour society describes today's way of life for the majority of people in developed countries. By introducing the artificial light and developing it to be cheap and widely accessible, the foundation was set for the extension of daily activities. It allows for production, consumption and motion 24 hours a day. This means that the night can be used for social and leisure activities as well as the increase in productivity. In today's world, this is mainly seen in industries, where a night shift is introduced to increase production and allow for the international market. The change of working hours in industry conditioned other services (shops, daycare centres) to have flexible working hours as well. Another major sector gaining from artificial light is agriculture. Plants grow faster when exposed to the light; therefore the possibility to grow plants in the greenhouses under the eternal light is changing the food industry and providing enough food for the planet.

Being a part of 24-hour society has its consequences. People sleep

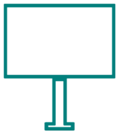
2 hours less on average than 50 years ago, and that's causing them to feel more stressed, depressed, anxious, the health problems such as diabetes and heart issues are becoming frequent, suicide rates in developed areas are growing. Most of these problems are the direct outcome of living without dark skies, being surrounded by artificial light.

LIGHT POLLUTION

Quoting the International Dark-Sky Association: "Light pollution is excessive and inappropriate artificial light." It is widely spread throughout the developed world and presents one of the largest problems of today. It's shown through the effects of light trespassing, skyglow and glare.

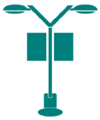
Figure 11. Light pollution (Hudson, 2017)

Main sources of light pollution



1. Electronic Advertising Boards and Commercial Centers: Many of the large electric sign boards in the cities and on highways are lit up by powerful lights. Restaurants and shops in the towns also use a lot of light to attract costumers.

2. Night Sports grounds: Floodlights that light stadiums and other places of sports often contribute to light pollution as the powerful lights end up upwards.



3. Streetlights and car lights: In some cities, hundreds of miles of powerful streetlights stay on all night. Together with the vehicles that use the roads, all contribute a lot to the light being directed above and to other unintended places.

4. City Parks, Airports, public places: Many of these areas use many old-fashioned lights that are not shielded and have a lot of it emitting light upwards.

5. Aesthetic light: Garden and landscape lights intended to add aesthetics to the landscape and architecture often end up as a nuisance at night, because they tend to irritate people as they walk or drive in these areas.

Measuring light pollution

The level of light pollution in a certain area can be measured using the Bortle dark-sky scale. It's been created by John E. Bortle to evaluate the darkness of an observing site and to compare the darkness of observing sites. The scale ranges from Class 1, the darkest skies available on Earth, through Class 9, inner-city skies. Class 9 means that light pollution is 100-200% brighter than the natural light.

Figure 12. Bortle scale (Bortle, 2001)

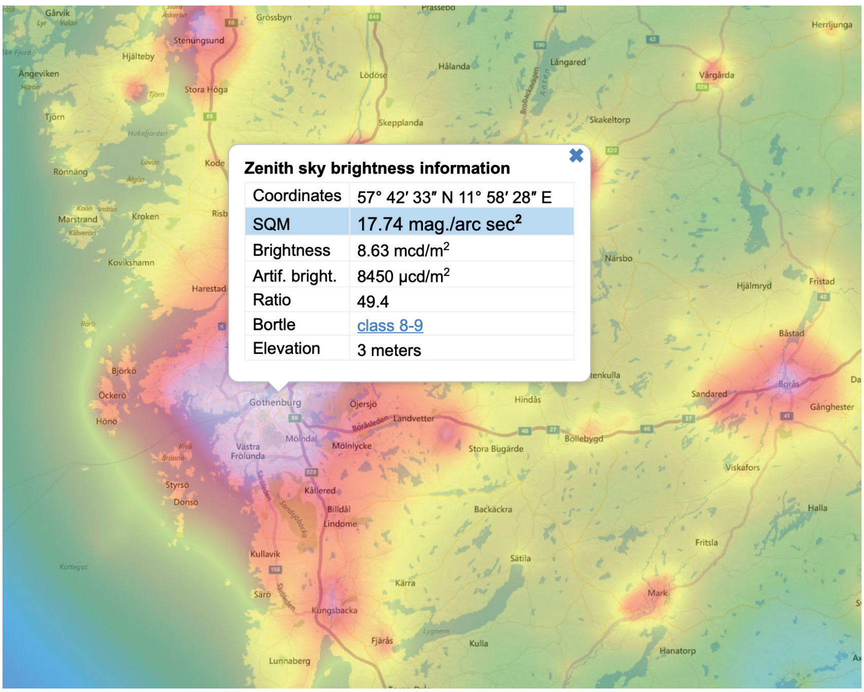


Figure 13. Light pollution over Gothenburg (source: lightpollutionmap)

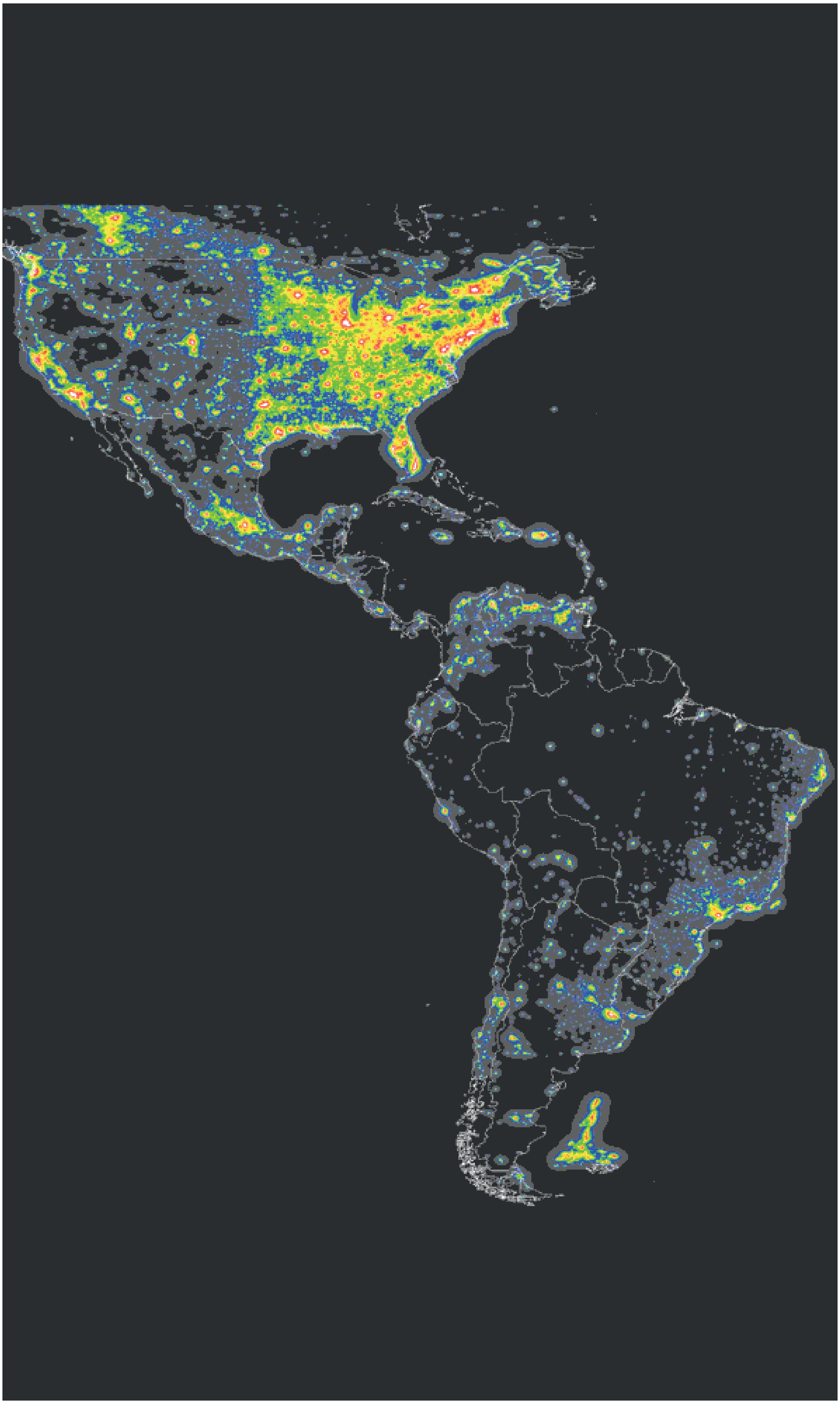


Figure 14. Light pollution map

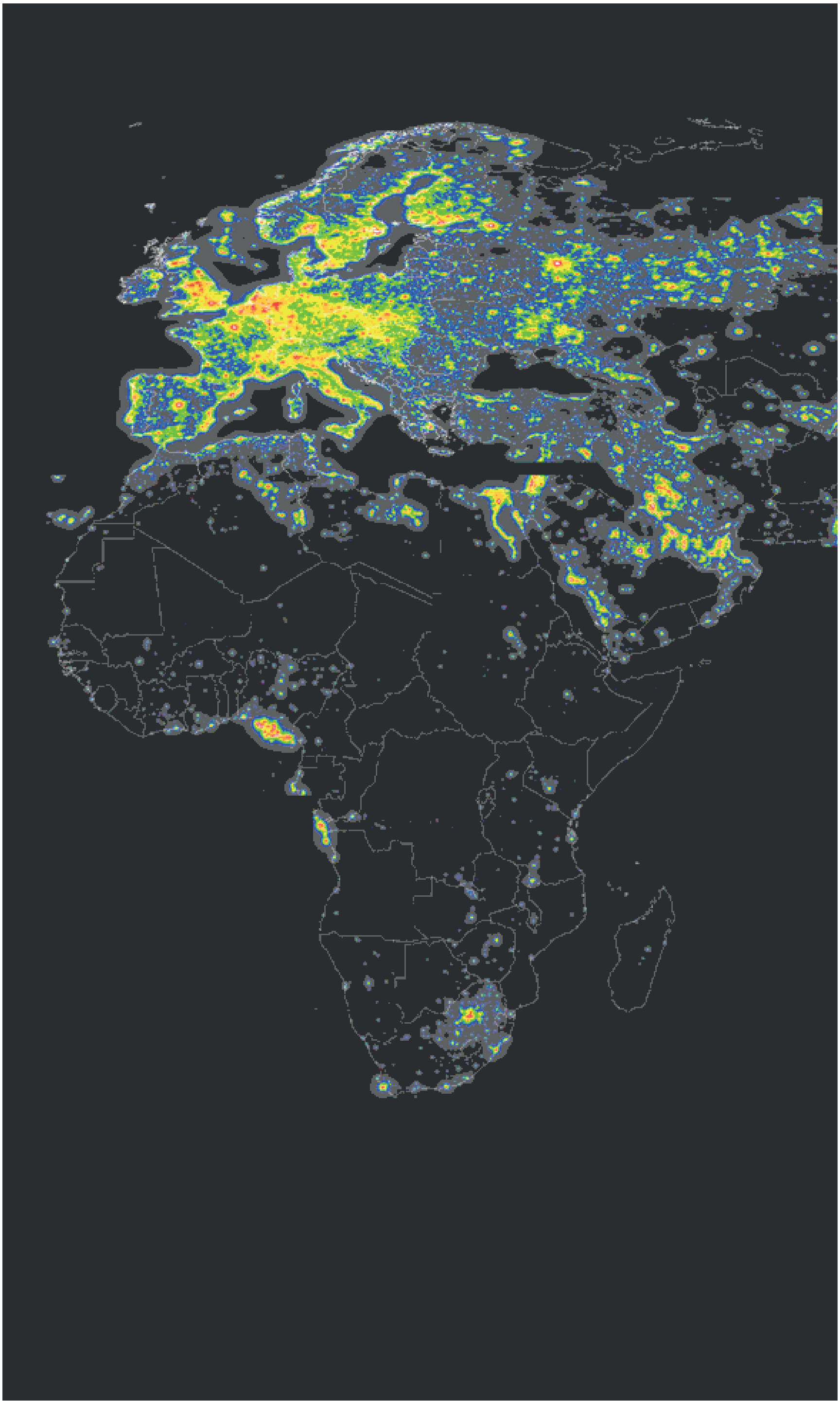


Figure 14. Light pollution map

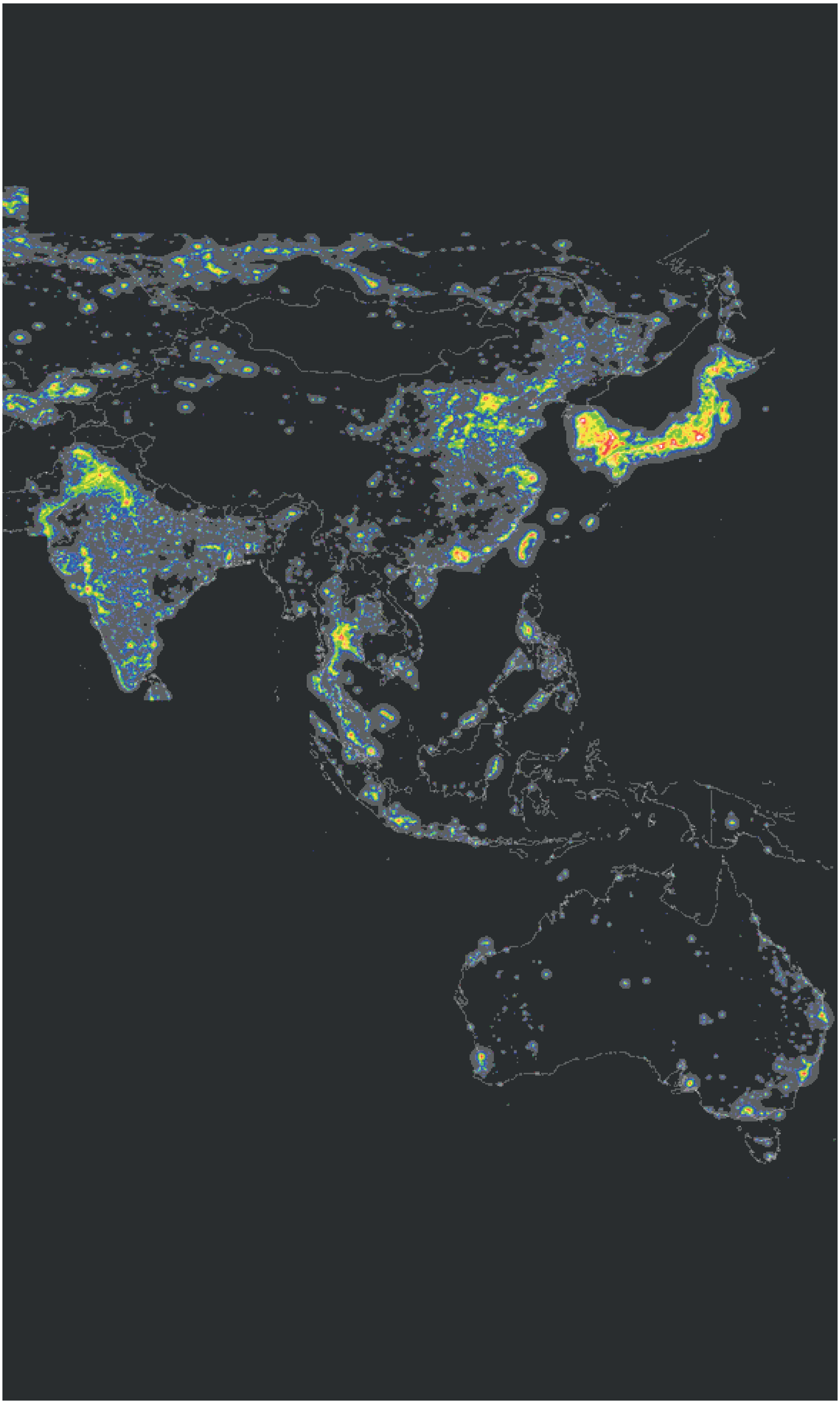
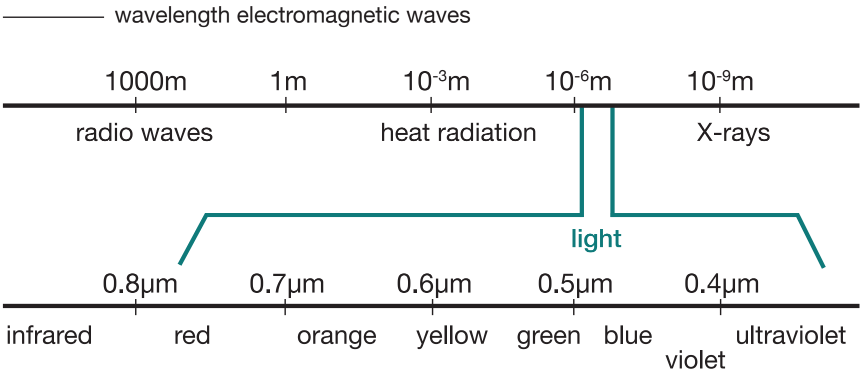


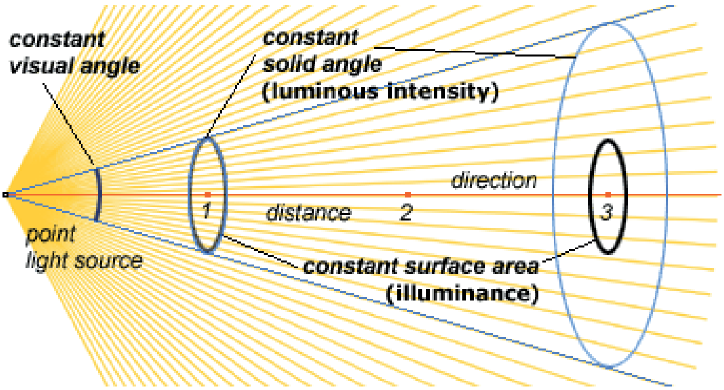
Figure 14. Light pollution map

HOW DOES LIGHT WORK

From a physical point of view, light is defined as electromagnetic radiation energy. The word usually refers to the visible light, the electromagnetic radiation spectrum ranging from 0.38 to 0.78 micrometre (1µm = 10-6m) visible to the human eye. Radiation with shorter or longer wavelengths is called invisible light.



Physics also teaches us that light as such cannot be seen, but what we perceive as light is actually the luminance of surfaces. To understand this, terms luminance and illuminance must be defined.



"Luminance is the amount of visible light leaving a point on a surface in a given direction. This "surface" can be a physical surface or an imaginary plane, and the light leaving the surface can be due to reflection, transmission, and/or emission."

Luminance is used to indicate how much luminous power will be identified by the human eye looking at a surface from an angle of interest. It is used to determine the brightness of a surface.

