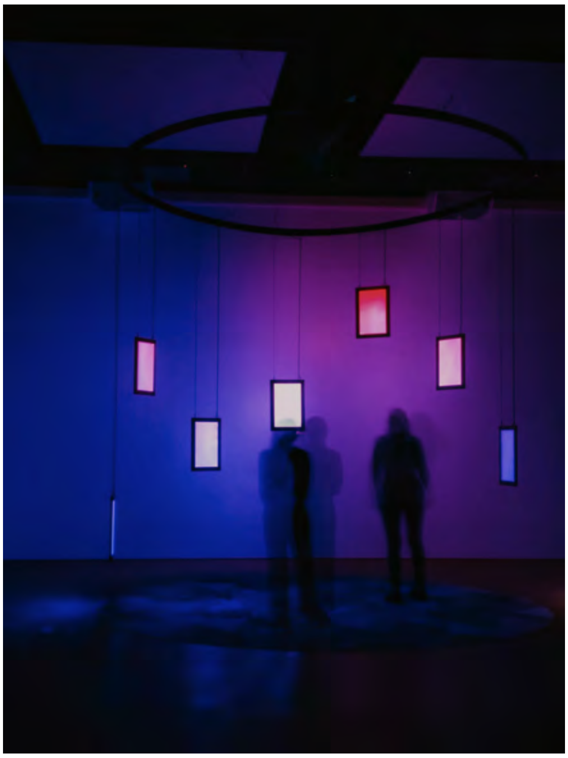

Ambient Atmospheres

Topology of Light

Master's thesis in Computer Science and Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
Gothenburg, Sweden 2021

Master's thesis 2021

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Cover: The interactive light installation of the Bright Memories Exhibition.

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Abstract

Artificial lighting systems that are controllable by users are becoming more common. Even though such systems are called smart lighting, most interactions with such devices are limited to color and brightness changing. Lights controlled in such a way often juxtapose with their environment and do not result in wanted atmospheres. This thesis explored a design space of working with artificial light and how it can be utilized in new ways to recreate natural light settings. Our explorations resulted in an array of smaller prototypes that embody our ideas and knowledge. These prototypes were used in public experiments to start conversations. As the final artifact, we created an exhibition with an interactive installation and a series of posters that communicate our idea of ambient light sampling and recreation.

Keywords: ambient, atmospheres, artificial lighting, ubiquitous computing, exhibition, interactive installation, transparent design, post-phenomenology, playful hacking, research through design.

Acknowledgments

Thank you Mafalda for encouraging us to take on this project, your inexhaustible source of inspiration and your invaluable support.

Thank you Rune and Andreas from Kollision for the inspiration and knowledge of how to work with light and for lending us light fixtures.

Thank you Gunnar for the guidance of working with electronics.

Thank you Jonaz and the team at A Working Lab for letting us host the exhibition in your studio, your support and your encouragement.

Thank you to all visitors of the exhibition that provided interesting insights and let us rediscover our own design.

Mattias Hallin, Gothenburg, June 2021
Frederik Max Göbel, Gothenburg, June 2021

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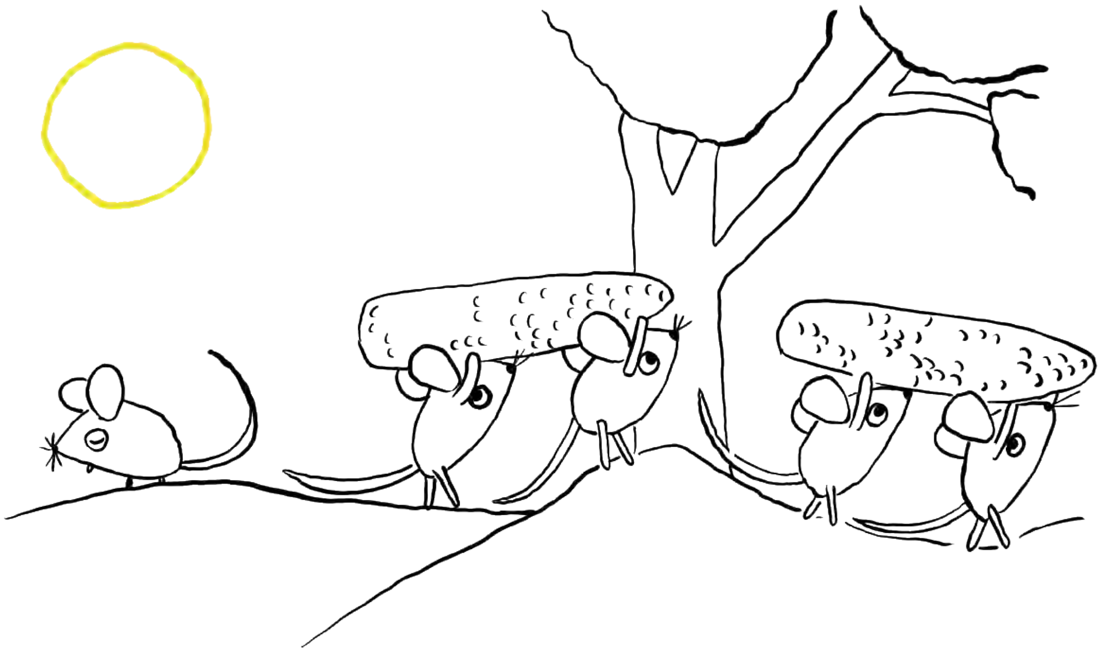

With the winter closing in, all the mice are busy collecting food, except Frederick. Frederick, the mouse, is busy collecting sun rays, colors, and sounds. While first made fun of by the other mice, they are soon thankful for Frederick's supply of reminders to gone summer days [1].

There is a growing trend of ubiquitous computing where computational capability embeds into everyday objects [2]. With it, new research investigates how interactions with these devices will look like in the future. At the same time, intelligent lights gained traction in the last couple of years, but most interactions with such lights are still limited to the change of hue or automatic on/off switching. Furthermore, there has been minimal advancement in the lamp shapes themselves to reflect the digitization of light. With only the bulb itself changing, static physical lamps, and disregarded environments, unnatural compositions emerge. However, if instead all these materials are used as a compound, they might produce a multitude of ambient atmospheres.

Each generation of smartphones brings an increasing quality of visual and auditory recording. For now, these recordings are made user-accessible through photos and videos. While these do great jobs by acting as memory bridges to remember scenes from the past, it seems they are only mirroring their analog equivalents. The digital medium allows nonlinear playbacks but also the near-instant analysis of a recording. Furthermore, smartphones can capture even more information during recordings like orientation, movement, and time.

In this thesis, we use the concept of recording abstract light atmospheres as a starting point for open explorations in the field of artificial lighting. While we probed how visual information enriched with extra data like time and location can quantify an atmosphere, the main focus of our work lay in the representations of these sampled atmospheres through different artifacts.

We closely engaged with light as a design material and created a platform for working with light. We communicated our knowledge through different mediating artifacts during the process, and we contribute to the field of interaction design with knowledge about designing with the involvement of light.

To communicate our idea of light sampling and start a conversation about non-utilitarian use cases of light, we created an installation showcasing the effect of light on a viewer's mood. The exhibition is contextualized in a fictional world in which no virtuality exists to invite the visitors to create their own interpretation of how exactly the exhibited devices work and how they translate to our world of technology.

1.1 Research Question

Through exploring the design space of working with light we will generate knowledge about the use of light as a design material. This leads to our first research question: **What should be considered when working with artificial light as a design material when trying to recreate natural light situations?**

In addition, through our tangible prototypes and applied work, we also expect to learn about tools and methods that can be used when working with light. Therefore, leading to the question: **What should be considered when using digital and physical tools to support the artificial light design process at different stages?**

Our process will take on the form of Research through Design (RtD). This means that we will continuously build and iterate on prototypes that embed our knowledge. We plan on making these prototypes public to explore how to communicate knowledge in a RtD process. Finally we will present and evaluate an interactive exhibition which will be used as a space for discussions about the future of artificial lighting. Our commitment to the RtD process and our stance to communicate our knowledge during the process leads to the third question: **What value can be provided and supported by different mediating artifacts in an RtD process?**

1.2 Stakeholders

This section presents the stakeholders of the project. During the master thesis, we reached out to different companies and research groups to ask for help or input during the project.

1.2.1 Chalmers University of Technology

The main stakeholder of this master thesis is Chalmers University of Technology. Chalmers provides the requirements and guidelines which the thesis will have to fulfill in order to be accepted. Chalmers provides an examiner approving and grading the thesis and an academic supervisor supervising the academic and learning part.

The Interaction Design Program teaches a multitude of skills to bring an idea from needs and requirements through research and ideation into interactive prototypes ready for evaluation. The courses provide different approaches towards Interaction Design. This project will utilize previous skills, especially from the courses Human-Centered Design, Tangible Interactions, Designing User Experiences, therefore, fulfilling the requirement to involve significant specialization in a master thesis connected to the Interaction Design Master Program.

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Supervisor: Mafalda Gamboa
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1.2.2 Mattias Hallin

Mattias has a bachelor's in Industrial Design Engineering from Chalmers University of Technology. He found an interest in digital interaction and design and therefore decided to pursue a master's in Interaction Design. Here, and during his exchange to Simon Fraser University in Vancouver, he developed his skills in interaction design and front-end programming. By combining his digital and physical design skills, Mattias does not miss a chance to create exciting and innovative interactions.

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1.2.3 Frederik Göbel

Frederik received a bachelor degree in computer science at the Freie Universität Berlin. In parallel to his bachelor studies, he took courses in photography and design at the Universität der Künste Berlin and the University of Applied Sciences Potsdam. Drawing from this background, Frederik enjoys working on any part of the design process. He especially likes creating tangible artifacts not involving screens.

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1.2.4 RISE

RISE, Research Institute of Sweden, is a Swedish state-owned research institute. They collaborate with academia, business, and society in the Swedish innovation system and research interaction design and experience design of future services, products, and environments. In a conversation with the researcher and developer Gunnar Oledal, he agreed to supervise an ad-hoc basis in tech-related issues.

Gunnar Oledal
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1.2.5 Kollision

Kollision is a design lab in Aarhus, Denmark, specialized in public installations utilizing light as a design medium. After an initial conversation with two of the partners, Andreas Lykke-Olesen and Rune Nielsen, we sent a collaboration proposal (see A.1) including an introduction to the subject, a description of what we want to build, what we want from them, and what they would get in return. Kollision agreed to help us by lending us a couple of DMX wash lights helpful in our experiments. Kollision also supported us with inputs and expert knowledge in the field.

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1.2.6 A Working Lab

A Working Lab (AWL) is a project by the Akademiska Hus to research the future of office buildings and spaces. AWL combines contemporary trends of working like co-working, makerspaces, and flexible space possibilities. Jonaz Björk is the digital set designer of AWL and responsible for the Learning Lab.

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1.3 Delimitations

One of the original concepts that started this project was the idea to sample atmospheres at different places and transfer their light settings to new contexts.

Even though we think this is possible with technology that exists today, we do see it as a complex problem that we do not have the skills to solve. Instead, we focused our project on exploring how to create light atmospheres through artificial lights, now and in the future. We still circled back to the original idea when designing our exhibition. However, in that context, we saw the sampling as a process that was already conducted and left us with data describing light settings.

We also planned on exploring how different light settings and animations would result in emotional responses. While we first gathered feedback in this direction, we did not create a formal framework, nor did we conduct quantitative evaluations.

Although multiple variables like sound, scents, touch, etc., can be argued to aid and affect the creation of ambient atmospheres, this project is limited to visual cues. It focuses on how these atmospheres can be created by working with light.

We limited ourselves to the use of LED lights, when building light sources, as these have the advantage to be easily controlled though digital medias.

2

Background

This chapter describes the research area of working with light and atmospheres but also related work and research in the field.

2.1 What is Light?

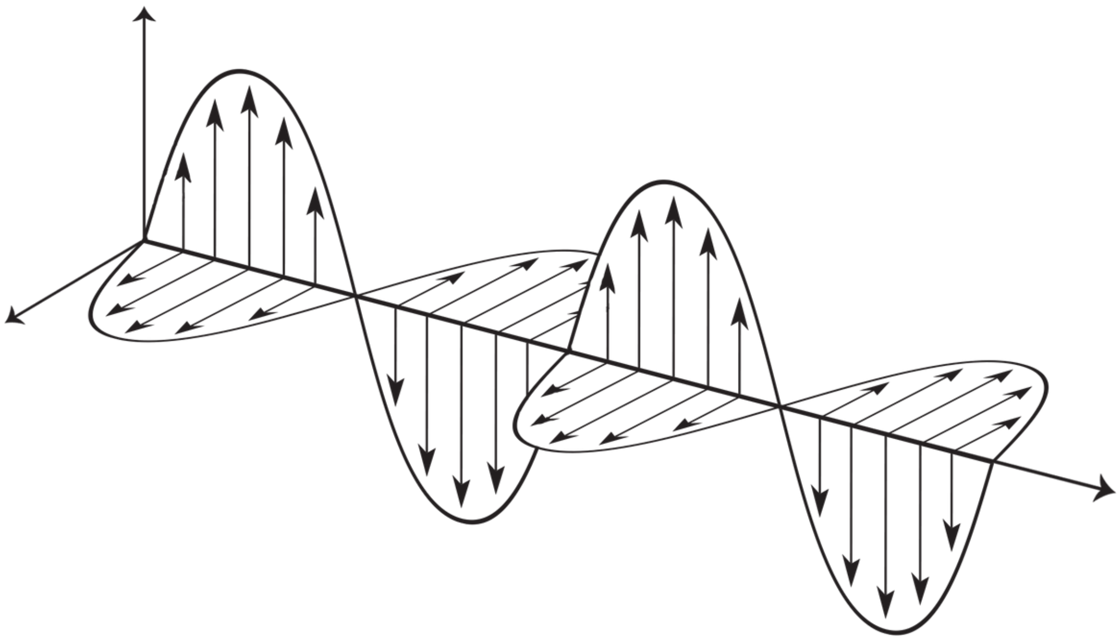


Figure 2.1: Visualization of a light waveform.