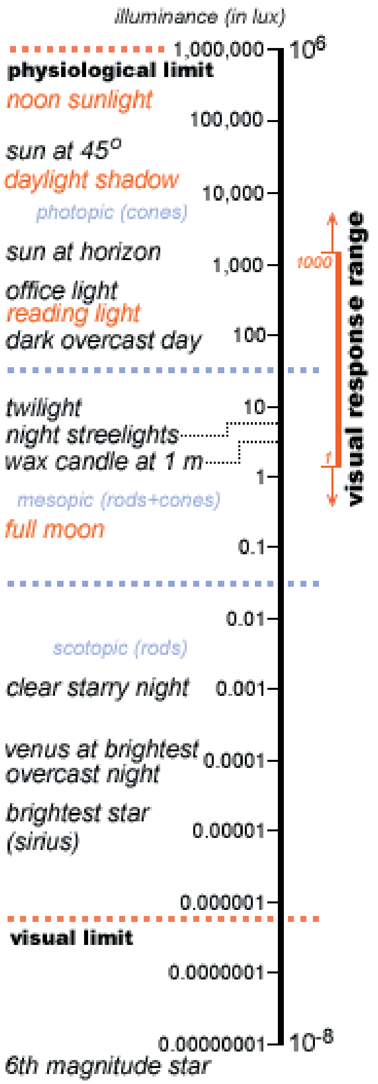
luminance benchmarks

cd/m^2	trolands	source
$7.0 * 10^{10}$	$2.5 * 10^{11}$	Lightning flash
$3.2 * 10^{9}$	$1.1 * 10^{10}$	Sun (zenith)
$1.0 * 10^{8}$	$3.5 * 10^{8}$	Photoflash
$1.6 * 10^{7}$	$5.6 * 10^{7}$	Carbon arc lamp
$4.0 * 10^{6}$	$1.4 * 10^{7}$	Eye damage after brief exposure
$4.3 * 10^{5}$	$1.6 * 10^{6}$	Sun (horizon)
$3.2 * 10^{5}$	$1.2 * 10^{6}$	Eye damage after long exposure
$3.2 * 10^{5}$	$1.2 * 10^{6}$	Upper photopic limit
$1.2 * 10^{5}$	$4.5 * 10^{5}$	60W incandescent light
$3.0 * 10^{4}$	$1.2 * 10^{5}$	>White paper in noon sunlight
$1.7 * 10^{4}$	$6.7 * 10^{4}$	Lower limit of photopic metamers
$1.3 * 10^{4}$	$5.1 * 10^{4}$	Clear sky (horizon)
$1.1 * 10^{4}$	$4.4 * 10^{4}$	T8 fluorescent light
$1.0 * 10^{4}$	$4.0 * 10^{4}$	Cumulus cloud 90° from sun
$7.0 * 10^{3}$	$3.3 * 10^{4}$	Low beam car headlights
$6.0 * 10^{3}$	$2.8 * 10^{4}$	Average sky
$4.2 * 10^{3}$	$2.3 * 10^{4}$	Full moon (zenith)
$3.6 * 10^{3}$	$2.1 * 10^{4}$	>White paper in daylight shade
$2.5 * 10^{3}$	$1.5 * 10^{4}$	Clear sky (zenith)
$2.0 * 10^{3}$	$1.2 * 10^{4}$	Cloudy sky (zenith)
$2.0 * 10^{3}$	$1.2 * 10^{4}$	>White paper in dark cloudy day
$1.3 * 10^{3}$	$8.1 * 10^{3}$	Upper limit of mesopic metamers
$5.6 * 10^{2}$	$4.7 * 10^{3}$	Full moon (horizon)
$5.2 * 10^{2}$	$4.5 * 10^{3}$	Stiles-Burch 10° primary lights
$3.2 * 10^{2}$	$3.0 * 10^{3}$	Upper mesopic limit
$2.8 * 10^{2}$	$2.7 * 10^{3}$	>White paper under surgical light
$1.7 * 10^{2}$	$1.7 * 10^{3}$	White of color plasma television
$1.3 * 10^{2}$	$1.3 * 10^{3}$	Overcast sky (zenith)
$1.3 * 10^{2}$	$1.3 * 10^{3}$	>White paper under office light
$1.0 * 10^{2}$	$1.0 * 10^{3}$	White of computer monitor
$1.0 * 10^{2}$	$1.0 * 10^{3}$	Wax candle flame
$8.4 * 10^{1}$	$9.2 * 10^{2}$	>White paper under reading light
$3.0 * 10^{1}$	$4.8 * 10^{2}$	Green electroluminescence
$5.0 * 10^{0}$	$1.0 * 10^{2}$	LED light
$1.0 * 10^{0}$	$2.3 * 10^{1}$	Clear sky, twilight (zenith)
$2.4 * 10^{-1}$	$6.0 * 10^{0}$	Brightest star (Sirius)
$1.0 * 10^{-1}$	$2.6 * 10^{0}$	Clear sky, dusk (zenith)
$1.0 * 10^{-1}$	$2.6 * 10^{0}$	Lower mesopic limit
$6.0 * 10^{-2}$	$1.6 * 10^{0}$	>White paper under full moon
$1.3 * 10^{-3}$	$3.6 * 10^{-2}$	Absolute threshold (single flash)
$3.2 * 10^{-4}$	$9.0 * 10^{-3}$	>White paper under starlight
$4.0 * 10^{-4}$	$1.1 * 10^{-5}$	Starless night sky
$7.5 * 10^{-7}$	$2.1 * 10^{-5}$	Absolute threshold (steady light)

Source: Wyszecki & Stiles (1982), Packer & Williams (2003), Makous (1998), Handbook of Space Astronomy & Astrophysics (1982), Hunt (2004)

"Illuminance is the total amount of visible light illuminating a point on a surface from all directions above the surface. This "surface" can be a physical surface or an imaginary plane."

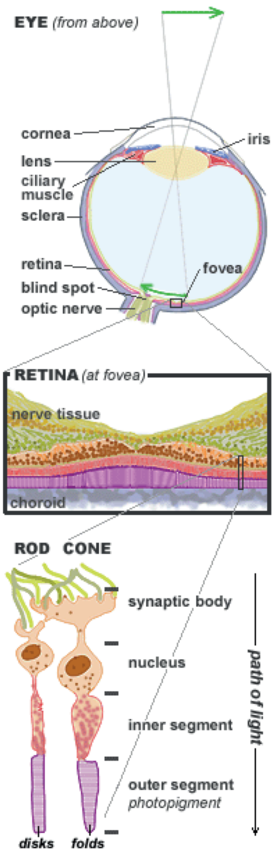
Illumination is the quantity of available light falling onto a surface. It can be used to determine the minimum required amount of light for a specific task.



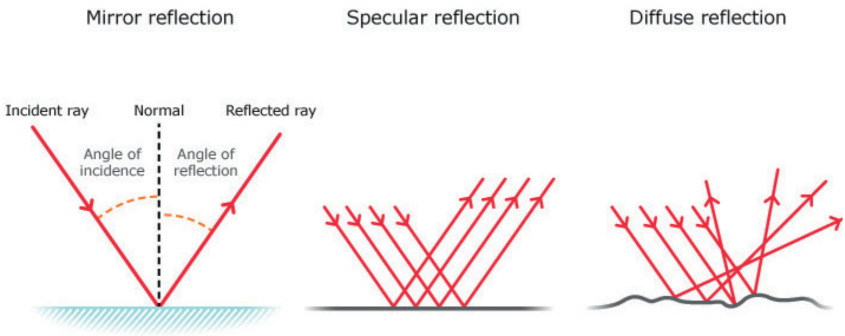
How we see

The human eye is a sensor that is designed to adapt and function in a very bright environment but also at dusk, when only the moon and stars might be visible. The eye recognises visible light from a light source directly or from the reflection from another source. This allows humans to understand depth and perspective and observe the environment spatially. Seeing and recognising objects is achieved through differences in light intensity (luminance) and colour.

Human eye requires only a small amount of light to work. Studies have shown that the minimum comfortable illumination is 75 lx for working indoors. Even though the human eye is capable of seeing when only moonlight is present, this ability is reduced among the people who grew up and/or spent the majority of their lives in highly urbanized areas.



Surface reflection



As previously mentioned, the light becomes visible only when it touches upon the surface. The way it's perceived depends on the way light is absorbed, reproduced and reflected. Surfaces like glass mirror or high-gloss reflecting materials can produce a reflection that is as strong as the light source itself (direct light). On the contrary, the Lambertian surface has perfectly matte properties, and it reduces the light intensity by scattering it in all directions. This means that the luminance of this surface is the same in every direction. Most of the materials are hybrids, meaning that they belong in between these categories, and reflect and diffuse the light at the same time. Another essential property of the surface determining its reflectivity is the colour. Darker shades have lower reflectance factor, as shown in the table below.

Colour	Reflection Factor (%)
White	70-80
Grey	20-60
Black	< 4
Yellow	30-70
Red	10-35
Green	12-50
Blue	8-55

Material	Reflection Factor (%)
Aluminum, pure, highly polished	80 - 87
Aluminum, anodised, matt	80 - 85
Aluminum, polished	65 - 75
Aluminum, matt	55 - 75
Aluminum coatings, matt	55 - 56
Chrome, polished	60 - 70
Vitreous Enamel, white	65 - 75
Lacquer, pure white	80 - 85
Copper, highly polished	70 - 75
Nickel, highly polished	50 - 60
Paper, white	70 - 80
Silvered mirror, behind glass	80 - 88
Silver, highly polished	90 - 92
Oak, light polished	25 - 35
Granite	20 - 25
Limestone	35 - 55
Marble, polished	30 - 70
Plaster, light	40 - 45
Plaster, dark	15 - 25
Sandstone	20 - 40
Plywood, rough	25 - 40
Concrete, rough	20 - 30
Brick, red	10 - 15
Paint, white	75 - 85
Paint, medium grey	25 - 35
Paint, dark blue	15 - 20
Paint, light green	45 - 55
Paint, dark green	15 - 20
Paint, light yellow	60 - 70
Paint, brown	20 - 30
Paint, dark red	15 - 20

4
PRELIMINARY DESIGNS

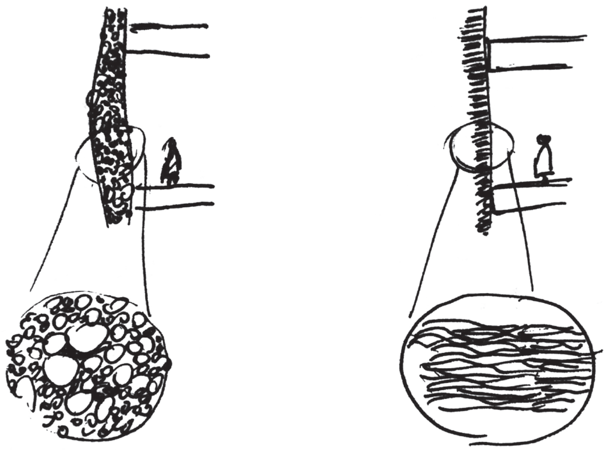
Throughout the research, many design approaches to the problem of light pollution were explored. Some of them were purely conceptual ideas, while the others were developed to a more concrete level. This chapter will shortly present the most successful ones and the ones with the potential of evolving into future projects.

All concepts are introduced with the hypothesis, basic sketches of implementation and studies of light reflection. Some of them are further tested and presented in Chapter 6: Experimental Investigation.

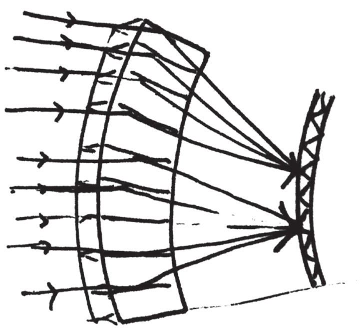
The aim is to present these concepts and show the potential and variety of facade design in the battle against light pollution.

Design concept 1: TRAP THE LIGHT

Hypothesis 1:
Complex geometry will force light to reflect multiple times and get lost within layers.



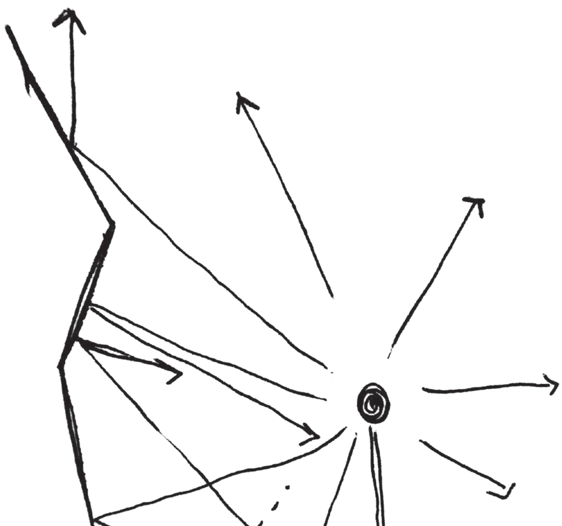
Hypothesis 2:
Reflected light is focused onto the (focal) surface at different points, entering the tube in which it will stay trapped. Inspired by lobster eye.



Design concept 2: TILTED SURFACE

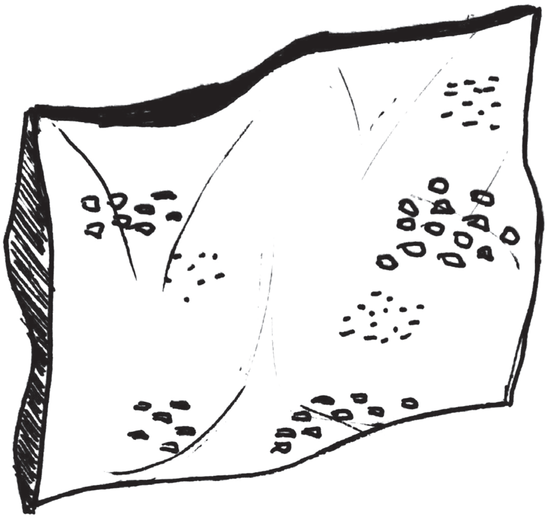
Hypothesis:
Adjusting the angles of the facade surface according to the light situation, so the light is always reflected downwards.

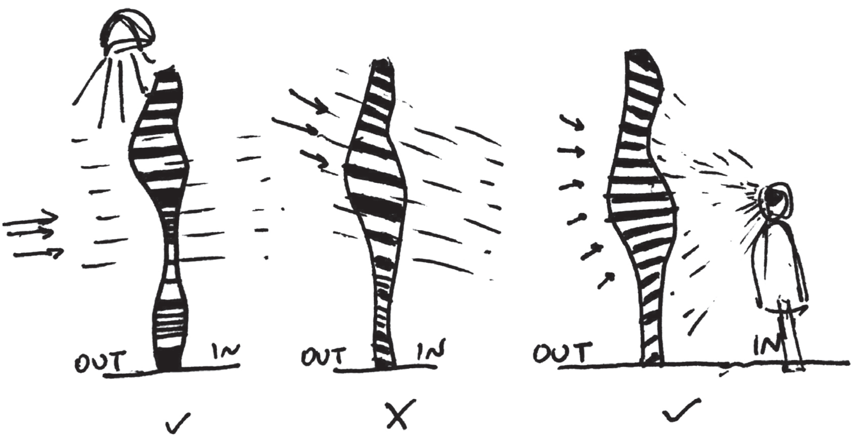
This was explored in a series of experiments (check Chapter 6 Experimental investigation).



Design concept 3: PUNCTURED WALL

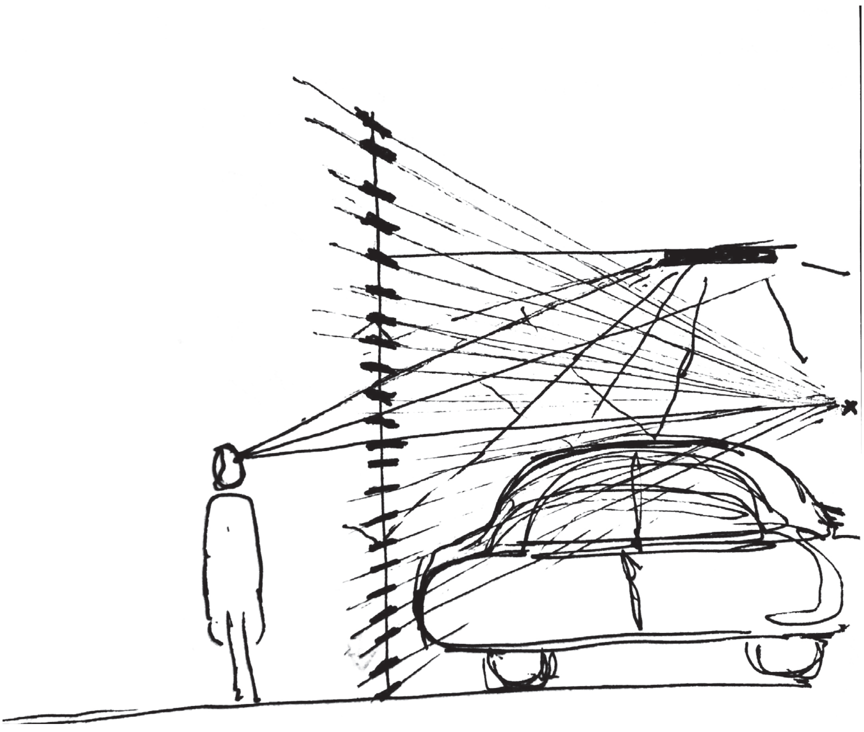
Hypothesis:
Opening up the wall to allow for transparency in areas where light is not intrusive. Size of the openings and thickness of the wall differ according to the light situation (larger openings / thinner wall in areas with good lighting).





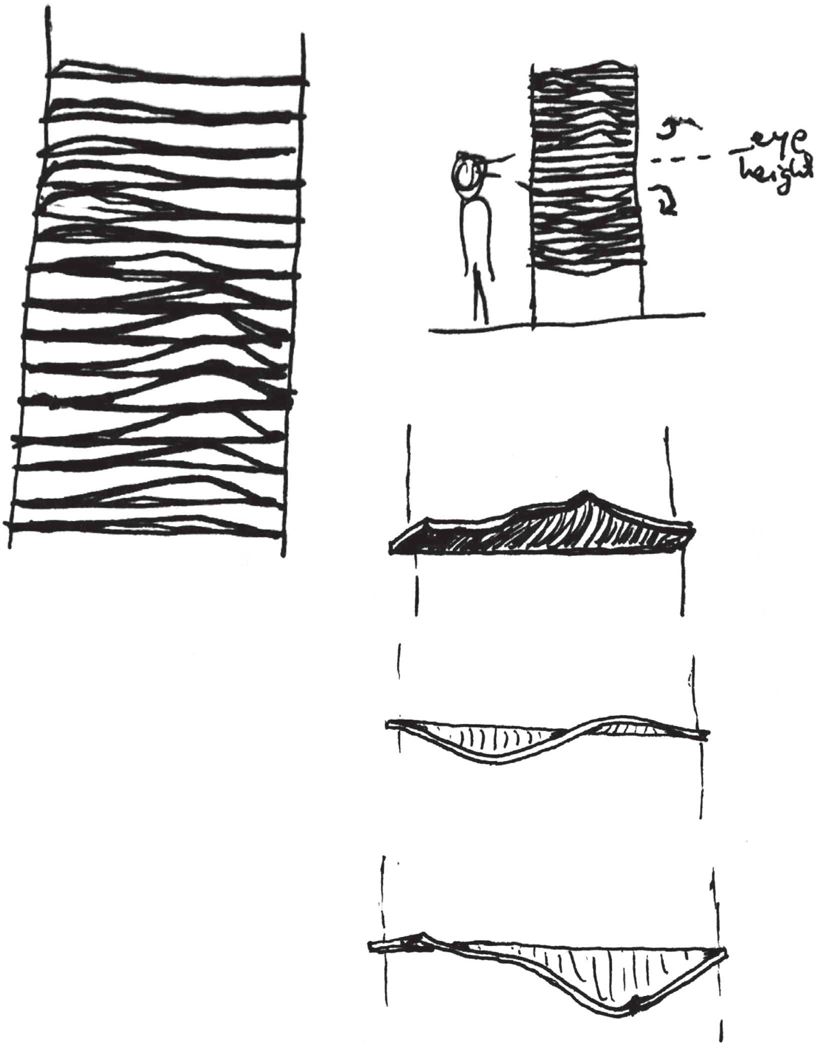
Design concept 4: HORIZONTAL LOUVRES

Hypothesis:
Horizontal louvres alow for transparency, and by rotating them the light will be controlled, less light will trespass.



Design concept 5: HORIZONTAL TWIST

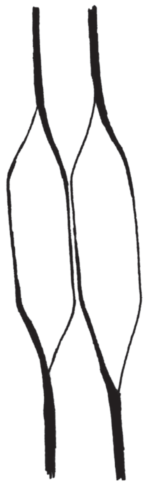
Hypothesis:
Horizontal louvres with changing cross-section are twisted at points of light sources to block glare and light trespass.