When working with light, this question arises, earlier or later. It is not answerable by a simple definition, and even finding a language to describe light situations is not a trivial task.

We used our own language to describe different light situations, and most of the time, we used the same vocabulary, often with the help of photographs. Direct or indirect, soft or hard, and warm or cold are opposites we often used. Our pool of linguistic descriptions was quite often exhausted, making us fall back to use images to express imagined light settings.

After talking with the light designers Lykke-Olesesen and Nielsen from Kollision, we understood we had to take a step back and define how we consider light. They walked us through many of their projects. In their work, they design the light itself but also the surfaces the light is supposed to interact with. Through this, they use material properties to transform and shape regular light sources into impressive experiences. They, for example, used copper to create a slight orange hint in one project and felt fabric to create smooth gradients in another.

In the episode *Vad är ljus?*, Swedish for *What is light?*, of the Swedish podcast *Filosofiska rummet*, a physician, a photographer, and a light researcher are asked to define light from a scientific but also philosophical standpoint [3]. Lindén, a seemingly philosophical physician, explains how light and darkness has to coexist. The contrast is important in order for us to perceive it. He explains that a waveform, illustrated in Figure 2.1, might be the scientific definition of light but the perception is more complex. The light designer and researcher Enger describes the difficulties of communicating light in an objective way and her research revolves around creating a sensorial language for light that enables people to talk about it in a common language. Similar to how knowledgeable talk about wine. In a publication Boork *et al.* developed methods to communicate light and lighting to make it easier to design light environments with a user centered perspective [4].

In our research in scientific fields, we read a lot about the quantification and recording of light. This field focused on how to assign numerical properties to make them understandable by computers. Interestingly enough, neither Lykke-Olesesen, Nielsen, nor Enger uses scientific terms to describe light. Quantifiable properties like lumen, wavelength, and illuminance lose their explanatory power once a human interprets the light. Lightwave or particle does not matter; what matters is how it arrives in our eye and how it translates from a multitude of photons into emotions. What we perceive is a result of reflections from objects in our environment. Light is the interplay of objects, the created shadows, the colors, and the highlights.

This definition might seem broad and unscientific, but it enables us to utilize an important tool, our own emotions. Instead of describing light in numbers it helps us to create atmospheres using our own intuition.

Different authors working in the field of light describe how to think about light when working with it. Lynes describes natural light in a mathematical form [5]. They describe different mathematical models to quantify light situations. For us the visualizations of how lights interact with each other were especially interesting. In that model, light is thought about as vectors that interact with each other. A overview of human perception of light is provided by Kalff [6]. We were intrigued by the visualizations of how different regions of light colors can help humans to focus.

2.2 What is an Atmosphere?

Atmosphere is a word that intuitively makes sense but thinking and reflecting about it make it intangible and hard to define. This section describes how we understand it and approach the engagement of working with it. This project is a project about light but especially complex light settings. These settings consist of various light sources with diverse attributes like distance, motion, diffusion, reflections, and colors. It is the combination of these attributes together that makes a (light) atmosphere. We are not interested in quantifying these variables; we are interested in their interplay and how it changes feelings and perceptions.

From a phenomenological perspective, it might be tempting to describe an atmosphere as a “feeling”, or a feeling we have while being at a particular place. Vogels says that “an atmosphere [is] not necessarily [giving] rise to a particular feeling, it only has the potency of changing people’s affective state” [7]. What Vogels describes is that atmospheres are always perceived with a previous mental state. With this definition, there is an atmosphere at all places, at all times. The atmosphere of the place might not be strong enough to affect how one feels or ones mental state might also not be in a position to be changed. This can be experiences by heading to a dull place and soaking in the details, the light movements and colors for a few minutes, without thinking about them. One might feel that this place has an atmosphere after all and changes how one feels.

Multiple researchers have tried to quantify and define this relationship between light, affective state, and feeling, Vogels for example [7]. They found strong correlations between perceived atmospheres and light settings. A repetition of the experiment in a different cultural setting confirmed many of these findings [8]. Although it differentiated in some of the outcomes, it still resulted in similar correlations. With this in mind, one can argue that light perception within conscious meaning-making is partly socially learned.

Human centric lighting is another big field within light research today. Researchers are trying to find links between light situations and our hormonal state [9]. They have been able to find many correlations that the influence of light is also dependent on other attributes, time, for example.

Multiple projects in the interaction design field have already tried to use these findings to create atmospheres in different use cases. Zhao *et al.* [10] and Ross and Keyson [11] both make use of changing the light together with other media and propose novel ways to interact with light.

Our research differentiates from the research of Zhao *et al.* and Ross and Keyson by having the ambition of opening up a design space, we are not limiting ourselves to one context and one atmosphere. Instead, our interest lies in how different situations of natural or real light phenomenons can transform into new contexts. How are atmospheres expressed with artificial light perceived differently, and how can interaction with light offer unique experiences.

In our research, we tried to concentrate on non-symbolic perception without a gestalt analyzes of the environment. The feeling of a day in the forest during summer is not recreated by the trees but by how they function to change the perceived light. They may diffuse the light in a greenish tone, and the leaves' motion creates shadow patterns and flashes of light.

2.3 Light Psychology

Light psychology is an ongoing research area. At the same time, there is an excellent pool of findings on the perception of colors [12]–[14], Less research has been done about the influence of light ambiances on human psychology, even though correlations between the atmosphere and experienced mood have been found [7], [8].

A study by McCloughan *et al.* researched the influence of lighting on attributes in the *Multiple Affect Adjective Check List* and concluded that there is an influence in short and long term mood [15].

Dynamic light situations have also been researched. Wang *et al.* found correlations between light movement and perceived atmosphere [16]. Song and Yamada showed that emotions towards a computer changed depending on the light situation [17].

Apart from research about the influence of a light situation itself, a research area is exploring the interactions with light and input devices to control it [10], [11], [18], [19].

2.4 Light in Interaction Design

To the best of our knowledge, we are the first to explore the transport of whole ambient atmospheres. However, there have been several projects investigating the concept of ambiance change through light [10], [11], [20].

A noteworthy project is the *Mediated Atmosphere* at the MIT Media Lab. Their project explored how light can change the environment to help a user concentrate or restore energy. In addition to light sources, they used wall projection and sound [10].

The *SentiBooks* project explored how to use colored light to change the perceived atmosphere while listening to audiobooks [20].

A project proposing *Ambient Display Robotics* was written by Rea *et al.* Their robot, a Roomba cleaning robot, is equipped with LEDs that can be controlled by people in the room and the robot therefore becomes "an abstract aggregate of the current mood of the room" [21].

A paper that is aimed at the control of light and provides a framework for that was written by Ross and Keyson [11]. They also use image projection and audio in addition to light to change the ambiance of a room.

Zhao *et al.* researched context-aware lighting in an office space using Google Glass [19]. A testing room was prepared with multiple light sources that can light up different parts of the room. The brightness of each light source can be controlled individually and the temperature of the light all together. Zhao *et al.* derived the contextual control axes to *focus* and *casual*. The Google Glass senses different activities and changes the light by being aware of the context. Tasks as reading, study, or crafting increase the *focus* and results in an even and neutral bright white light while a phone call with a friend reduces the *focus* and increases the *casual* leading to a dimmer and warmer setting in the room. The research of Zhao *et al.* confirmed that such a system has the potential of improving performance, comfort, and energy efficiency.