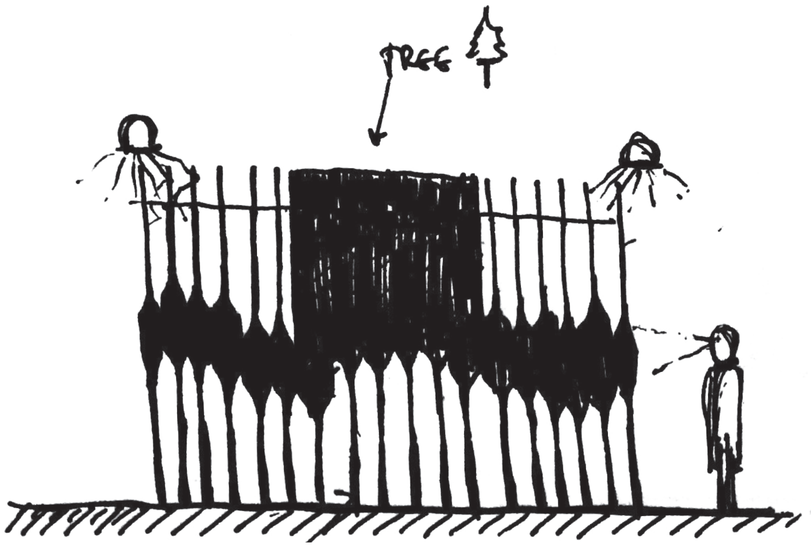


Design concept 6: VERTICAL TWIST

Hypothesis:
Vertical louvres are twisted at points of light sources to block glare and light trespass.

This was further explored and presented in Chapter 6 Experimental investigation.

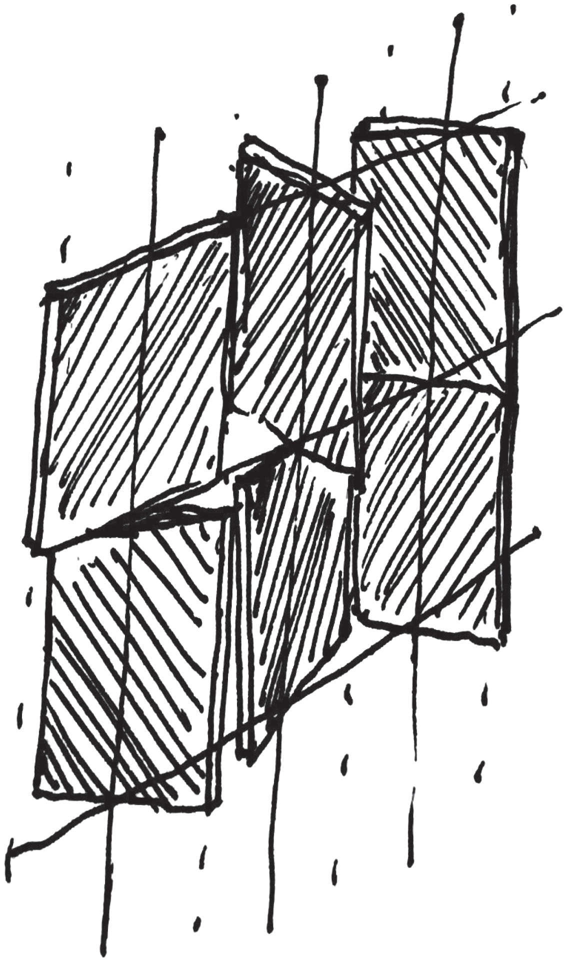




Design concept 7: VERTICAL ROTATED

Hypothesis:
Vertical louvres, divided into smaller elements, could be rotated horizontaly according to the light to reflect it or block the glare.

This was further explored and presented in Chapter 6 Experimental investigation.



Design concept 8: VERTICAL STACKED

Hypothesis:
Small elements, stacked one on top of the other, creating a vertical louvre could be rotated individually to accomodate light situation.

5 EXPERIMENTAL INVESTIGATION

To achieve the final design, many experiment have been done and they are presented in this chapter. The span of used methods ranges from physical testing of forms and materials, digital simulations using different softwares, analytical calculations based on the literature to sketching and designing ‘the normal way’. Some experiments were more successful than the others, some showed very dissatisfying results but overall they all contributed to reaching the final goal.

Experiment 01:

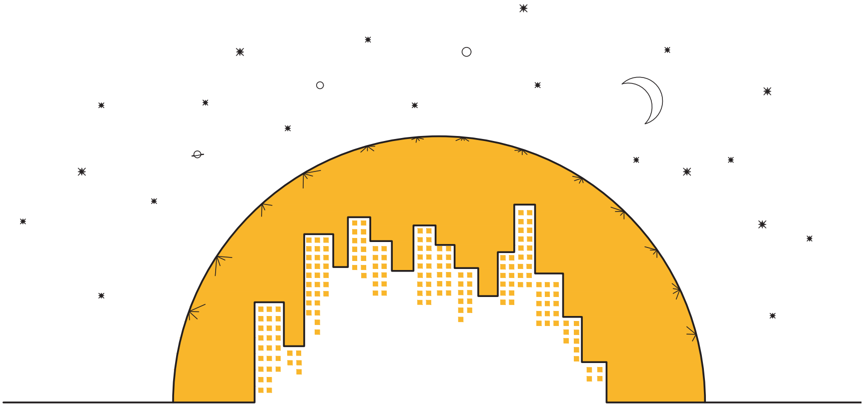
Utopian scenarios

How would the world look if the light pollution was gone and how could that be achieved?

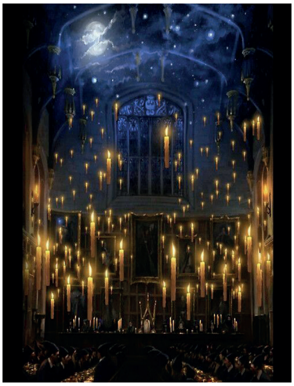
Having only a few limitation, such as the interventions are possible only within the scope of architects work (eg. no urban design, no changing the street lights, no politics and laws) or individual actions, allows for utopian scenarios. In all of them the main concern is saving the planet from light pollution. Proposed actions vary in their scope and feasibility but it's safe to say that none of them have the real potential of being executed.

Methods:
Using imagination and transfering the ideas to paper through sketches. Searching for inspiration and similar projects. Combining multiple ideas to emphasize the proposal.

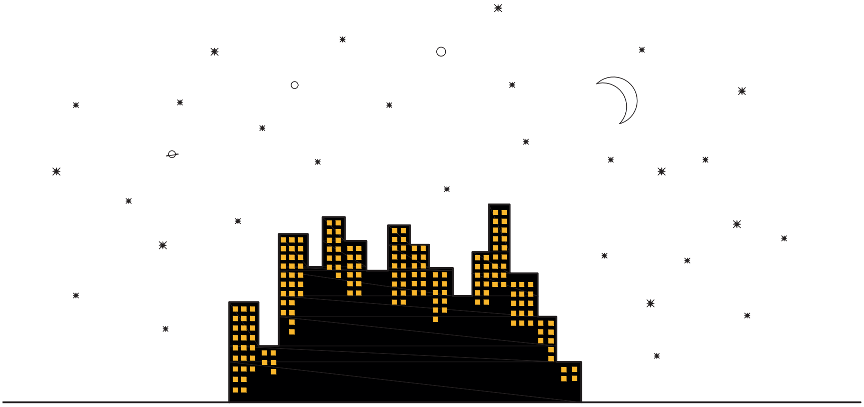
Scenario 1.1: THE ENCHANTED DOME



By combining reference such as the "Manhattan Dome" project by Buckminster Fuller and the "Enchanted ceiling" in the dining hall of Hogwarts School of Witchcraft and Wizardry used in the Harry Potter series (created by J.K. Rowling) the first proposal was born. It is based on the problem of waste light in the cities that is affecting a much larger area around the city. Therefore, the city should be covered by a dome so the light pollution is concentrated without disturbing the environment. That would ensure the preservation of nature and starry sky outside the big urbanized areas. On the other hand, the inhabitants of the cities would live under the constant bright sky which might influence their mindset and initiate the change in the usage of lights. The only connection to the sky would be through the artificially (magicaly) projected stars on the inside of the dome.

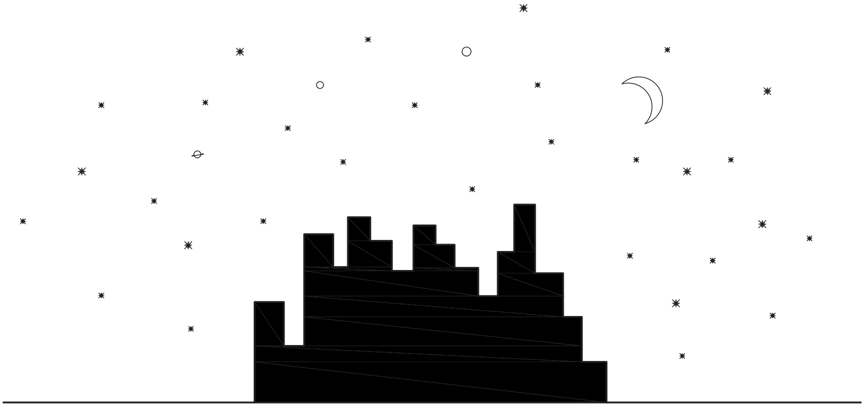


Scenario 1.2: THE BLACKEST BLACK



In February 2019 a Kickstart campaign was created to launch the "Blackest Black 3.0" - the darkest pigment ever made, that can absorb more than 99% of visible light. By using this pigment to cover all surfaces in the cities, almost all light would be absorbed and the light pollution would be gone. Current limitation is that the pigment is not suitable for the outdoor use but that is likely to change in the future. Another disadvantage to this method is the loss of beauty in the cities, architecture, light, materials, everything will look the same. As explained in the previous chapters, light becomes visible only when it reflects of something, so if the light would be absorbed instead of reflected, it would not be visible, therefore the city would be very dark.

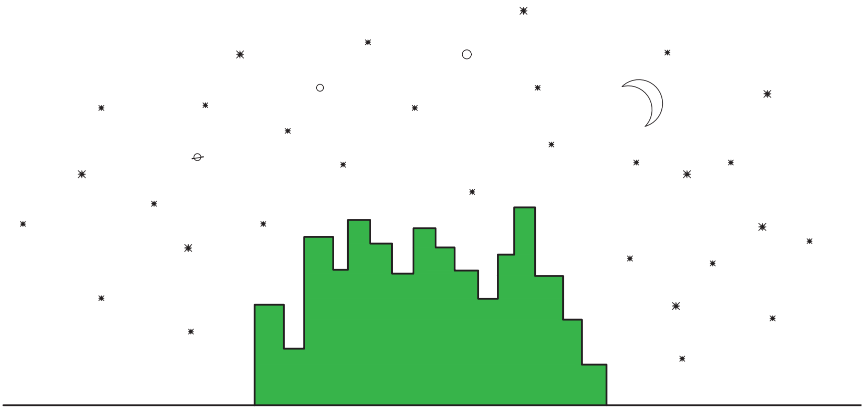
Scenario 1.3: THE CURTAINS



This scenario is based on the idea of putting dark curtains over the buidings during night to prevent unwanted light from coming inside the buildings. At the same time, dark textile would absorb waste light preventing it from ending up in the atmosphere. This way, light pollution would be significantly reduced.

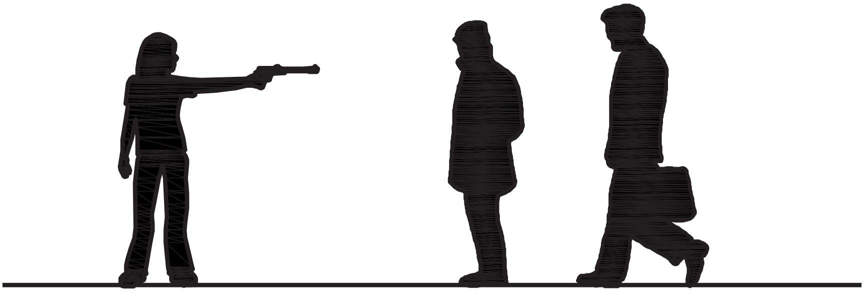
Reference project: Showroom by LDA.iMdA Architects

Scenario 1.4: THE FOREST

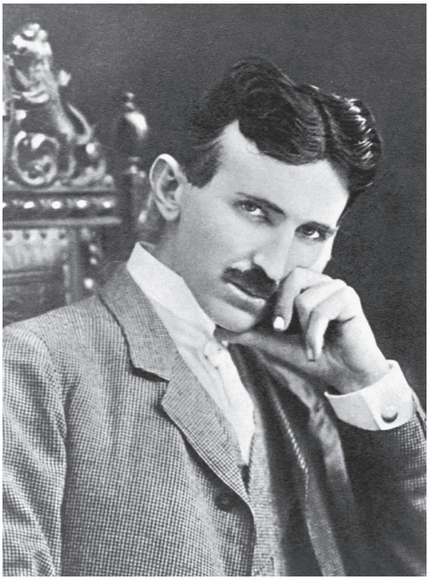


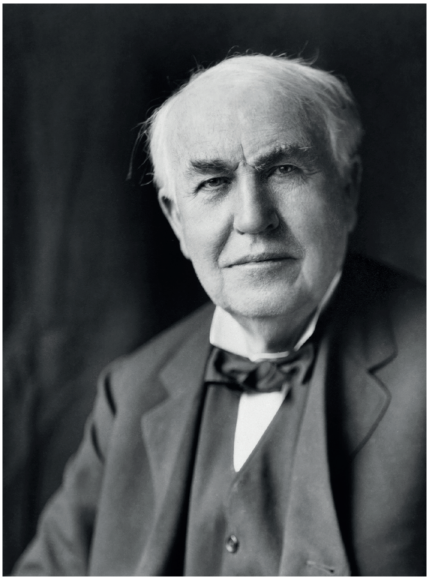
Eventhough green, plant covered facades are gaining attention in the last years, architects are not using them because of their light absorbing properties. Their other advantages such as low- ering the temperature in the cities and purifying the air are much more exploited. Therefore, if the entire city would be covered with plants, it would not only solve the problem of light pollution but also improve other living conditions in urbanized areas.

Scenario 1.5: TIME TRAVEL



All light sources in the cities are powered by electricity and consume high amounts of energy while causing light pollution. Solution: no electricity. By travelling back to the 19th century and executing Nikola Tesla and Thomas Edison, if would be possible to prevent the invention of electricity and electrical lighting. The process would probably have to be repeated as someone else might have the same idea about electricity.

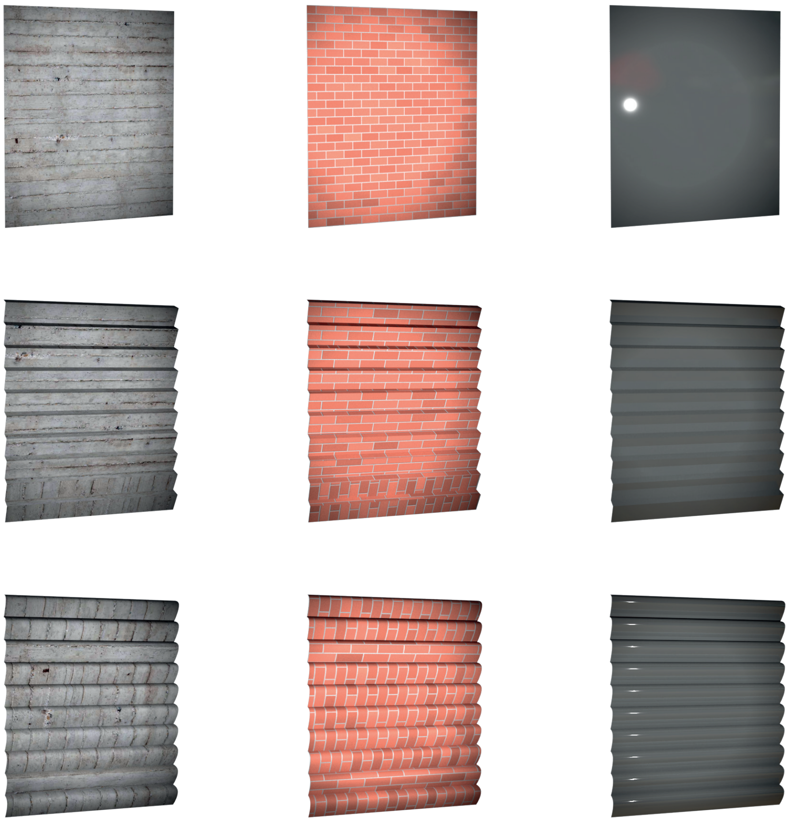




Experiment 02:

Visualization

This experiment was supposed to present the changes of the light reflection when one of the parameters is changed. Analized parameters were form, material and light position. Test was done using Vray software which proved to be an inappropriate tool for this kind of research. The results were almost the same, which is the contradictory to the literature.
Since the results of this experiment will not be used in the further research, only a small fragment of the study is presented here.



concrete brick aluminium

Experiment 03:

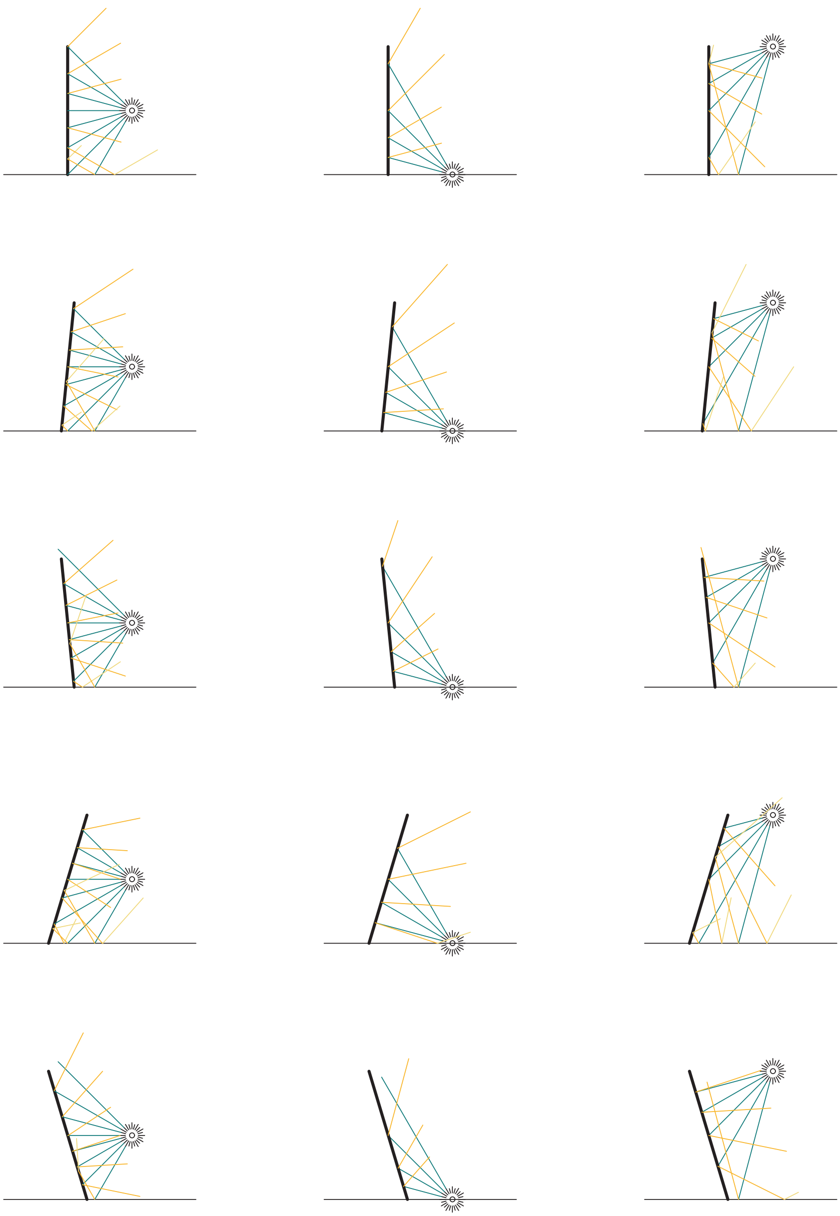
Form finding

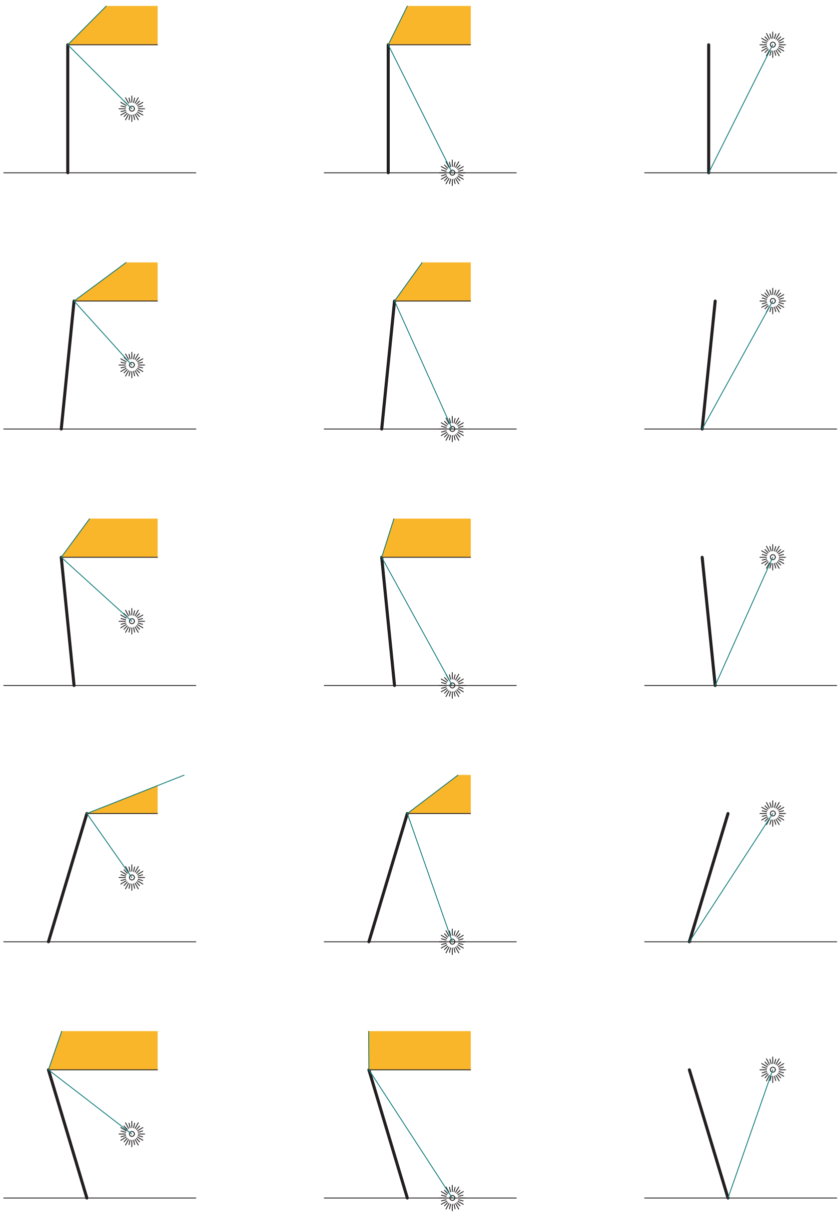
Ongoing experiment based on the basic principle of light reflection (The angle of incidence is equal to the angle of reflection).

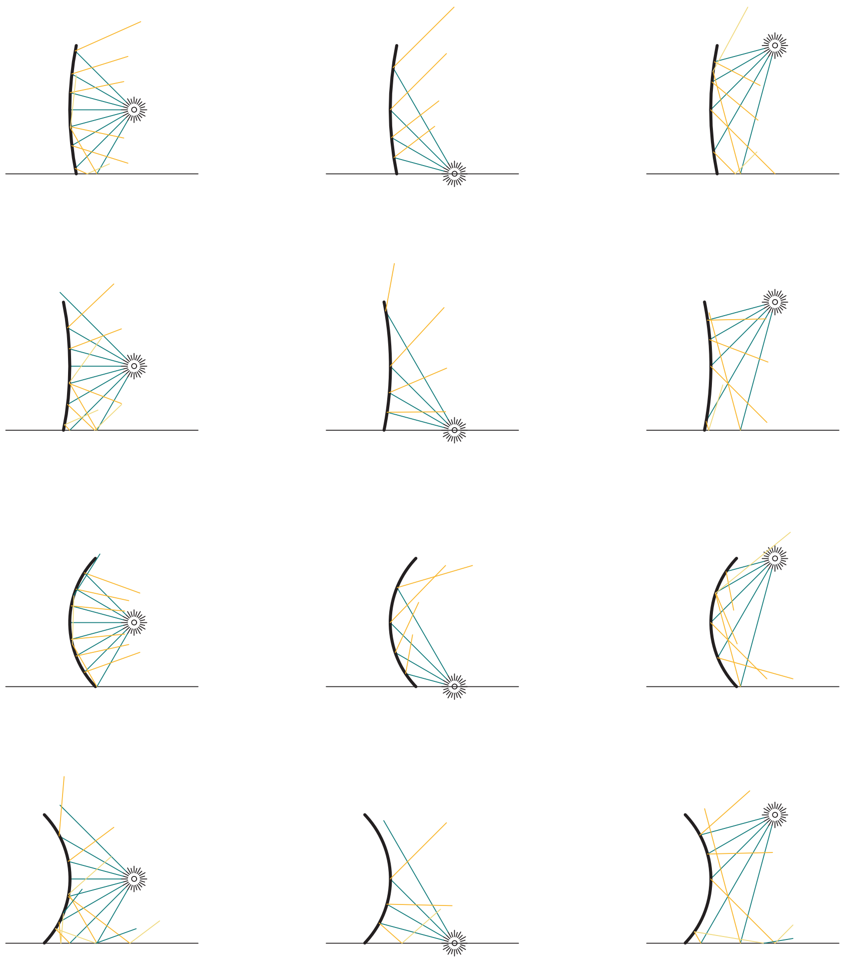
Different geometries are analysed according to the 3 positions of light sources. These geometries will be used as principle elements for creating a form of the facade.

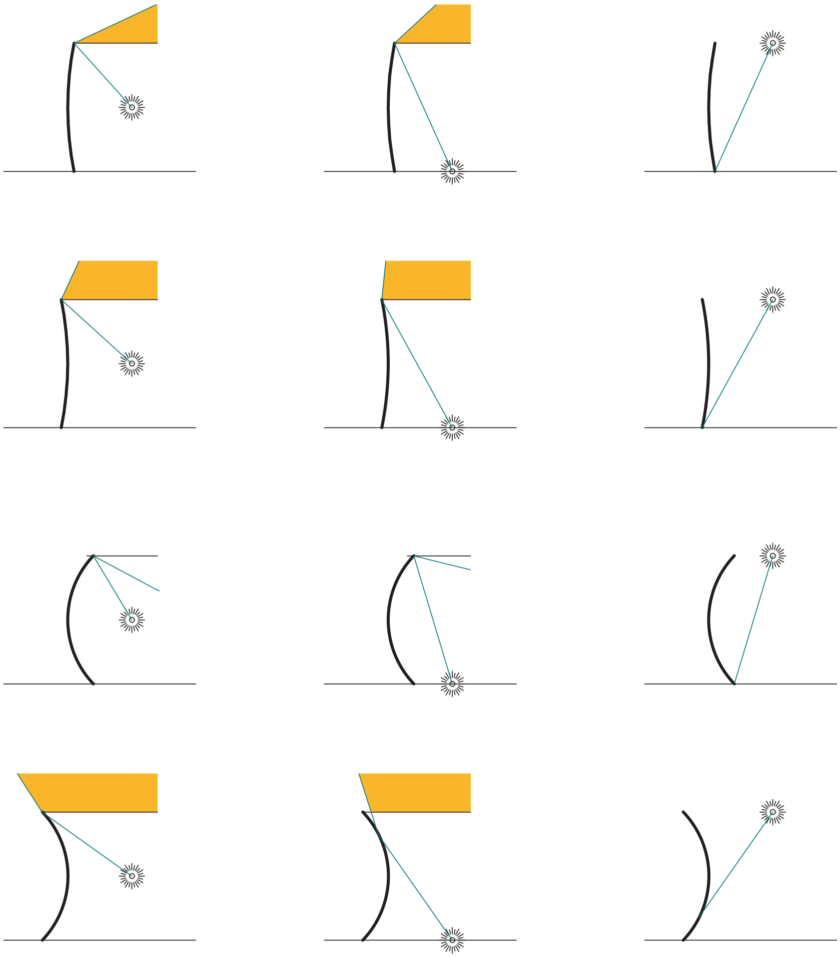
Reading instruction:
blue lines are light rays coming directly from the light source
yellow lines are reflected rays

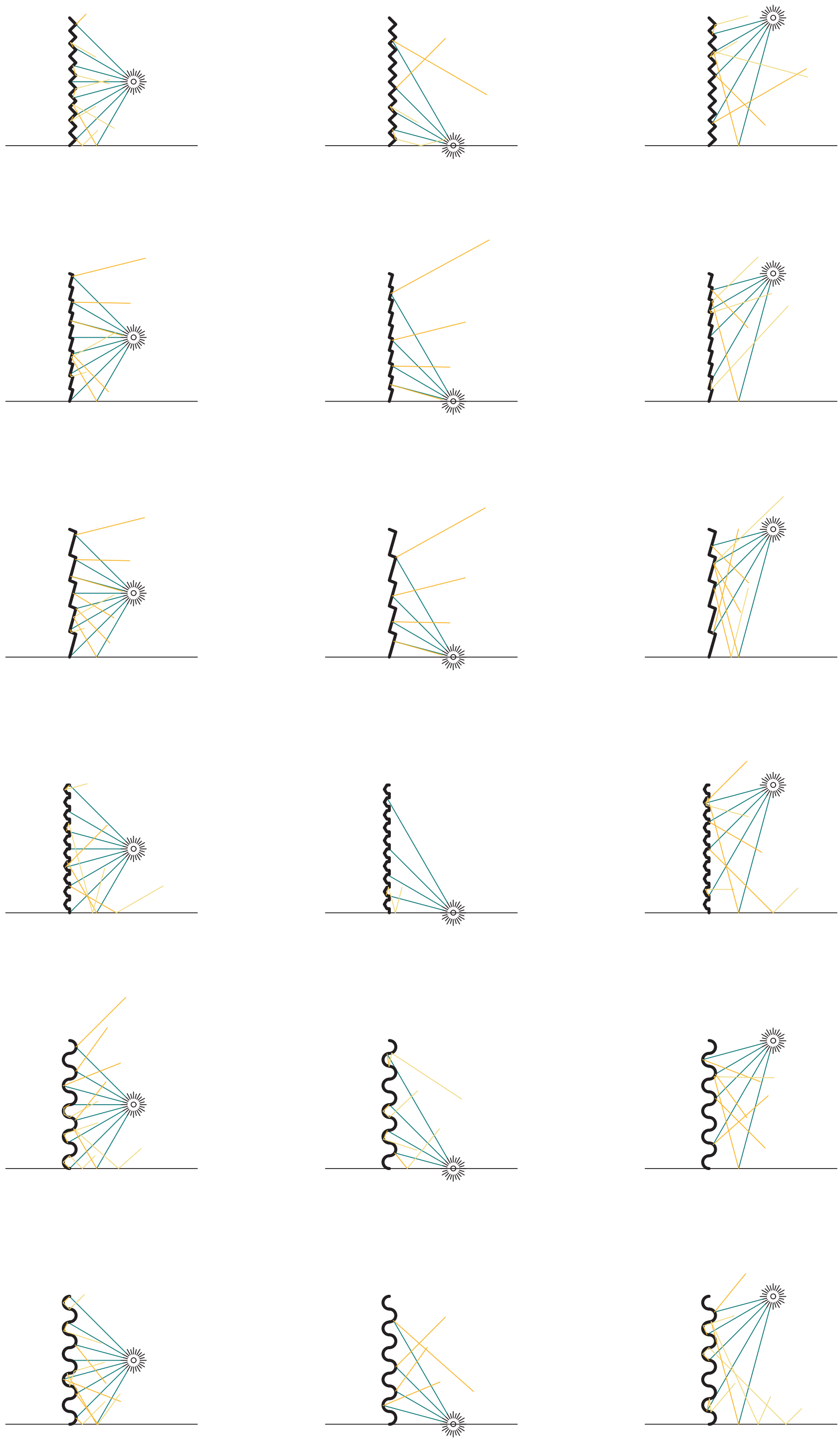
Second part of the experiment shows the amount of light ending up in the atmosphere and being considered light pollution by being reflected of the facade.