2.5 Light Sampling

While light sampling itself is not an independent research area, it is explored in different fields. Most of it in the field of Augmented Reality (AR) [22]–[25]. Light sampling is used to generate light direction and brightness, for example, to make virtual objects fit into the environment.

While some of these proposed algorithms utilize more than single RGB images, [22], [25]–[30] they should give a good indication of the possibility and fidelity of light sampling.

Other directions of light sampling research do not calculate attributes of light directly but instead focus on creating High Dynamic Range (HDR) image maps from a single limited field of view images [31], [32] or HDR images [33].

2.6 Human Centric Lighting

Bedell defines Human Centric Lighting (HCL) as “a type of lighting that can benefit the biological, emotional, health, or wellbeing of people” [34]. Intelligent lighting systems can do this by mimicking the brightness and hue of daylight over the day [35]. As light conditions affect the biological rhythm and cognitive performance applying HCL can improve alertness, mood, and physical performance through the day and positively affect sleep and wake cycles. New technology makes it possible to closely adapt the temperature, illuminance, and distribution of the light to resemble natural conditions.

Bedell discusses the complexity of working with human centric lighting, remarking that it is easier said than done to provide guidelines of how the lighting environment should universally be: Different people have different preferences. Bedell, for example, proposes minimal ambient light when writing to focus on the words while wanting a more lite environment when talking on the phone or answering emails [34].

LightingEurope wants to look beyond energy efficiency as it can increase the efficiency as well as lowering errors, absence, and accidents. Environments that would benefit are, for example, education, work environment, healthcare, smart cities, and domestic [36].

2.7 Smart Light Market

It already exist a multitude of intelligent artificial light sources and control systems on the smart light market. Some products are designed to solve specific problems while others carry a hedonic purpose. This section describes how the smart light market can be categorized in different themes regarding purpose and use. From streamlining solutions to different connection protocols and how light actually can be used to enhance the wellbeing.

2.7.1 Streamlining

One popular aspect and theme of smart lights today is streamlining the use of multiple light sources. Some examples of features that help streamline the user experience are *Scenes*, *Remotes*, and *Scheduling*.

The Scenes and Scenarios help the user customize groups of lights with different properties for different situations to let the user adjust the lights efficiently. With the ability to schedule events, the user can automate scenes to occur on decided intervals. Physical remotes of various and innovative kinds streamline the interaction with the lights by complementing or even replacing the standard light switches.

2.7.2 Interconnections

Connectivity on different levels is also another essential part of how intelligent lights streamlines the use of lights. Depending on the communication protocol (Wi-Fi, Zigbee, or Bluetooth) of the smart light system chosen, the user might need a gateway to connect and control the smart lights from a phone or extend the network. The smart light environment can also be connected to other Internet of Things (IoT) devices and control them from the same environment. Events and scenarios can then also be triggered by other smart devices, opening up new possibilities in smart homes.

2.7.3 Pleasure and Media

While the previous aspects improve usability by increasing effectiveness and efficiency, there are also aspects in how smart lighting increases the user experience by increasing the pleasure and "fun". However, this, of course, has to be regarded as subjective. These are examples of how intelligent lights can be used for interior styling.

Various features convert dynamic pixel or rhythm information into light effects, making the lights change in sync with music or video. Static conversion of images can also be done by sampling dominant colors representing the image in a smart light environment.

A distinction between functionality and pleasure can also be made between different light sources. *Light Panels* is a light source that is regularly used for decoration and interior styling. Depending on the shape, the panels can be combined in patterns and controlled according to the same pattern.

2.7.4 Human Centric Lighting

By mimicking natural light, the ergonomics of artificial light can be increased. Some smart light systems provide the ability to adjust the temperature and brightness of the light depending on the time of the day to increase the user's well-being.

2.7.5 Multi-zone Light Source

The last theme is light sources with multiple controllable zones. There are Light Emitting Diode (LED) strips, LEDs arranged along a strip, where the user can control the diodes separately and customize the behavior to create patterns and motion. There are also smart lights that use separate zones to allow the user to direct the light by focusing the luminance from certain zones.

2.8 A Working Lab

We talked to Björk, a digital set designer responsible for the Learning Lab, a subpart of *A Working Lab* (AWL). The learning lab consists of a maker space, a flexible classroom, and an event studio. During the project, we were offered the studio as the event location for our exhibition.

The event studio is a ca. $180\,m^2$ big empty room with ca. 4 m high ceilings. The room is equipped with a modern lighting, audio, and presentation system. The idea behind this room is to see how a possible future for lecture halls might look. Instead of having a prearranged seating area, it contains a supply of modular seating blocks, curtains, and other elements to transform it depending on the task.

The room has a complex and feature-rich lighting system. Unfortunately, it is not entirely usable as the current interface only allows for a fraction of interactions. On the ceiling, eight big lightboxes can provide background illumination. Technically it would be possible to control each box independently and even light them up in gradients. Each box has multiple smaller lights inside, but they can only be set to solid colors as the interface is limited. In addition to the boxes, the room contains a multitude of independently controlled Red Green Blue (RGB) spotlights that can highlight regions in the room. To light up the walls, the room has several RGB wall washers. A series of projectors can project images on the wall, high resolution in theory, but this only works in low quality due to technical constraints.

Björk mentioned that he would like a way to separate the room into different regions of atmosphere or use the light as a counter. He furthermore thought it could be nice to have the light react to the weather outside. The failure of the control of the studio space but also the ideas of Björk show that there is a knowledge gap and need in better light control and ambiance creation.

2.9 Light Playground

Previous to this thesis, one of the researchers, Frederik Göbel, developed an online playground to explore light settings [37]. This playground is implemented as a website on which users can control colors and animations of colors to transform their computer screen into an artificial light source. By scanning a QR-code with a phone, the user can change animations and colors on the screen, allowing them to step away from the screen or create indirect lighting by turning it. The user can choose between various modes: *Color*, *Sun Simulation*, *Direction*, *Warm & Cold*, and *Rhythm*.

2.10 Research Opportunity

Smart lights are not utilized to their full potential. Dynamic light sources exist, but current solutions lack a way of letting users easily recreate complex and "real" light scenes. Most current approaches merely allow changing the hue, brightness, and temperature. One of the most advanced features is the simple sampling of colors from an image to "[r]elive your favorite picture" [38]. In our opinion, these "scenes" feel artificial or "out of sync". Such algorithms search merely for dominant colors in the picture and randomly distributed them between the lights. In our opinion they do not share the same emotional impact of real light situations.

Light is not only defined by color. The environment reflects light; it can therefore be direct or indirect. Natural light has rhythms, from slow fading, like a sunset, to sparkling reflections on a wet street. We believe that all these different qualities of light should be used together to create unique but still natural feeling light situations in the future.