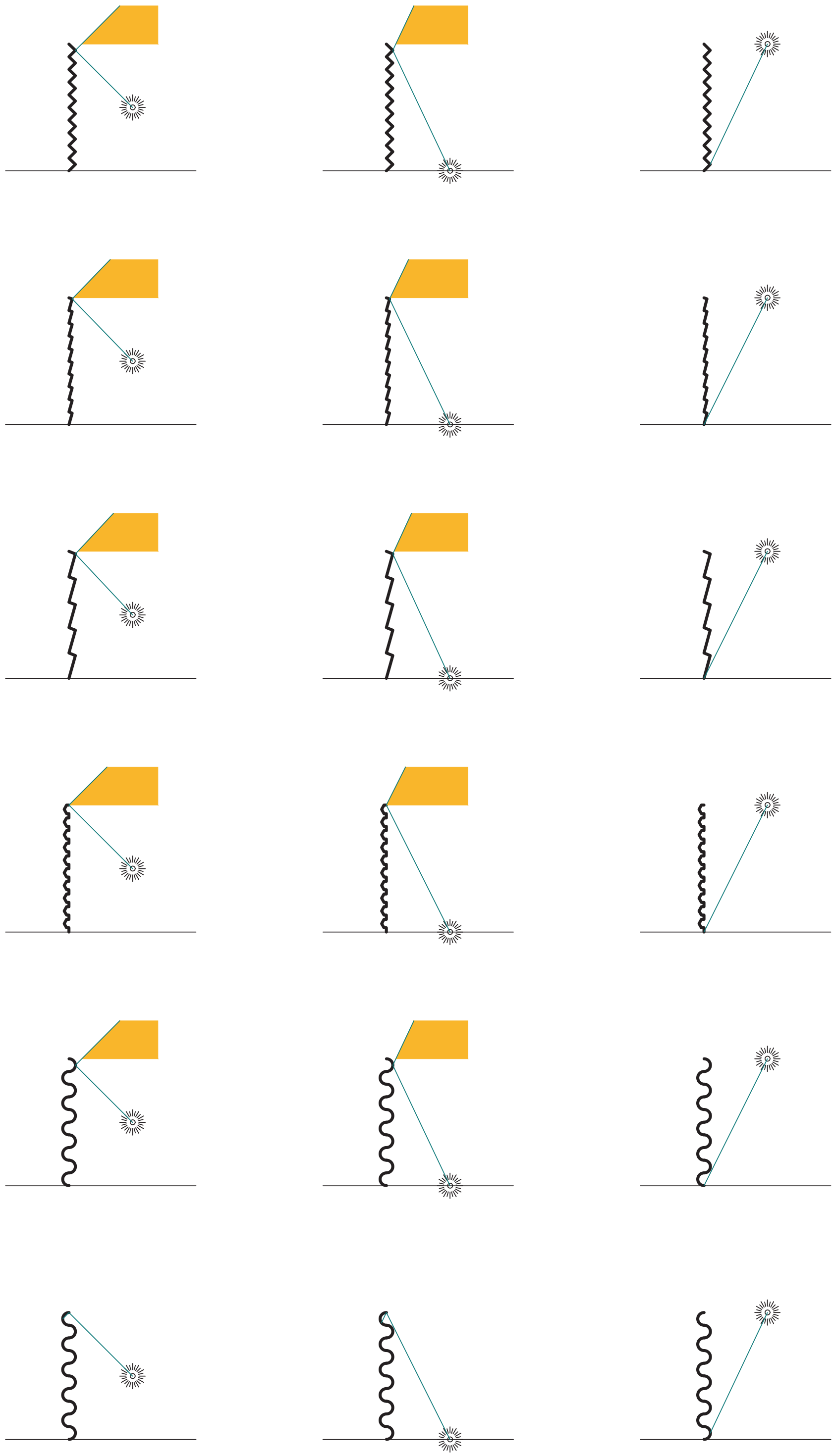


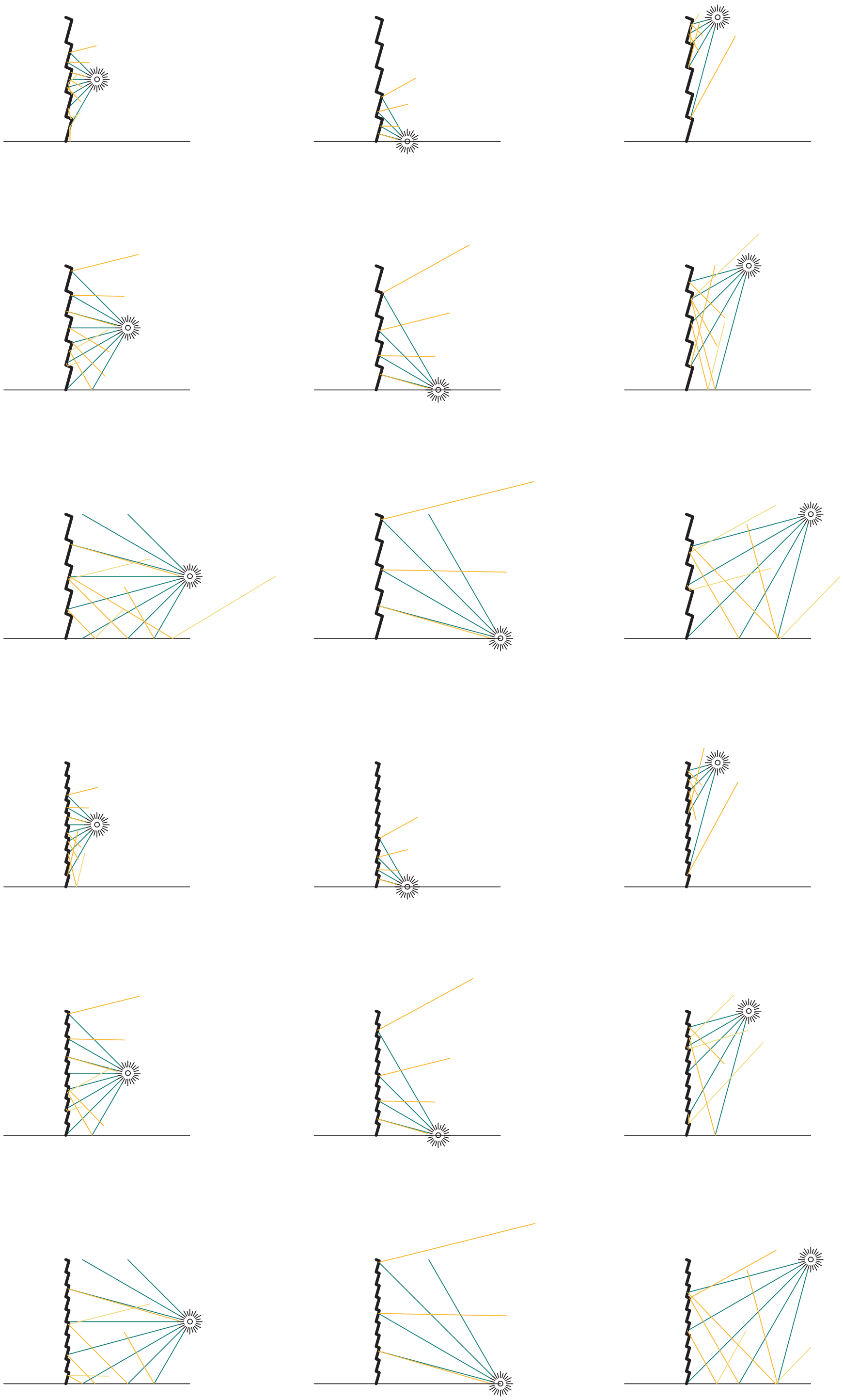








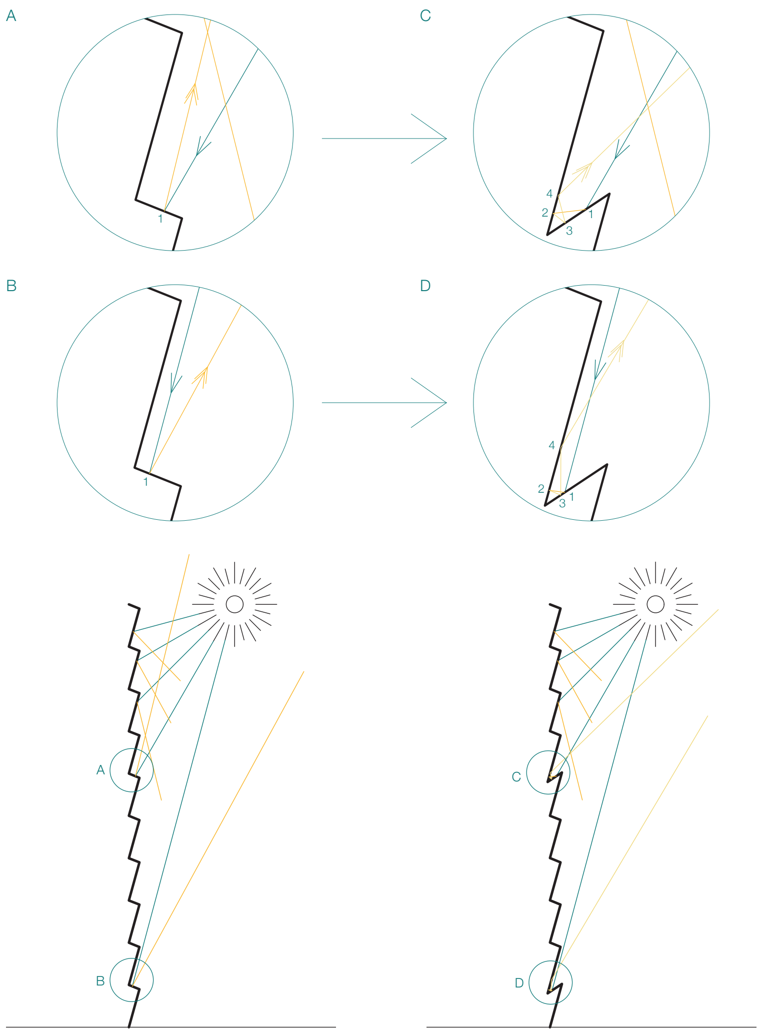




Experiment 04:

Angle study

Shown bellow is the effect on the light reflection caused by changing one surface's angle. Details A and B show that light is directly reflected upwards, while the details C and D show surface with changed angle where light is reflected 4 times.



Experiment 05:

Physical model

Building a physical model that can simulate the case study site is the foundation for the future design experiments. Lorensberg P-hus was chosen as the case study and one part of it was made in a 1:20 scale model. Focus was on simulating the light conditions and light pollution effects, such as glare, light trespass and skyglow, that are happening there.

Lorensberg P-hus

This model was used for the following experiments concerning the facade design. It provided a good environment for testing and comparing different designs and gaining practical knowledge about reflection of light and light pollution.

Model 1:20

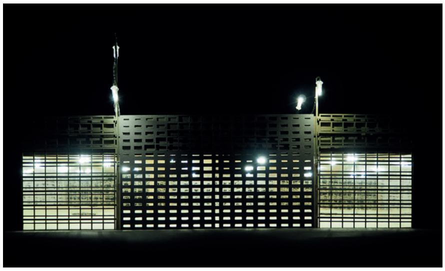
Phase 1: EARLY STUDIES

During the first tryout, results were dissapointing but real. Five different designs were tested and compared with the original, existing facade. Facade concepts such as horizontal and vertical louvres and punctured wall were researched. Current structure was used to determine the distances between louvres or openings, and the amount of light seen at a certain spot was influencing the width of louvres (more light more width) and the size of the openings (more light less open).

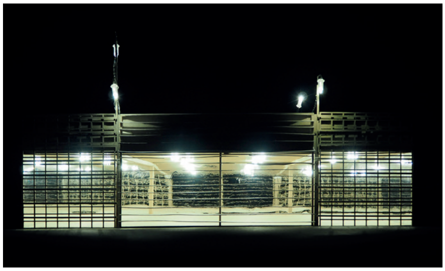
All results were more or less the same, with very slight oscillation when it comes to light pollution. Main reason for this is that the design was not extreme enough: distances were too big, widths were too small.

Never the less, some knowledge can be gained from this phase of the experiment and used in the following experiments. Use of horizontal louvres (designs 2 and 2a) projects good results when looked from the front (everything is dark in the upper part of the facade) but it also increases skyglow effect as the streetlight is directly reflected upwards. This could be fixes by changing the angle of the louvres. Vertical louvres (designs 3 and 3a) showed better results when it comes to the upper part as they reduced the area affected by light coming from the luminaire. Because of their geometry, light is reflected downwards between the louvres so the skyglow is reduced. Overall, both designs are too transparent and don't address the problems of glare and light trespass. Design 1, on the other hand, reduces these problems, but also reduces the transparency. It is also noticable that the interior is more illuminated in this case because the interior light is reflecting back of the facade instead of leaving the building.


original


design 1

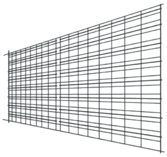

design 2

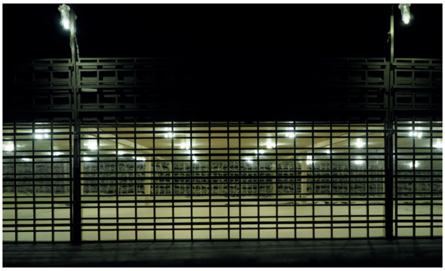

design 2a


design 3

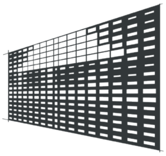

design 3a

Original

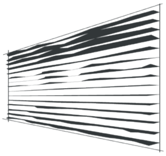




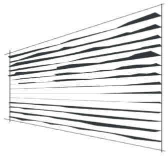
Geometry 1



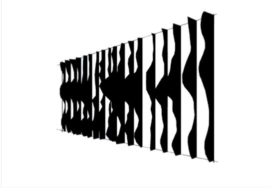
Geometry 2

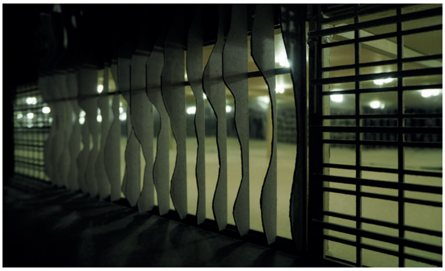


Geometry 2a



Geometry 3





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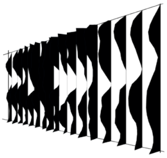


Phase 2: VERTICAL LOUVRE STUDY

After Phase 1, some conclusions were drawn that guided the experiment forward. At this point, the case study was chosen, so design became more specific, site oriented.

With transparency as one of the major requirements, the punctured wall was put on the side and design continued exploring the louvres. The problem of skyglow appearing with horizontal louvres could be fixed by rotating the elements, although that would decrease transparency, so this design was also not used in the following study.

This phase of the experiment is focusing only on vertical louvres and how their geometry responds to light pollution. It all began with a simple vertical louvred facade. Further investigations included different types of rotations and twists.

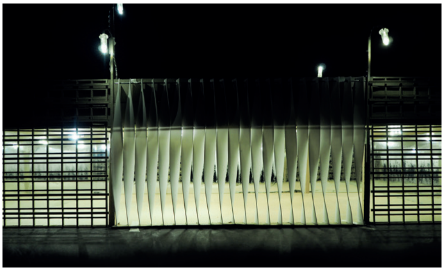
original

design 4

design 5

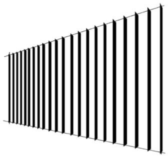
design 6

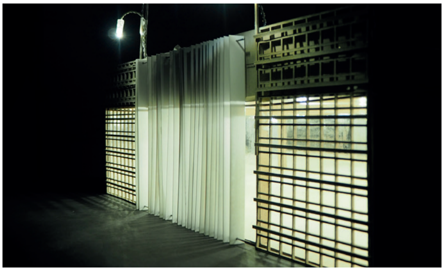
design 7



design 8

Geometry 4





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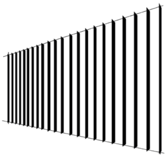

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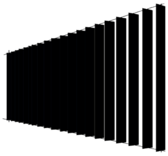

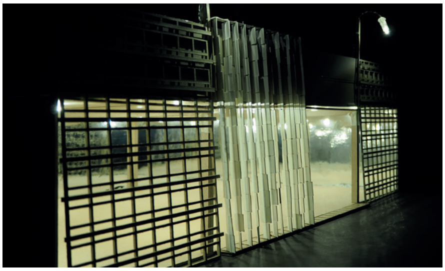

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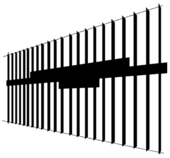
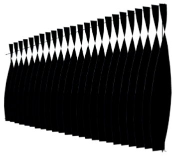
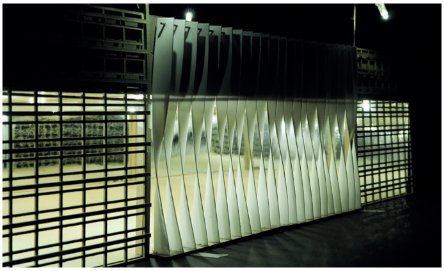
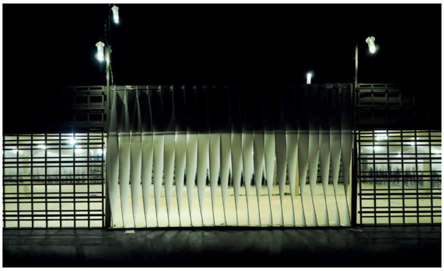


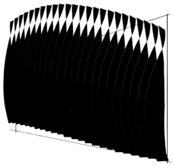
Geometry 8

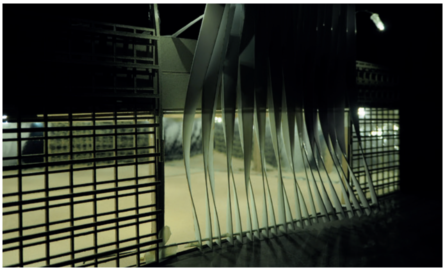


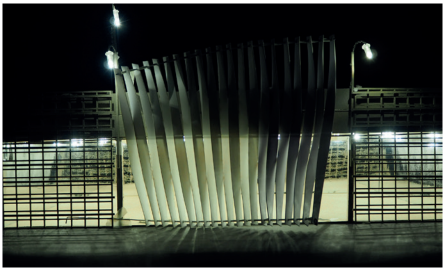


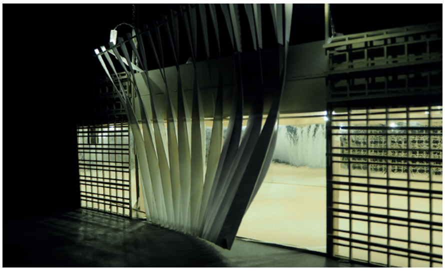


Geometry 9









6
CASE STUDY

This chapter will focus on the development of the final design. After many preliminary designs and experiments, one design was chosen as the most appropriate for the selected case study, and it is developed more deeply, looking into its form and materiality, exact dimension and production.

It is essential to highlight that this part of the research shows only one way of approaching light pollution. This approach is not the best nor the only way to reduce light pollution, but only one of the many concepts presented in this thesis.

The chosen case study is the Lorensberg P-hus, and it will be analysed at the beginning of the chapter. Design criteria will follow and then the development of the facade design will be presented.

SITE - LORENSBERG P-HUS

The chosen case study is the Lorensberg P-hus in Gothenburg, Sweden. This parking garage was designed by Fredblads Arkitekter and built in 2012. It can accommodate 466 vehicles and is located in the central area of Gothenburg, between Korsvagen, Gota Platsen and Heden. Car access is available from Ostra Vallgatan and Sveagatan, but the chosen facade is overlooking Sodra Vagen street.

The parking garage is a low building, consisting of the ground floor and top deck. The facade is made out of metal structure following a grid of 350x200mm. This design allows for transparency, ventilation and connection to the surroundings. Following the safety regulations, parking is very brightly illuminated, and because of its transparent facade, the light is not controlled, and it's polluting the environment. Light sources are directly visible from the outside, creating glare and light trespass problems.

This case study was chosen because of its specific character of a non-stop functioning building. This means that the light cannot be turned off during the night as the building is being used. Considering safety regulations, light intensity can't be lowered and shielding the lights will not fix the problem because of their position in the building. Changing the light colour could improve visual comfort, but the glare would still be present.

Another exciting aspect of the location is various light sources coming from multiple directions. This is used as the design inspiration in combination with functional elements that are protecting the environment from light pollution.

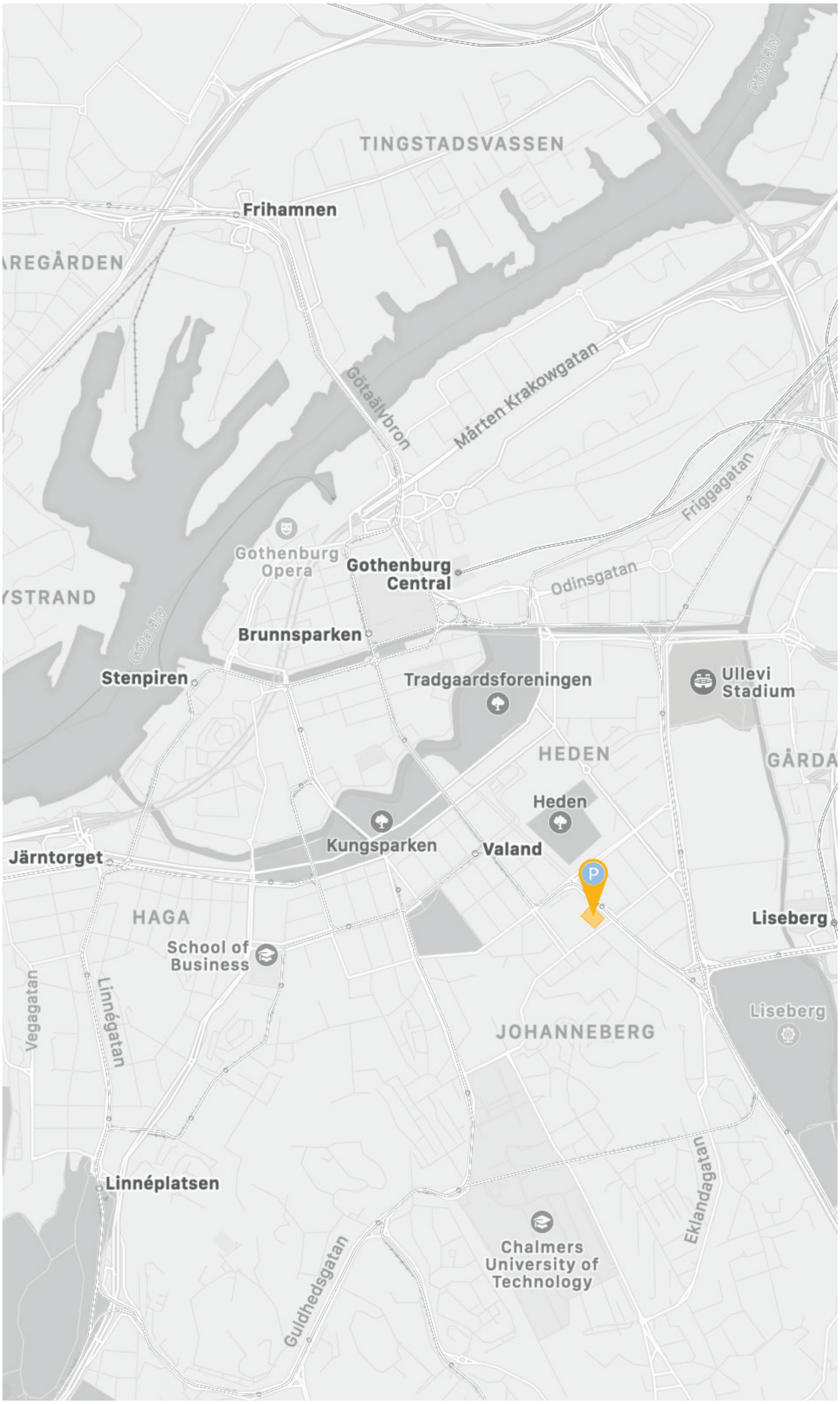

TINGSTADSVASSEN
Frihamnen
REGÅRDEN
Göta älv
Götaälvbron
Mårten Krakowgatan
Friggagatan
Gothenburg Opera
Gothenburg Central
Odinsgatan
STRAND
Brunnsparken
Göta älv
Stenpiren
Tradgaardsforeningen
Ullevi Stadium
HEDEN
GÅRDA
Heden
Kungsparken
Valand
Järntorget
P
Liseberg
HAGA
School of Business
Vegagatan
Linnégatan
Liseberg
JOHANNEBERG
Eklandagatan
Linnéplatsen
Chalmers University of Technology
Guldhedsgatan