There is not much research about either of these light attributes or technical usages. Therefore, we want to open up a design space instead of creating a marketable solution, for a not entirely understood problem that might not even exist. We furthermore believe the public should lead the discussion about future lighting systems, instead of companies or design labs, as light is a universal, all concerning, element.

We hope that our work will spark a discussion about new ways of using the recent development in the field of artificial lighting and ubiquitous computing. We furthermore hope that our design explorations in the fields of artificial lighting and ambient atmospheres will inspire researchers and non-researches alike to expand their minds and rethink how light will be used in the next decade.

3

Theory

This chapter covers theoretical frameworks used in the project. To make sense of the complexity of working with light and how knowledge is generated we make use of various theories and approaches.

3.1 Wicked Problems

Design problems, in general, can be described as wicked. *Wicked Problems* are problems that have no clear boundary or definition and are therefore not trivial to solve [39]. Such problems have no one perfect solution, as that would require complete knowledge about all the effects of such a solution and all interconnected reasons why the problem even exists. Reaching this state of knowledge is nearly impossible in *Wicked Problems*. Solutions to *Wicked Problems* can not be tested prior to implementation, and there is no single solution, merely better or worse ones.

3.2 Research Through Design

One strategy to tackle *Wicked Problems* is through *Research through Design* (RtD). Through continuous iteration, problems can be identified early and prioritized. Different iterations can address different problems resulting in a better understanding of the design space.

RtD, firstly coined by Frayling in 1993 [40], is a design approach used to conduct scholarly research that rejects the thought of research being a synonym to science [41]. New knowledge is generated through the design process, and the practice of researching with a focus on improving the state of the world through disrupting, transforming, and complicating the current state [41] instead of creating knowledge through confirming or rejecting a statement [42]. The result from such research is not necessarily a new product, instead it can aim to open a new design space [43].

Instead of focusing on extensible and verifiable theory, design researchers build on each others' results and suggest alternative solutions; created artifacts and systems communicate proposed solutions or create new ones. The resulted theory in RtD has the intention to improve the practice of design and this theory can be of several forms but the contribution is the created artifact [44]. By reflecting on how integrated theories from other disciplines affect the process Zimmerman *et al.* means that the resulting artifact can challenge or refine the general theory. RtD is, by many, seen as a design inquiry with a goal of societal change by using the strength of design practice in interpreting and framing situations; created artifacts and systems communicate proposed solutions [42]. Engaging in conceptual work in multiple forms is an important part in RtD. The conceptual work favor highlighting issues, dimensions, and criteria that facilitates successful decisions. Different disciplines can then draw from conceptual perspectives of each other to inspire new design [42].

3.3 Postphenomenology

Modern technology, of which artificial light is a part of, is growing in complexity; with that its influence on human perception is ever increased. An approach to make sense of this influence on human perception and behavior is *Postphenomenology* [45]. That is the study of how inanimate objects and especially technologies mediate or shape human experience. *Postphenomenology* does not only explore how human experience is shaped by technology but also how objects invite and guide humans to specific actions. Following postphenomenological ideas enables one to think about how the interplay of humans and technology shape our world and experience.

3.4 First-Person Methods

Postphenomenology is an contemporary answer to the philosophy of phenomenology. In phenomenology the world is made sense of through the lens of humans perception. Therefore *first-person experiences* and *sense-making* are used as main modes of inquiry. *First-person* methods and accounts are used to study consciousness before a reflection about it is made [46]. By studying the consciousness when it emerges, a different understanding can be perceived. Through a first-person approach, the researcher focuses on the experience and expressions that communicate, such as gestures and body movements. Experiences can never be fully described in words and text and therefore need to be felt.

3.4.1 Somaesthetic

In the field of Interaction Design a relatively new school emerged that makes heavy use first-person-methods: *Somaesthetic*. In this school the dissolution of the theoretical duality between mind an body is advocated [47]. Following these ideas, feelings, senses and sense-making are strictly linked. One cannot design for either body or mind without designing for the other. Many of the somaesthetic designs are created to increase this mind and body union and to help people train their appreciation of these somatic qualities. However, somaesthetic can also be part of the design process without resulting in a design aiming to enhance somatic sensations.

3.5 Showroom Design

Showroom is a program in *Research Through Design* that does not draw from classical sciences but is instead inspired by art and design [48]. For us, the *Showroom* design served as a platform for evaluation and discourse in the form of an exhibition. Designs become devices for debate and discourse rather than a series of hypotheses, as in *the lab*, or objects to be observed in the open, as in *the field*.

As the *Showroom* can itself contain tendencies of *Speculative Design*, we see it as something that does not need to be formally evaluated. Instead, the showing of the artifact can be evaluation itself. Therefore, instead of analyzing it formally, one can discuss its effectiveness, occurring topics, and other insights in detail to provide gained insights to future designers [49]. The design itself does not need to be the answer to a problem and does not need not be evaluated in its success in solving something. Instead, the design can be a a proposal and therefore, only the response to this suggestion can be discussed.

3.6 Speculative Design

A direction inside the *Showroom* program is *Speculative Design*. In contrast to most design directions, it is not focused on creating a viable or even desired product. Instead, it deals with visions of a future and, through this, tries to spark conversation or debate. Therefore the communication with the public is the most significant part of speculative design. While different forms of communication are possible, it often takes the form of an exhibition [49]. Many of such speculative designs use prop-like and tangible devices that transfer an idea without using digital material [49].

In the last years there has been a stream of designers inside of the speculative design field that criticize speculative designs that are only gimmicky or overly dystopian just to be disturbing. They furthermore wish for new ways of communication apart from exhibitions and art galleries [50].

3.6.1 Retrofuturism

One direction in design, and particularly speculative and critical design, is *Retrofuturism*. In this design language, technology from the future is contextualized with aesthetics from the 50-60s. This merge of mostly wooden products with high tech is quite powerful in communicating the idea of new technology [51], [52].

3.7 Ambiguity as a Resource

Ambiguity is usually considered something to avoid but can be a resource if treated correctly [53]. Gaver *et al.* states that it can encourage close personal engagement and generate discussion. He defines ambiguity and separates it into three areas; ambiguity in information, context, and relationship. *Ambiguity in information* refers to ambiguity in the artifact itself, and ambiguity can conceptually blur the present information. Designers can use it and impel people to question the truth and meaning. *Ambiguity in context* is the discussion of interpretation and can question related technical genres. *Ambiguity in relationship* is about the evaluative stance and aid people to consider new beliefs.

Adding ambiguity by conceptually blurring information can impel an over-interpretation of the information. It highlights perspectives for consideration without solutions. Not understanding is not a failure if they are curious enough to seek the answer.

3.8 Affective States

To quantify humans' *affective state* and think about the relation of different emotions, the so-called *Circumplex Model of Affect* by Russel is often used [54]. In this diagram, the x-axis represents the *valence* aspect of the emotion, while the y-axis is the *arousal*. Different emotions are arranged in a circle around these two axes. One can think of the relation of the emotions as how similar they feel. The model can be used to describe which emotion the designer is aiming for or what emotional journey a user should have.

3.8.1 Movement

There is a growing body of research regarding the movement of objects and shapes and its' relation to human psychology.