Figure 15. View from Sodra Vagen

Figure 16. View from Sodra Vagen

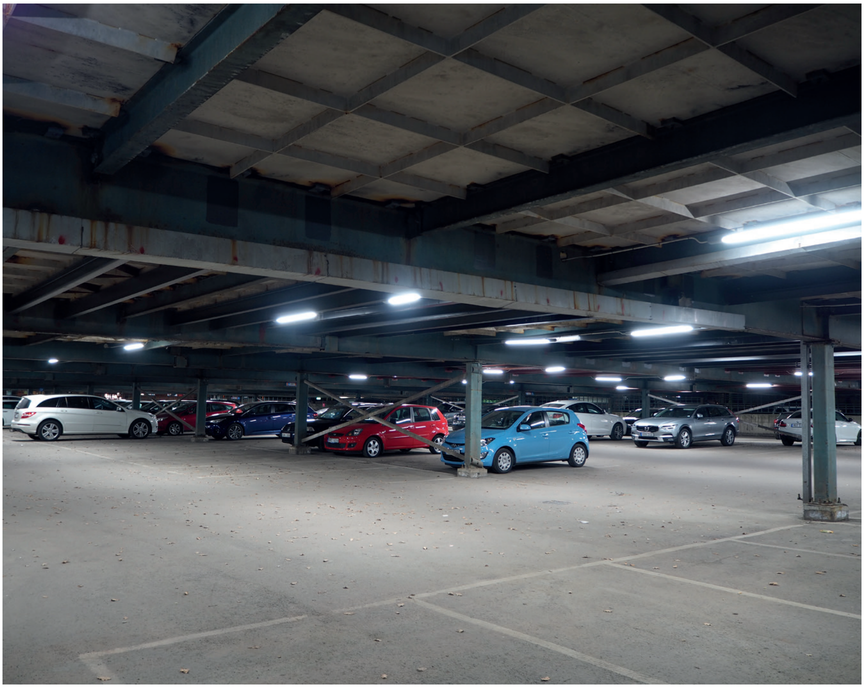
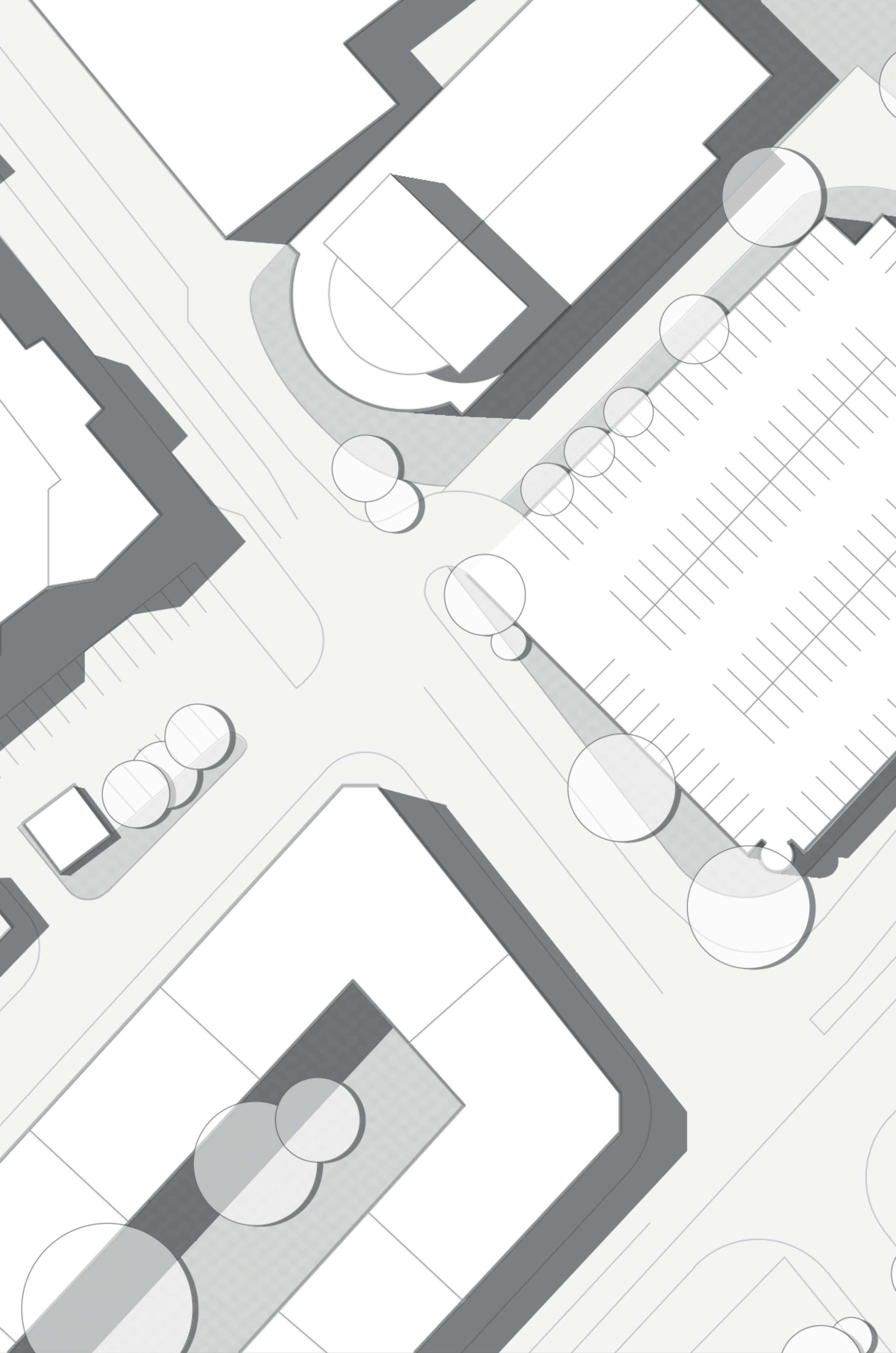
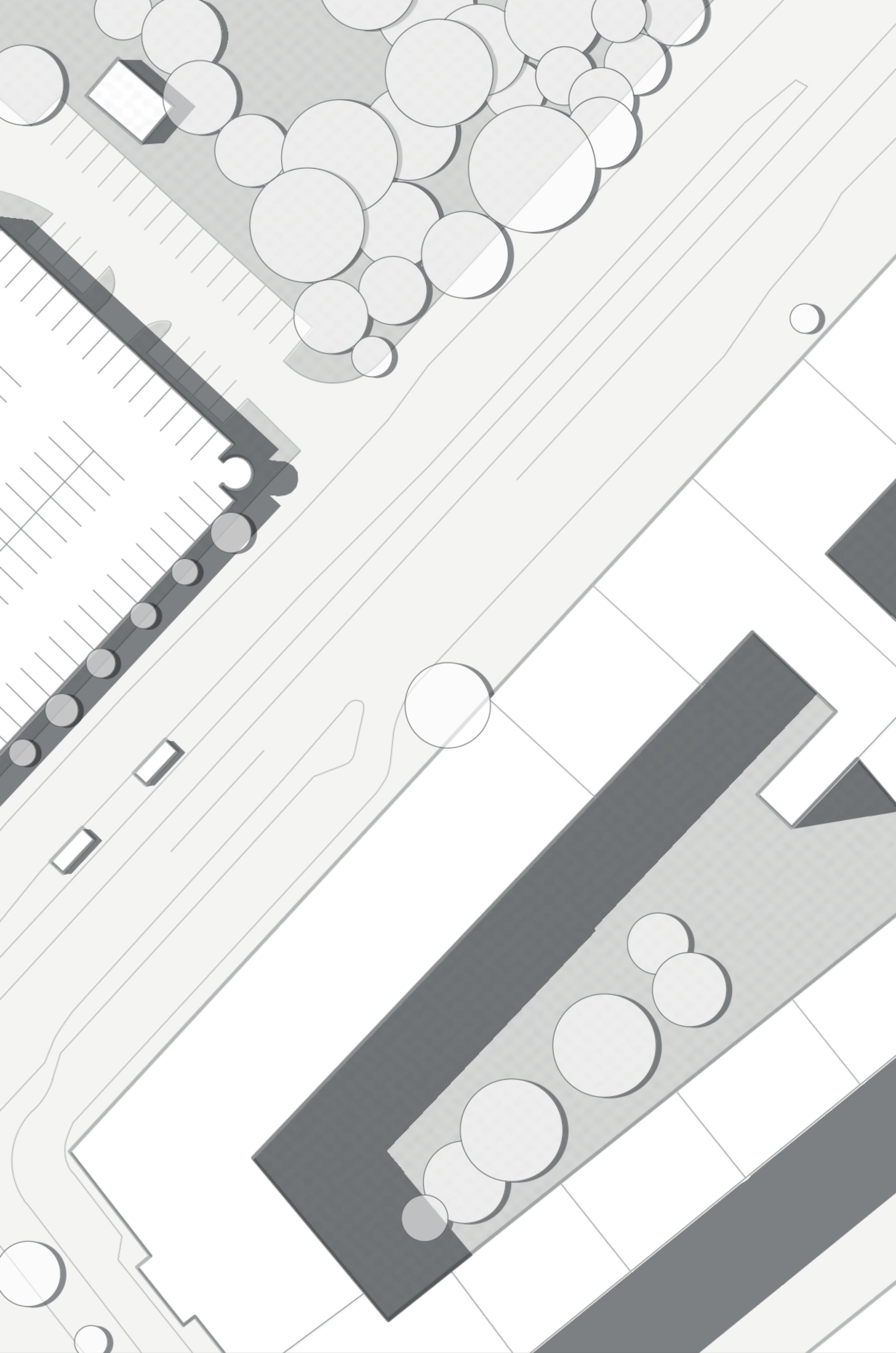


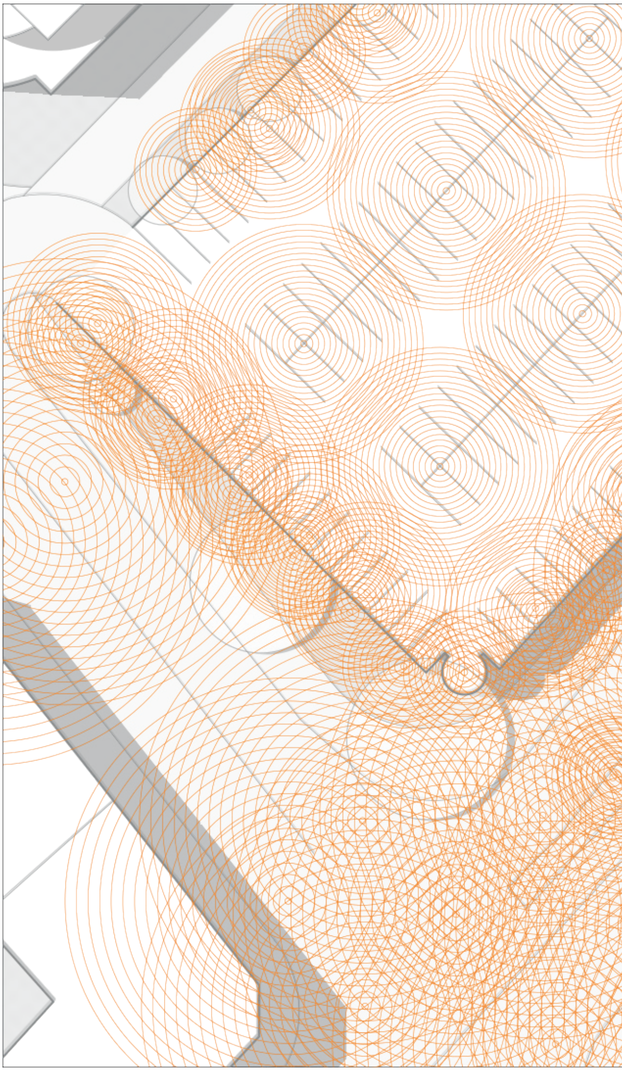
Figure 17. Interior

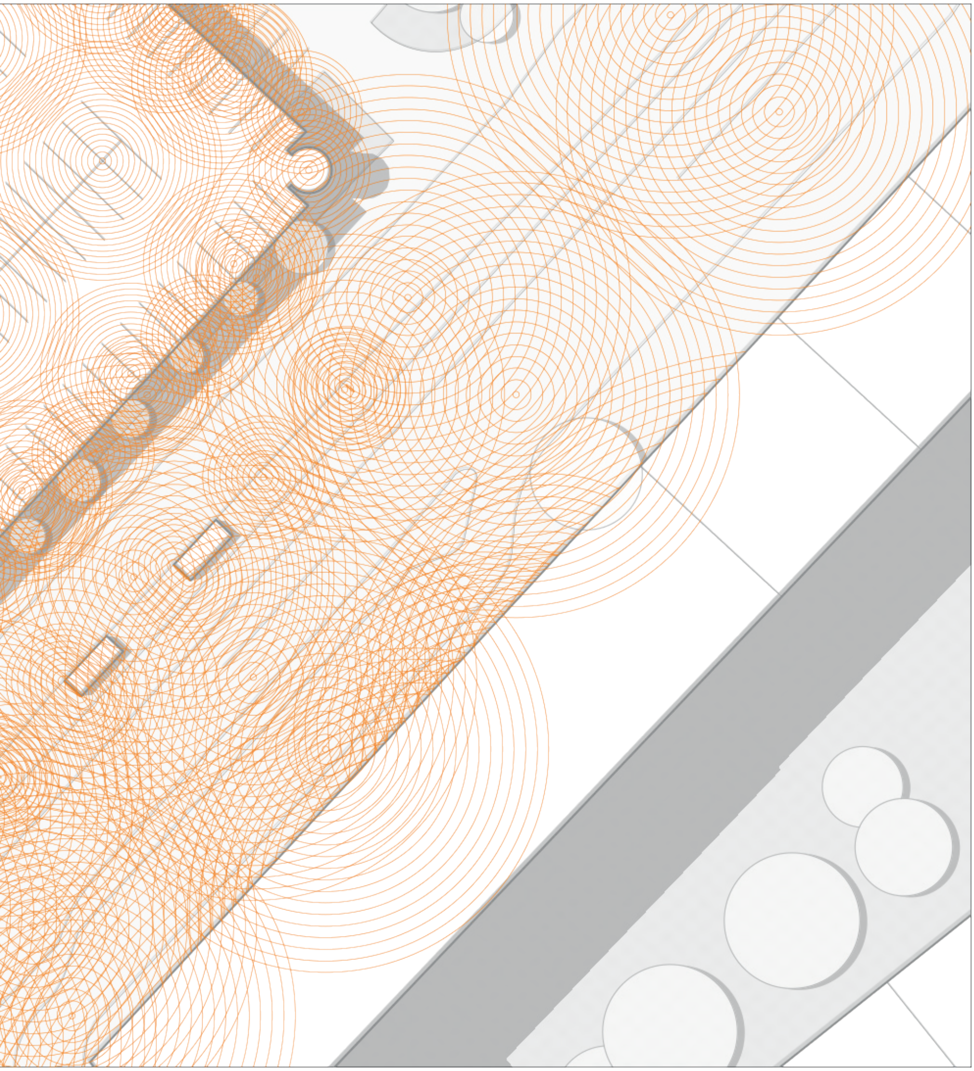
Figure 18. Top deck

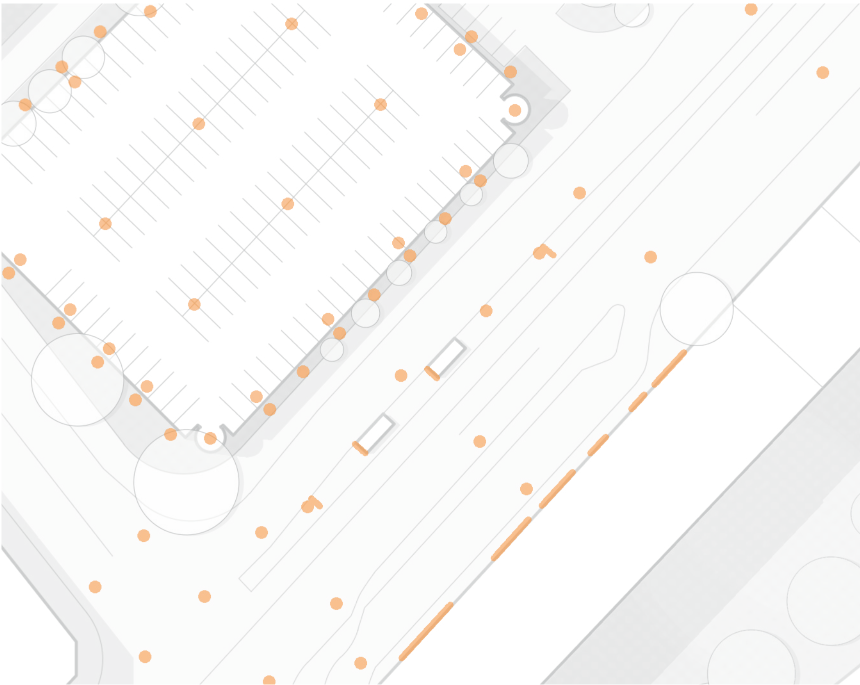




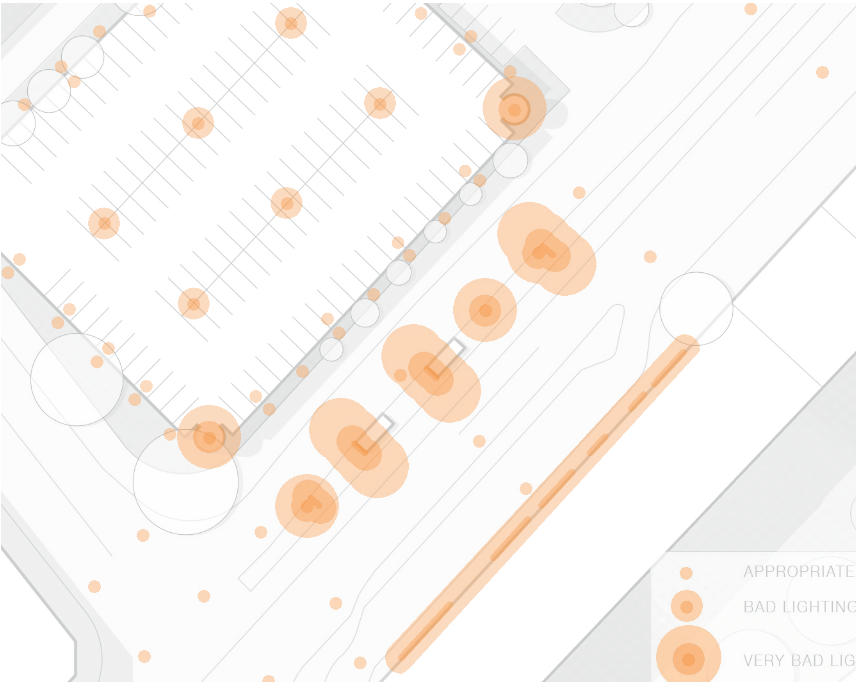
LIGHT ANALYSIS







Light sources



Light evaluation

DESIGN CRITERIA

PRIMARY CRITERIA:

users	- safety	- max transparency
	- comfort	- no light pollution
		- human scale
architecture	- aesthetically pleasing	
	- easily adjustable concept	
sustainability	- minimum light pollution	- no glare
		- no light trespass
		- no skyglow

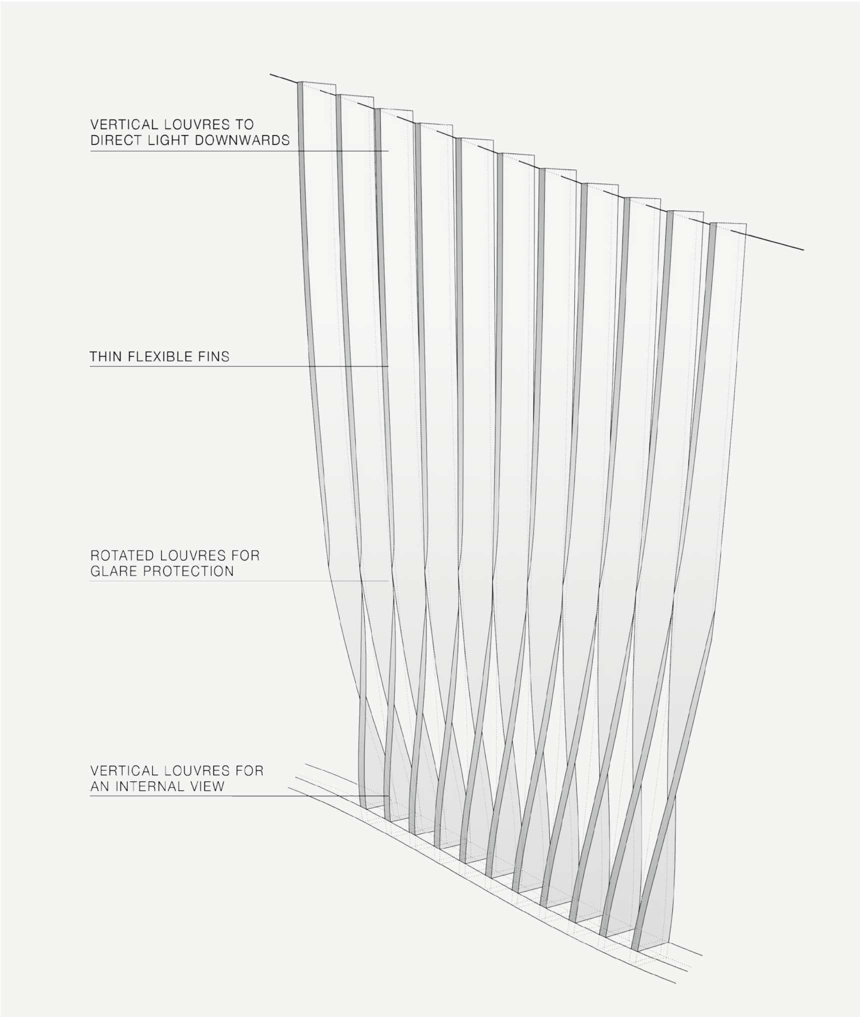
SECONDARY CRITERIA

sustainability	- minimum embodied energy	- minimum material
		- eco friendly materials
	- minimal impact on the existing nature on the site	
production	- minimum embodied energy	
	- minimum waste material	
structure	- prefabricated panels	
	- easily replaced panels	

low maintenance

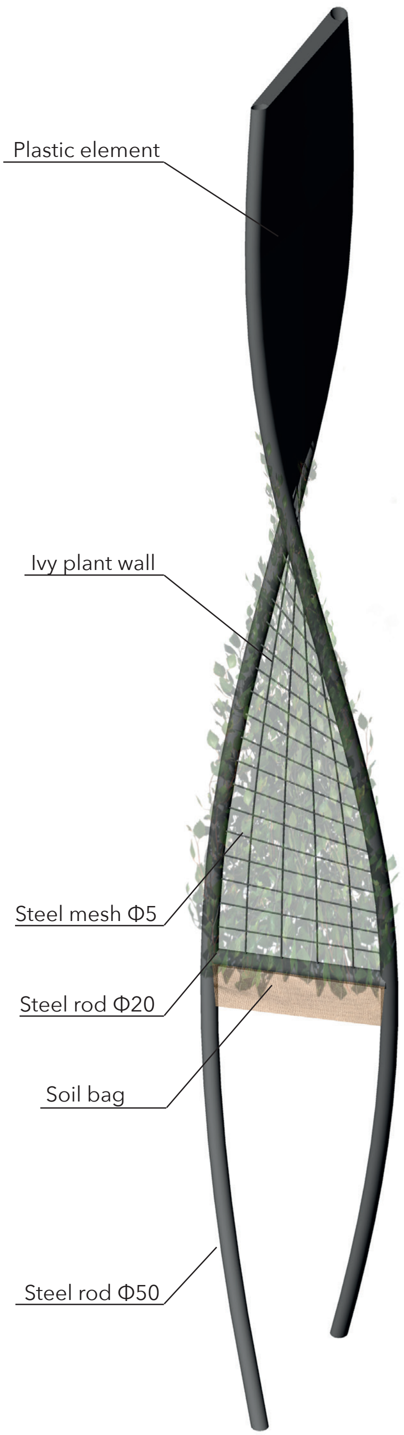
FACADE ELEMENT

As a result of physical experiments, basic element of the facade was made. It is based on the vertical fins, but with a twist. This twist covers up the light sources and removes the glare problem. Remaining vertical parts allow for transparency, ventilation and they direct light downwards, reducing the skyglow. This concept is easily adjustable and applicable to other situations. Size of the elements is dependent on the material and light situation.



Initial element design

This was the result of the form investigation through physical model experiments. It represents modification of one vertical element, that was twisted for 180 degrees. Dimensions are directly influenced by the building itself, so the height is 4.5m and the width/depth is 0.5m. Thickness is dependent on the materiality, but should be minimal.

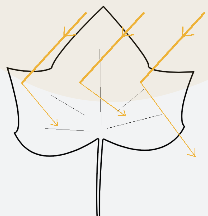


Developed design

Two textures are proposed as a solution for the facade and they are combined on this example. One is based on the plant wall and presents the extension of the greenery next to the building, while the other concept is a modern, technical way of using complex geometry to absorb light.

PLANT WALL

Simple solution of reducing light trespass and glare by adding a layer of greenery on the facade. Their rough, messy structure can diffuse light by scattering it and reduce light waste.



LIGHT ABSORPTION

Geometry of leaves, their irregular surface and overall form of the green wall reduces the light reflectivity by absorbing it and scattering in different directions.

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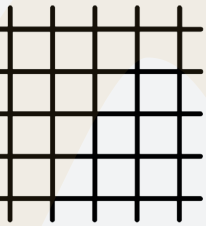

ESH SUPPORT

enery is attached to the
el through a metal mesh
80x75mm which pro-
s ideal conditions for ivy
nts to grow tall and dense.

PLANT TYPE

Ivy was chosen because of its properties such as fast growth, it requires little soil, it's an everygreen plant, can be green or red, it's easy to maintain.

ECO FRIENDLY

Using this panel will not only improve light conditions on the site, but also help with air purification and micro ecosystems.

COMPLEX GEOMETRY

Use of modern technology to produce panel with specific geometrical properties that will allow it to trap and absorb waste light, thus reducing light pollution.

LIGHT TRAPPING

Very dense but thin geometry lets light in, but then the light gets trapped reflecting off multiple surfaces inside the panel until it’s completely absorbed.

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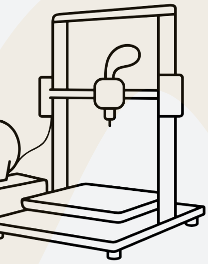
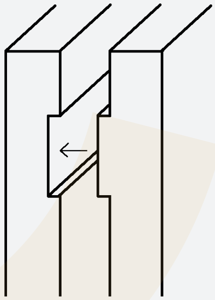


PRINTED PLASTIC

en method of produc-
s 3D printing as it allows
very precise and de-
l geometry to be made.



SIMPLE INSTALLATION

Panel is made in 2 pieces that are interlocked on site without additional joints.

BLACK SURFACE

Using black material will provide the panel with very low reflectivity coeficient, meaning that a lot of light will be absorbed.

Plant wall

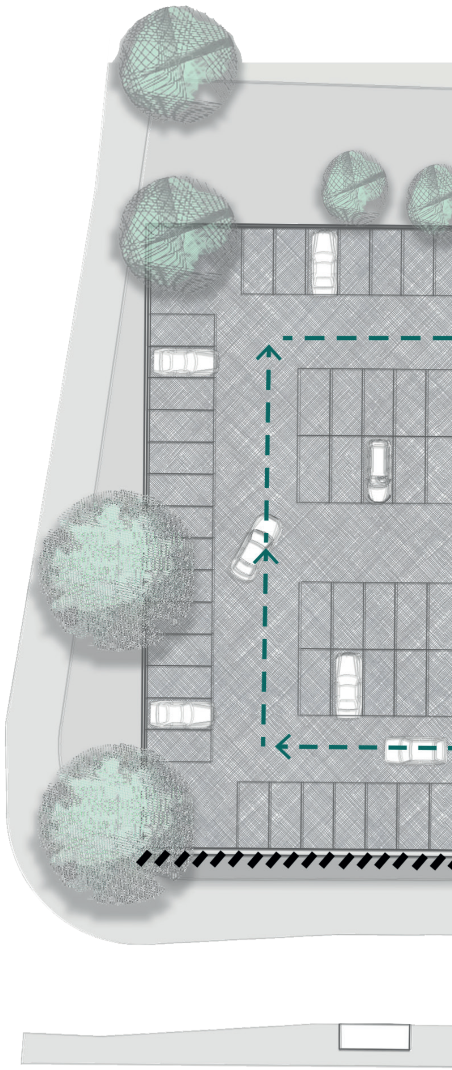
+ simple, fast application
+ improves building aesthetics
+ no need for a large initial investment
+ reduces air pollution
+ natural solution
- requires continuous maintenance
- cannot be controlled / predicted

Complex geometry

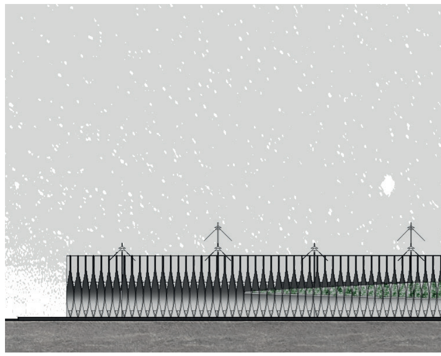
+ efficiently traps light
+ provides modern looking solution
+ high precision
+ no maintenance
+ easily exchangable
- high initial investment (time and money)
- aesthetical value is discussable

Looking at the close context of the building, 3 situations influenced the facade's overall design:

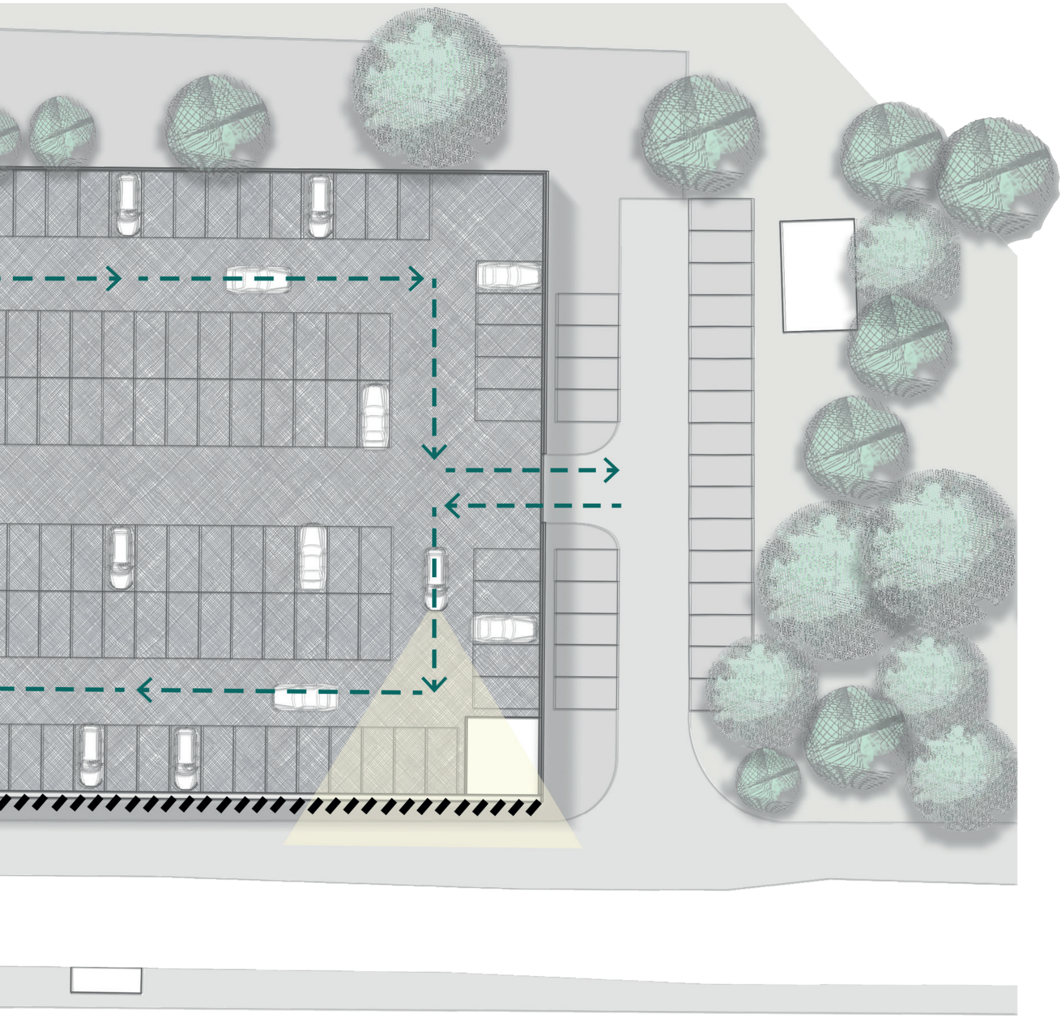
1. very different surroundings on the left and right side of the building
2. direction of the car movement inside the garage
3. service building by the right side of the facade.

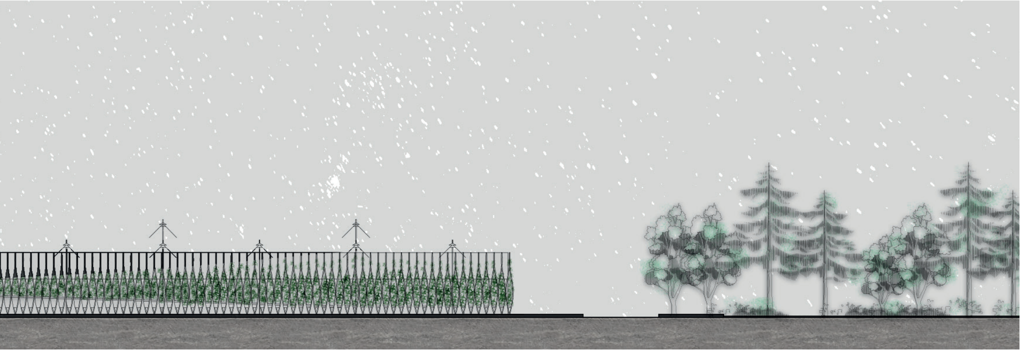


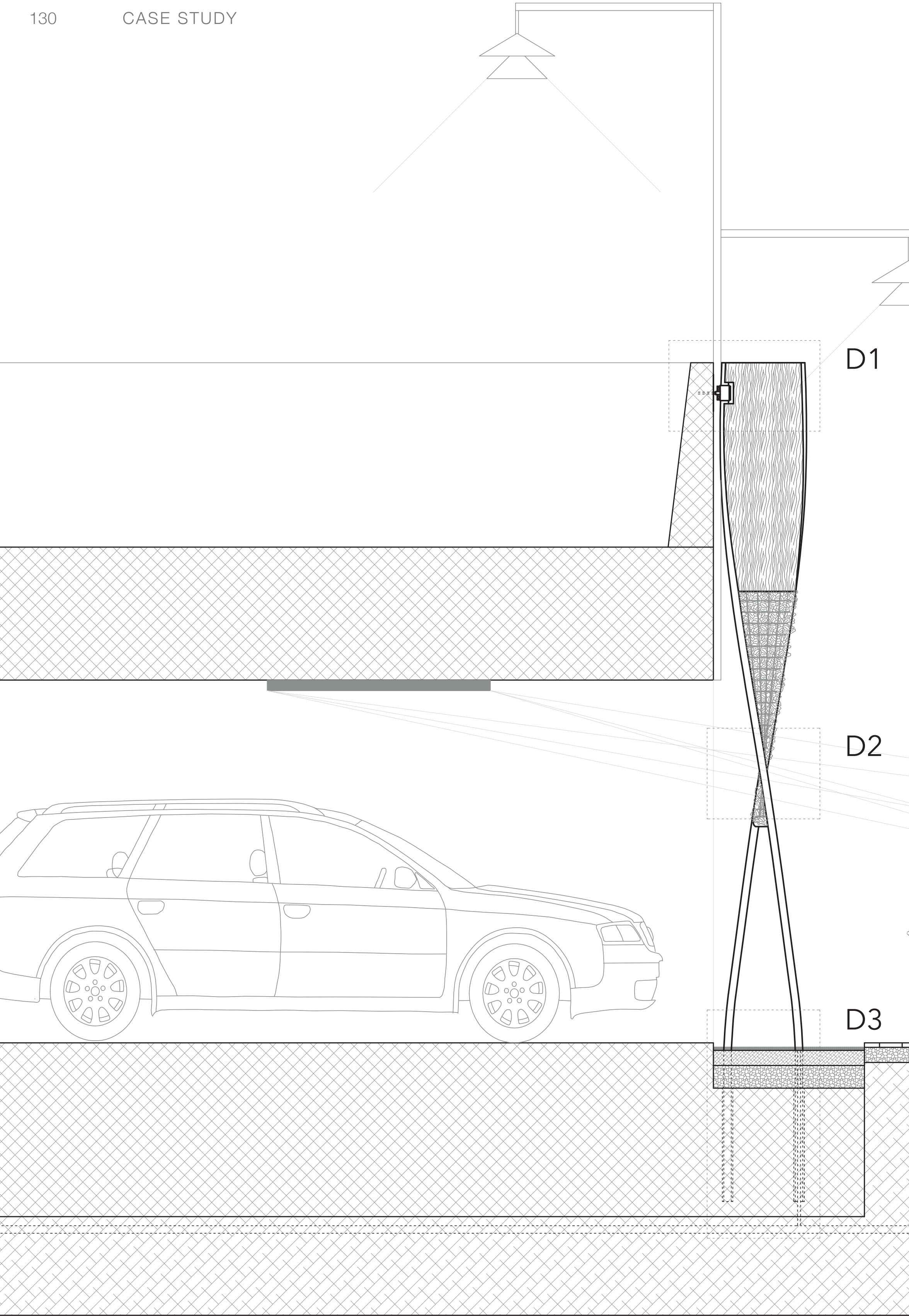
All of this defined the materiality and level of transparency. Park that exists on the left side of the building is very calm, green, with just a few lights, so the left side of the facade is mainly based on the green wall concept, attempting to enhance and extend this feeling. On the contrary, right side presents busy, urban lifestyle, and is presented through the modern, black plastic panels. Both of these materials start from the sides of the facade and merge towards the middle.



Most of the facade panels are completely transparent at the bottom, to allow for a visual connection in areas where light is not intrusive. Exception is left corner of the facade where headlights are creating additional intrusive light and the service station that is not necessary to be seen from the outside. This part is made of panels that are completely overgrown by plants therefore reducing the visual connection and waste intrusive light.