Lockyer *et al.* explored how the human perceives the motion of two-dimensional objects and their patterns. Their earlier work researched how simple 2D movement influenced affective qualities like *valence*, *comfort*, *urgency*, and *intensity* [56]. In later research, they extended their framework to include *Lamban movement principles* [55].

A different researcher, by the name Miyoshi, explored how the movement of three-dimensional objects can lead to *kinesthetic Empathy* [57]. He furthermore proposed a framework to work with objects in motion and how to categorize these motions.

We utilized some of these insights in the design of light ambiances and explored how far the abstraction through lights is still able to hold the semantic content to affect the affective state of a viewer.

3.8.2 Computational Compositions

When working with artificial light we had not only to make sense of the digital but also the physical world and both together. A model to think about these two worlds as a unity is described by Wiberg and Robles [58]. They propose the word *texture* and a way to think about compositions of digital and physical materials. In their model each material, digital and physical, has its own *texture*. The *texture* can be modified by changing how something is used. When used in composition these *textures* join to become a new *composite texture*. How well this works is defined by the distance and relation between the two elements. Designers can now evaluate the *composite texture* without having to think about the elements that make up the composition. The new *texture* might result in good design or if the relation does not work the resulting appearance might result in *kitsch*.

3.9 Communication Protocols

As mentioned in section 2.7.2, *Wi-Fi*, *Zigbee*, and *Bluetooth* are the most common network protocols on the smart light market. This section will explain communication protocols commonly used to transfer light information with professional light fixtures and stage lighting.

3.9.1 DMX512

DMX512 (from here on DMX) is short for digital multiplex 512 and is a standard for lighting control transmission, originally by United States Institute for Theatre Technology (USITT) [59], [60]. It is a communication protocol based on the balanced data-transmission standard RS485 and most commonly used for stage lighting [61]. 512 means that the protocol can carry data in 512 different channels digitally through only one data cable. Each channel carries an 8-bit value, a value between 0 and 255. Multiple channels can be used together to transport higher resolution values.

When a light fixture connects to a DMX universe, it reads from the address selected on the fixture. Different light fixtures have different amounts of channels depending on how much functionality is built-in. The channels can, for example, be: red, green, blue, strobe frequency, light intensity, tilting, panning, etc. Multiple light fixtures can read from the same DMX channel. A DMX controller will send out the data through the fixtures, and the fixtures understand where to read. DMX light fixtures connect in series where each fixture has a DMX input and output. Each series of DMX fixtures belongs to the same DMX universe.

3.9.2 Art-Net

Art-Net is a communication protocol to distribute DMX data [62]. Art-Net is implemented as an application layer on top of User Datagram Protocol (UDP); this allows using any physical transportation medium, such as Ethernet or Wi-Fi [63]. Art-Net uses an addressing scheme that, in theory, allows 32768 universes. In practice, this number might be limited by the throughput of the network. Art-Net also contains a method to discover nodes in a network via Art-Poll packages.

3.9.3 Open Sound Control (OSC)

Open Sound Control or OSC is a message-based communication protocol primarily used in sound and stage control [64]. It is based on URI-style messages that describe how specific values should be changed. OSC is implemented in various software for audio and light control.

4

Methodology

This chapter presents the general methodological approach and the methods used to support the design process in this project.

4.1 Process

The following sections describe different methods that we applied during the our project. Some, if not most, were not used in the formal way that they are described but served us as a background to implement our own interpretation of the method.

We close this chapter with an overview of our research approach and how we see its relation to research through design.

4.1.1 Intermediate Knowledge

The conceptual space between actual instances, the artifacts and abstract theoretical concepts is called intermediate knowledge [65]. Knowledge in this space can be of different forms. It can be evaluative like usability heuristics, generative like guidelines or it can prescribe ways of doing design like methods.

4.1.2 Annotated Portfolios

Annotated portfolios are a concept of communicating knowledge in a research through design process. They are intermediate level knowledge. Annotated portfolios are textual annotations to a collection of artifacts [65]. The artifacts can be presented in any way the designer chooses. But most often a visual representation in the form of images is chosen. The collection of artifacts described can be seen as an area in space arranged in the dimensions of the annotations. These dimensions can be chosen by the researcher to highlight and focus special concepts [66].

4.1.3 Strong Concepts

Another way to represent knowledge are strong concepts [65]. Annotated portfolios describe the artifacts or their qualities and are therefore strongly linked to these. Strong concepts on the other hand abstract and extract the knowledge from one implementation towards a more universal applicable concept. But even though more general are strong concepts in no way general truths.

4.1.4 Prototyping

Conceptual work is an essential part of the RtD practice [42]. Matthews and Wensveen defines four roles of prototypes and prototyping in design research; as an experimental component to test specific hypotheses, as a means of inquiry in an open-ended exploration, as a research archetype for illustration or demonstration, and as a vehicle for inquiry by driving the research direction [43].

4.1.4.1 Experience Prototyping

A Prototype is a representation of a concept built before the final artifact, it is a tool in the design process communicating design decisions and process [67]. *Experience Prototyping* is a form of prototyping involving active engagement with the prototype. It emphasizes the experimental aspect of conveying an experience. A representation is designed to explore, communicate or understand the interaction with an artifact (product, space, or system). Buchenau and Suri identify the kinds of activities in a design process where *Experience Prototyping* is valuable; understanding the existing user experience and context, exploring and evaluating the design ideas, communicate ideas to an audience. *Experience Prototyping* is not a method on its own but can be applied to prototyping methods of various fidelities.

4.1.4.2 Playful Hacking

Playful hacking is an approach within RtD inspired by play. It should not be regarded as a method but rather a mindset within conceptual work in design research. Playful hacking does not describe how to carry out a hack but provides guidelines for how hacking is part of the research. Goddard and Cercos stresses the importance of having fun to spark creativity in a research process [68]. Hacking should be seen as a creative play that boosts self-motivation. Through playful hacking, the designers can look through the constraints of the final goal in order to get a wider diverge. More time is allowed in thinking which leads to quick actions and making. Goddard and Cercos lists the main values of playful hacking; *Minimal Viable Product*, *Hacking as Play*, *Making mode of Thinking*, *End in Itself* and *Loose Structure*. *Minimal Viable Product* means that you should always think of the smallest possible contribution you can put together. *Hacking as Play* means that you should always make what you want to make. *Making mode of Thinking* means that you should start thinking as a result of making and reflecting. In playful hacking, outcomes are not planned, *End in Itself* means that the hacking should be approached as a possible ending of its own. Finally, *Loose Structure* means that the structure should be kept loose but enough to maintain the scholarly momentum.

4.1.5 Double Diamond

The *Double Diamond* is an iterative process model centered around diverging and converging activities. It can be separated into four phases that continuously repeat; *Discover*, *Define*, *Develop* and *Deliver*. In the discovery phase, the designer diverges and collects information to further understand the problem. It is followed by a converging activity of defining the problem with the insights from the discovery phase. The design activity diverges again in the development phase, where the designer(s) seek solutions to the defined problem. A final converging activity is carried out in the delivery phase, where different solutions are tested and analyzed. The *Double Diamond* is not a linear process but stages can lead back to previous phases; this is often shown via arrows. [69], [70].

4.2 Somaesthetic

One justification for integrating somaesthetic into contemporary design processes is for Höök that designers increasingly create for systems that do not rely on symbolic interactions [47]. Instead, new ways and bodily interactions should be explored. To engage with the design materials in a closer way Höök describes somaesthetic appreciation as a skill that is learned with time. Designers have to learn to utilize all their senses to understand new ways of using materials and designs. It is important to note that even though our final design might exhibit qualities commonly found in somaesthetic artifacts, we did not aim for this. We primarily see somaesthetic as a tool for us to engage with and make sense of light situations.

4.3 Participatory Design

Participatory Fesign is an approach in design when stakeholders are invited to join the design process to get a better understanding and find new angles [71]. It is not a method of its own nor rigidly defined but an approach to use methods together with stakeholders.

The idea of the participatory workshops is to let the participants interact with the prototypes by trying to accomplish certain tasks and evaluate outcomes in an ongoing conversation. We do not claim to have used *Participatory Design*, instead we borrowed the thinking of including external stakeholders and especially non-designers in the process.

4.4 Documentation

As our project is characterized as RtD, we made heavy use of multiple documentation methods.

4.4.1 Diary

Research in the field of design is highly personal. For designers to be able to generate research results, they must work autobiographical and make reflection and analysis part of their process [72].

Pedgley proposes *Diaries* as a tool of constant recording and reflection [72]. The *Diaries* help not only by making the final process of writing a report easier but also support increased alertness in the design activity. The author found that diary writing is easier to conduct as a retrospective activity at the end of a working day instead of parallel to the action. The diary entries should have an open-ended structure to support easier and more coherent writing, and they do not need to be polished texts. Instead, forms like bullet lists can be used. Pedgley proposed some guidelines for good practice of diary writing: *chronology*, *clarity*, *focus*, and *inclusion of images.*

4.4.2 Journal

While the diary serves as a private and autobiographical collection of daily advancements and reflections, the journal is an *Annotated Workbook* intended for the public [42], [73]. Documenting the design process by refining and annotating a collection of design proposals, inspirations, sketches, and other research findings lets interested people follow a research process. Bardzell *et al.* writes that knowledge in research is normally transmitted verbally while it is embodied in the artifact in RtD, the journals aimed to reveal this knowledge and connect it to theory [73]. Gaver mentioned that referring to existing design examples can inform how the idea developed [42]. He further argues how *Annotated Portfolios* are valuable as an alternative to the more formal presented theory in conceptual developments.

4.5 Project Management

To keep track of progress and decisions in RtD, we used methods to keep track of and prioritize tasks and decisions.

4.5.1 Kanban

Kanban is a scheduling method commonly used in agile software development and used to keep track of tasks by visualizing the workflow [74]. Cards represent work items, and columns represent different stages. A basic Kanban board usually consists of three columns; to do, work in progress, and done, but can be extended to fit the project it is applied in. The work items can then be checked out while being worked on and put into a stage that fits the updated status.

4.5.2 MoSCoW Model

The MoSCoW model is a technique that can be used to grade requirements and tasks [75]. MoSCoW is short for *Must have*, *Should have*, *Could have*, and *Will not* *have*. *Must have* features are fundamental to the project and are required to give the product a purpose. *Should have* are important requirements but not essential. They can be left out if there is a short workaround. *Could have* are features that would be nice to have but is, as well as *Should haves*, not essential. *Will not have* are features that are not needed or will not bring the project closer to its goal. It might be enhanced and provide value later in the project.

4.6 Evaluation

Primarily qualitative evaluation methods were carried out to continuously evaluate findings and to include external opinions in the design process.

4.6.1 Interviews

The in-situ interview method is recommended by Price and Jewitt to evaluate embodied designs [76]. They evaluate three different methods of conducting interviews and their effect on the generated feedback. They conclude that pure verbal interviews result in mostly high-level discussions about the actions the participants did. While not as deep as the following methods, it resulted in verbally conclusive data as the participants had to verbalize what they wanted to express.

Interviews in combination with videos of the action resulted in more reflexive insights. Participants were likely to reinterpret their own actions as they saw them from a different angle.

Interviews while being situated in the actions resulted in the most insightful and comprehensive data. The participants were able to demonstrate what they were talking about in the situation, which while being easier to for the participants, is harder to interpret by the researchers.

4.6.2 Focus Groups

Focus groups are a group of people discussing a specific subject [77]. While an interview is efficient in gathering qualitative opinions of the subject, a focus group adds the dimension of internal discussion about the subject, resulting in a deeper and more nuanced discussion. The group is usually consisting of people with a similar demographic.

4.6.3 Cued Testing

Participants are asked to look at the exhibition and to engage with it. Later they will be asked questions [78]. This method generated insights into how much knowledge the exhibition transfers and how visitors understand and apply it.

4.6.4 Thematic Analysis

A thematic analysis is an iterative method or process of arranging qualitative data into different themes [79]. It is divided into six steps; *familiarize*, *assign codes*, *search for patterns*, *review themes*, *name themes*, and *summarize in text*. In the first step, the researcher familiarizes with the data by going through it, transcribe if necessary and take notes. The second step is to separate the sentences or statements and assign descriptive codes. The researcher then searches for patterns in the data and uses the coding to create different groups with relating content. The themes are reviewed and finally rewritten into floating text.

4.6.5 Research Approach

In this thesis we explored, and hopefully opened, a design space of working with light in an interaction design context. The explorations in this space were open and not constrained. The space offered limitless directions, each connected in a web of possibilities. This complexity is often called a wicked problem [39], [80]. Stolterman argues that this complexity is what differentiates design from other scientific fields [80]. They continue by explaining how this complexity can not, and should not, be overcome. Instead, the complexity can be the driving force in the design process and can even lead to new ideas. We agree with this view on design research and therefore integrated this loss of control into our process by dedicating parts of the process to unstructured explorations that would later help to be more informed for the design of the final artifact.

We believe that RtD can be seen as a way of working with this complexity of design [40]. By exploring the design space and marking it roughly out, through the creation of prototypes, we further hope to enable researchers to start their design journey more informed. However, we also hope that our knowledge will be used generatively and spark new ideas.

Our work can be characterized as anti-solutionist as we do not aim to create a product or solve a distinct problem [81]. But in contrast to Blythe *et al.* we do not especially provoke silly, or nonsensical design ideas. Instead we see ourselves as playful hackers that explore a design space with an playful attitude [68]. The first part of our process was constituted as an ongoing exploration of how light can be shaped and materialized through different artifacts. While these prototypes are not yet ultimate particulars [80], or final designs they do stand for an exploration in the design space and can be seen as instances [82]. To describe the design space between these prototypes, we evaluated these as a compound in an annotated portfolio [66]. However, as the artifacts are still in a raw form, we did not only describe them in their current state but also the embedded knowledge. We furthermore extract strong concepts from these designs to make the knowledge of our thesis more accessible for future researchers in the form of intermediate knowledge [82]. The strong concepts can be seen as the dimensions of a space in which we will place our designs [66]. We believe that an annotated portfolio in this way supports our stance to open a design space as it is not only descriptive but also generative.