D1
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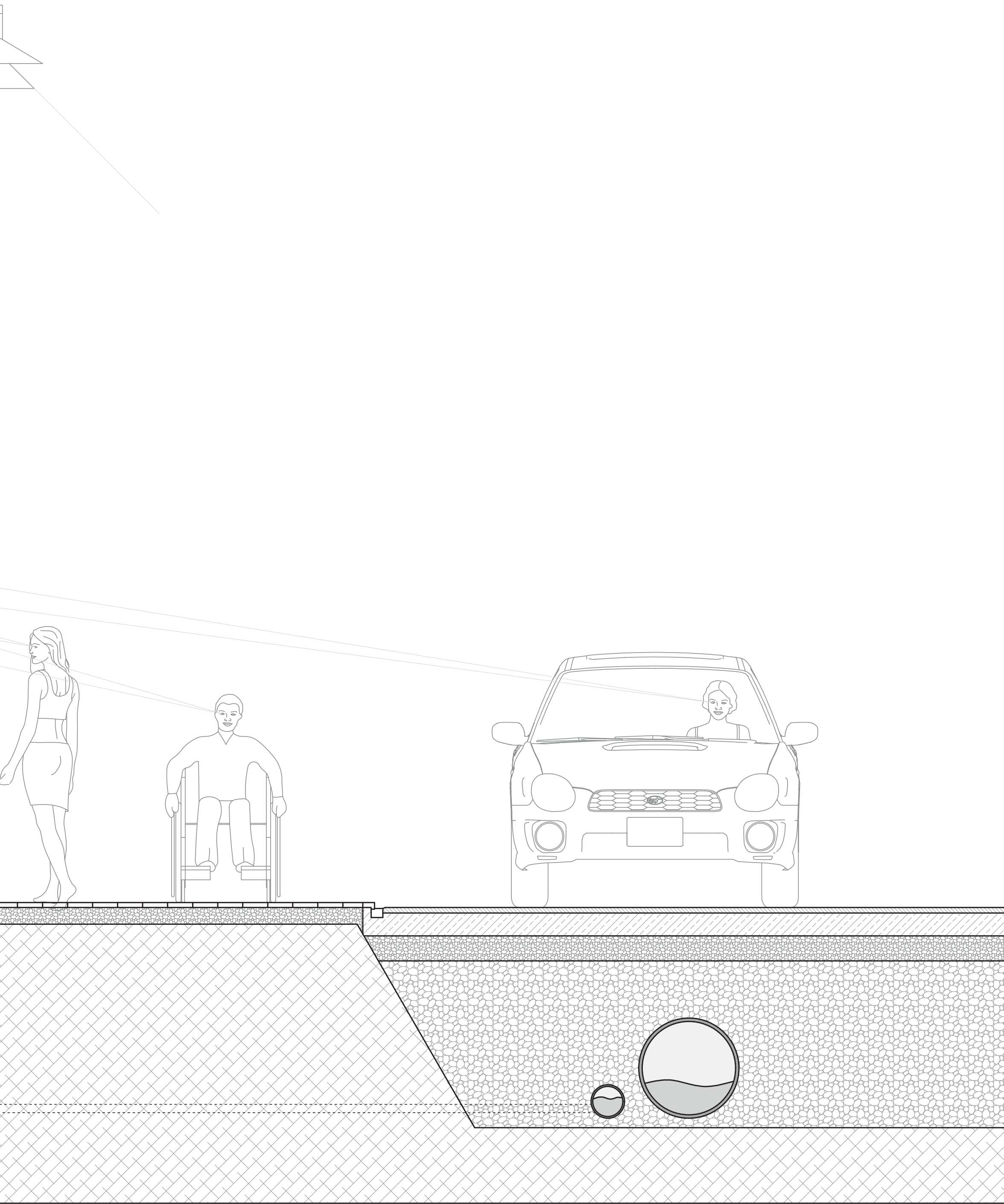
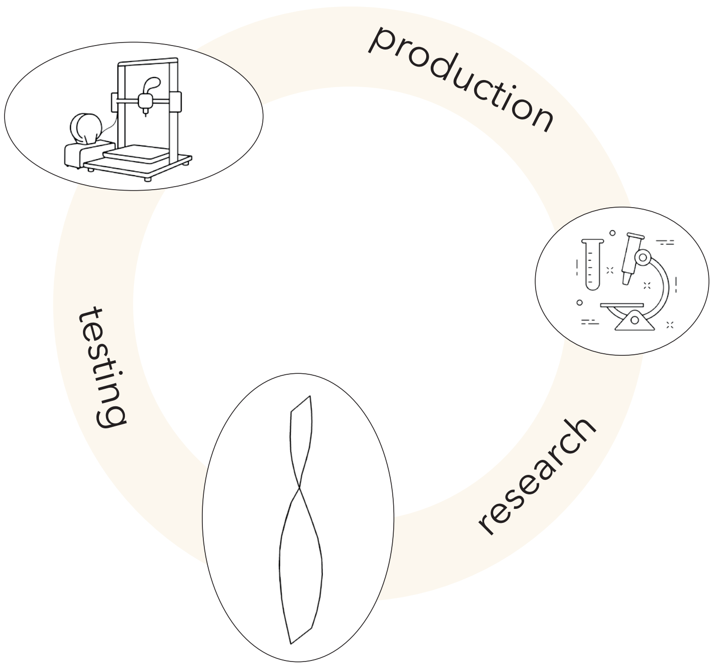


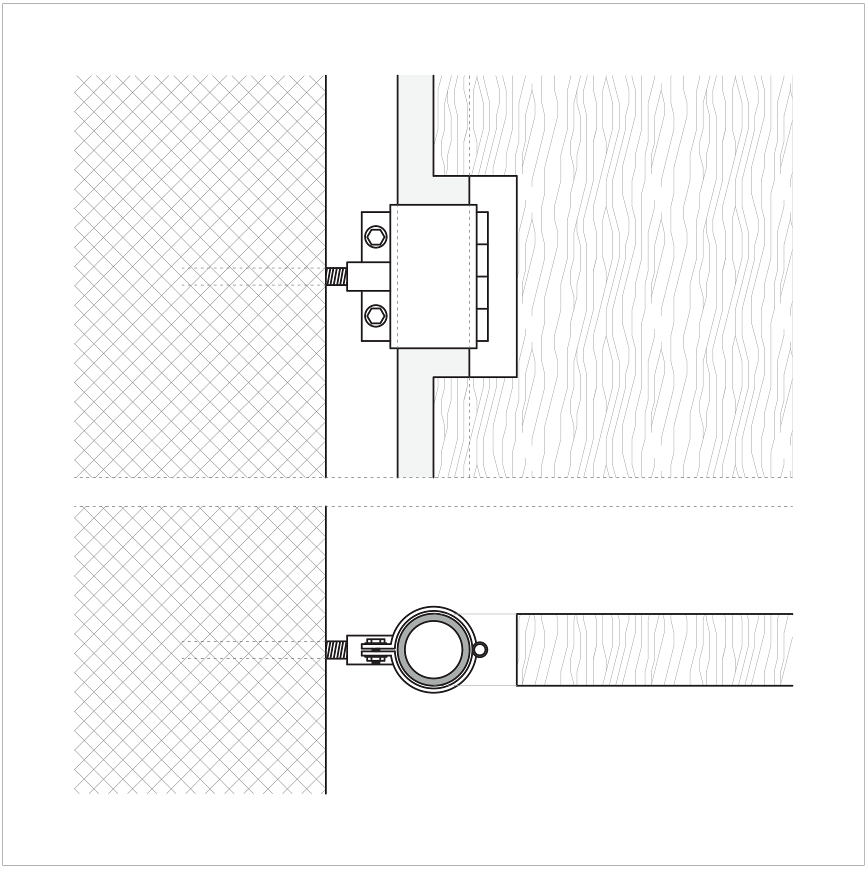
Construction

This facade was imagined as more than just a final product. The idea is to use this as a research ground where this thesis project, for start, could be tested in a real-life environment. By designing all elements and joints to be easily attached/detached and exchanged, base ground for a research facade was created. This allows for every element individually to be developed and changed as many times as needed without the need for heavy machinery or disruption of the area.

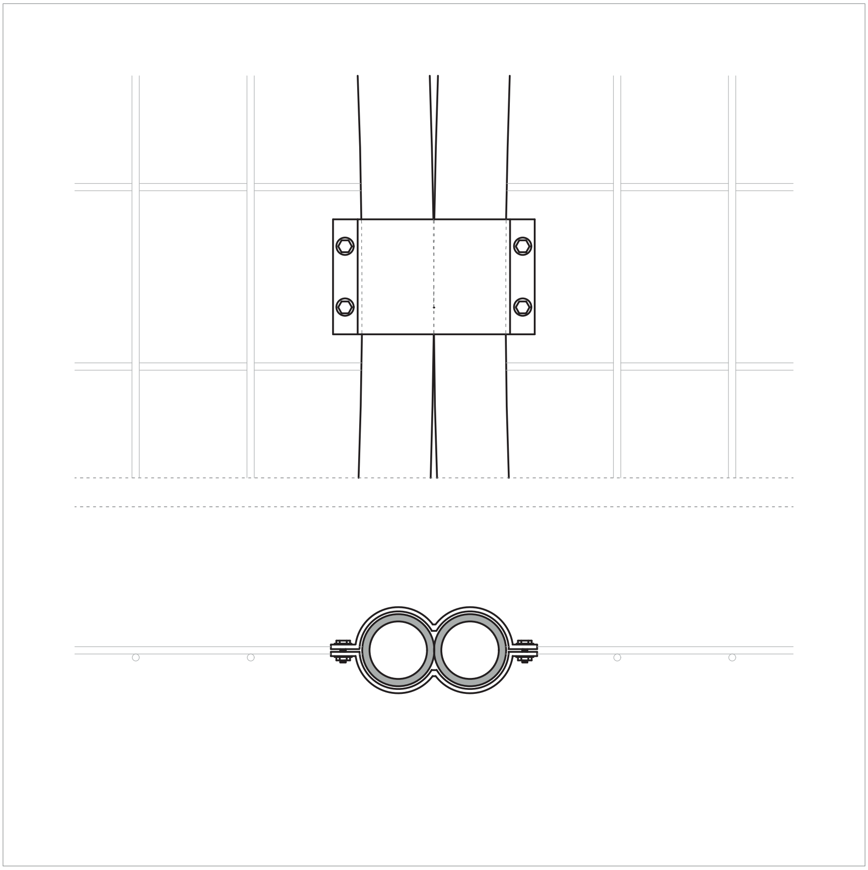
Every element is connected at 3 points: it's placed in the ground, connected to the building structure at the top, and interlinked with other elements in the middle, creating more resistance to the wind and other external influences.



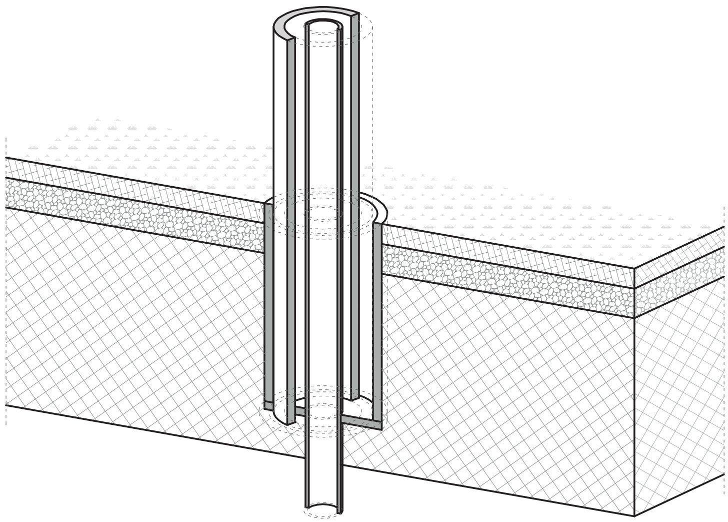
D1: Connection to the structure 1:5

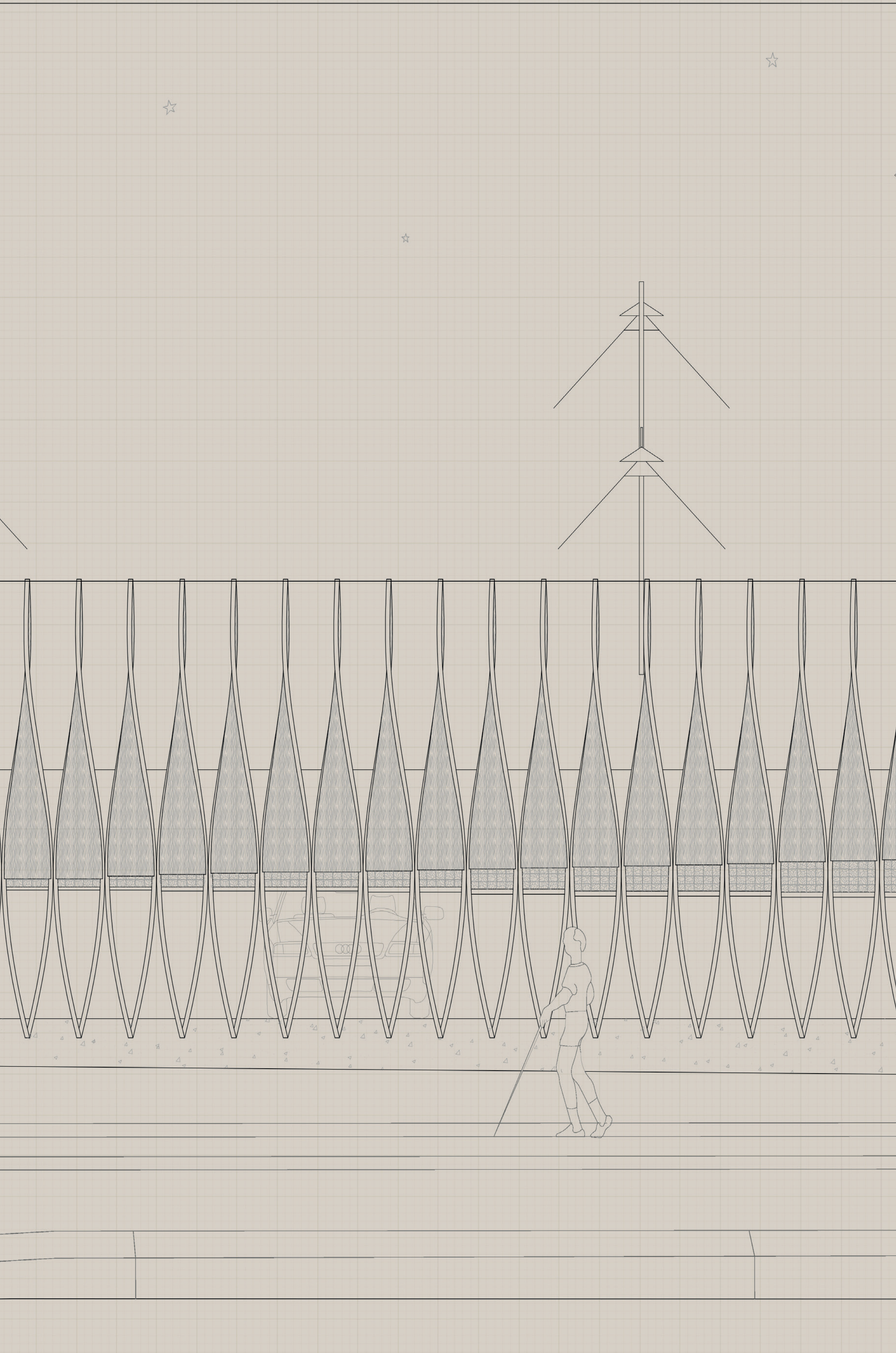


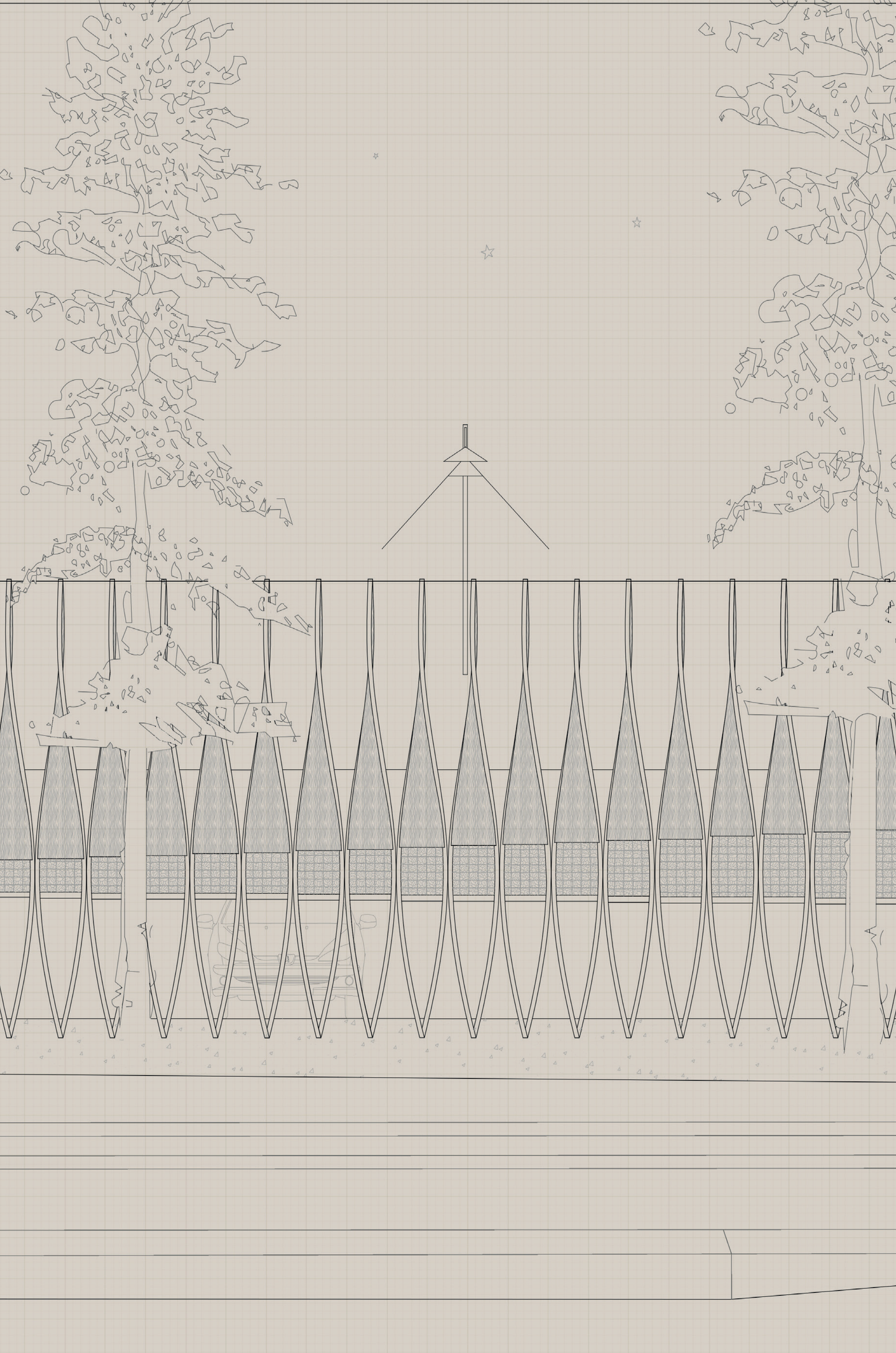
D2: Joint between elements 1:5



D3: Foundation axonometry








GÖTAPLATSEN

7
REFLECTION & CONCLUSION

This thesis began as a very wide research of the overall problem of light pollution. It took some time and a lot of narrowing down to reach a point of a specific site and be able to build a project around it. Looking back, it would be more productive, considering a very short time span, to start the thesis with a specific location in mind and build a research and design around it.

Light pollution as an urban problem is gaining more and more attention, but still not enough from architects. There is a definite potential in architecture as a mean of reducing pollution in cities, especially considering that buildings are one of the biggest causes of the problem, incidentally. Rethinking the way we design and form surfaces, which form built environment should take us to the right direction of making more healthy and human-friendly cities. This thesis is being only a tiny contribution to this, showing that it's possible to include environmental issues in the design and create something that has more than an aesthetical value.

The design presented at the end of this thesis is based on a theoretical research which led to assumptions about its value and productivity. In order to continue testing these ideas, they must be tested physically, in a real-life environment. Only after that, we could make real conclusions on the effect of facade design on light pollution. It is important to mention that this problem is something the autor was aware of, therefore the design is a proposed way of continuing this thesis and taking it to the next level. It also allows for further development of similar facade ideas, all in relation to reducing the problem of light pollution at the specific location, and then using the gained knowledge to educate and spread awareness about the global problem.

GLOSSARY

Artificial light - light source that is produced by electrical means

Brightness - perception elicited by the luminance of a visual target.

Colour - property of light as seen by people.

Colour temperature - temperature at which a black body would emit radiation of the same colour as a given object

Diffusion - spreading of something more widely.

Glare - shine with a strong or dazzling light

Glitter - bright, shimmering reflected light

Illuminance - amount of luminous flux per unit area.

Lambertian surface - ideal "matte" or diffusely reflecting surface

Light pollution - excessive and inappropriate artificial light

Light spill - light that illuminates surfaces beyond the area intended to be illuminated

Light trespass - poor control of outdoor lighting that crosses property lines and detracts from property values and our quality of life

Luminaire - electrical device that contains an electric lamp that provides illumination

Luminance - intensity of light emitted from a surface per unit area in a given direction

Luminous flux - measure of the perceived power of light

Luminous intensity - quantity of visible light that is emitted in unit time per unit solid angle

Reflection - throwing back by a body or surface of light, heat, or sound without absorbing it

Retroreflection - phenomenon of light rays striking a surface and being redirected back to the source of light

Skyglow - brightness of the night sky in a built-up area as a result of light pollution

Transmission - moving of electromagnetic waves through a material

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Dedicated Web Sites

1. Lighting research center: https://www.lrc.rpi.edu
2. IDA - International dark sky association: https://www.darksky.org
3. NASA: https://www.nasa.gov
4. Dark skies awareness: http://www.darkskiesawareness.org
5. National geographic: https://www.nationalgeographic.com
6.McDonald Observatory: http://mcdonaldobservatory.org/darkskies
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