We mainly used qualitative evaluation methods to evaluate the prototypes and gain insights into how they affected users. In that sense, our prototypes can be seen as technology probes [83]. In some instances, we collected quantitative data like usage patterns and preferred color settings. Even though this data was quantitative, we did not use or interpret it formally and only used it as an inspirational source.

Based on the knowledge gained from the first iteration, we created a final artifact, an exhibition, to communicate our knowledge to persons outside of the design research community and engage in conversations with different people. We believe that having an exhibition is a powerful tool to extend the visibility of our project outside of the interaction design community and to people that would normally not engage with the topic on their own.

To design the exhibition, we looked at different disciplines in RtD, for example, showroom [48] and speculative design [49]. We decided to utilize concepts from these fields even though our project contrasts with most of the designs in this space as we do not engage with a major problem of our time. Instead our work tries to propose at a changed usage of light. With that, we might also have speculated on a future in which interactions are done differently, maybe less goal-oriented, but that was not the main point of our design. We furthermore believe that even though exhibitions and with it the showroom aspect of speculative design have been criticized by some speculative designers [50] there is still a place for them to communicate knowledge. Especially because our project is not dealing with the great concerns of our time and we do not see us as speculative designers. Instead we see ourselves, in the furthest sense, as postphenomenological researchers that are trying to understand how technology, but especially artificial light, mediates human existence [45].

5

Phase I: Preparation

In the first phase of the project, we prepared and planned how to distribute the work in the coming months. We also compiled the generated knowledge and theories from our previous work. In this chapter we will elaborate on this initiation of our project.

5.1 Exchange of Knowledge

Previous to this thesis, two separate projects were conducted. One analyzed products on the smart light market to provide an overview of the current features and technology. The other project consisted of a literature review of sampling algorithms, light psychology, and light in interaction design.

In the first week of the thesis, knowledge was exchanged to make sure that we both share the same pool of insights by discussing the content of the reports. The literature review content from Frederik Göbel provided a good base for the theory chapter of the thesis as it covers the relevant scientific topics of our work [37].

Mattias Hallin's benchmark provided a summary of features that exist on today's smart light market to the background chapter. It reveals interesting opportunities for future applications of our thesis and anchors it in the real world.

5.2 Planning

We designed a process model that would fit our explorative and physical approach to design research. The process is strongly influenced by a double diamond design process but tweaked to fit our process.

5.2.1 Triple Diamond

To separate the project's different activities and phases, the project is divided into three phases; *preparation*, *conceptual exploration*, and *physical manifestation*. Even though they are divided overlaps, we need to separate the different work to keep track of the design process.

Instead of two diamonds, we added a diamond in the middle, making it a triple diamond model (Figure 5.1). One diamond for each phase. The first diamond represents the previous studies and the preparation. The result of this phase is a structure and plan for the upcoming phases. The conceptual work and prototyping are an essential part of our process as this is what is creating our knowledge; we give this its own phase. The diverging part of the second phase will be a new discovery phase where we are discovering through engaging with the material. It then converges into a guided exploration where we have a more extensive understanding of light phenomena. Results from the activities in this phase are documented in journals and diaries. The last diamond starts with a new ideation phase where the knowledge from the previous phase is used to design the final shape of the installation.

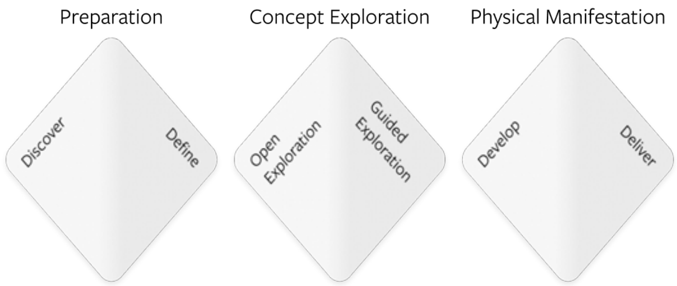


Figure 5.1: Triple Diamond process model.

5.2.2 Time Plan

The time plan can be found in A.2. As conceptual work and prototyping are a vital part of our process, we needed to plan what we want to build to know what equipment and materials we will have to order. A big part of the methods in the design process was centered around the conceptual work of interacting and engaging with the created artifacts.

5.3 Public Process

Our project aims to open up a design space of interactive and artificial lighting. Therefore we try to make the process public to share our gained knowledge and to invite people to join the conversation. To make the knowledge accessible, it has to be processed and presented in an interesting and inspiring way.

5.4 Light Sampling

A part of the project is the actual light sampling. We began investigating the possibilities and feasible options in sampling the different parameters. We know from our previous studies that parameters in intensity, direction, hue, size, etc., can be sampled. However, we had to investigate what we could accomplish for this project and how feasible implementing some of the algorithms was.

At the beginning of the project, we intended to explore the possibilities of videos captured by a phone and with a 360 camera. We early decided to limit our work to represent possibly sampled data instead and focus on building light representing artifacts.

5.5 Collaborations and Space Possibilities

As our research would rely upon physical prototyping and engaging with light settings, we immediately started looking into different space alternatives to carry out parts of the process. Due to COVID-19, spaces provided by the university and other public institutions were limited. Therefore, we looked into alternative studios or workshops and spaces where we could store material and prototypes. The different needs regarding space for this project were: *somewhere to build*, *somewhere to engage*, *somewhere to store*, and *somewhere to exhibit* our result. It could be the same space or different ones that cover the different needs.

As we were in need space and light materials, we looked for possible collaboration partners. We talked to different companies that work with light for possible collaborations. Unfortunately, most of these were relatively product-focused and not especially interested in our project itself. Therefore we shifted the focus of possible partners towards design studios and research labs. Out of the contacted companies, we received a positive response from *Kollision*.

Kollision is a danish design studio focused on public installations involving light. They were optimistic about our proposal and agreed to support us with knowledge and materials. They would have supported us with space, but unfortunately, this was not feasible due to COVID-19. They, however, borrowed us seven professional light fixtures (Figure 5.2). We also had several talks about the feasibility, direction, and structure of our installation.

(a) White light bar DMX fixture.

(b) RGB DMX three-pin wall washer fixture.

(c) RGB DMX four-pin wall washer. fixture

Figure 5.2: The different models of light fixtures borrowed from Kollision.

We also approached Gunnar Oledal at RISE, who has exceptional experience in electronics and prototyping. The project did not match any of their ongoing projects, but he was interested in the scope. He offered to support us with knowledge and hacks within prototyping with electronics on an ad hoc basis.

5.5.1 Low

As the search for a room turned out to be complicated, we finally settled on using part of the Interaction Design Studio called *Low* as our prototyping space. The space has the advantages that there is a wood, paint, and electronics workshop. Moreover, due to COVID-19 there is no active teaching in the studio which means that it is empty most of the time.

5.5.1.1 Dark Room

To have a dark space to engage with light settings, we arranged the studio's furniture to release a corner where a small room was formed using lockers. The distance between the lockers and the ceiling was covered with MDF-boards, foam sheets, and fabric to make it as dark as possible (Figure 5.3).

Figure 5.3: The dark room the Interaction design studio.

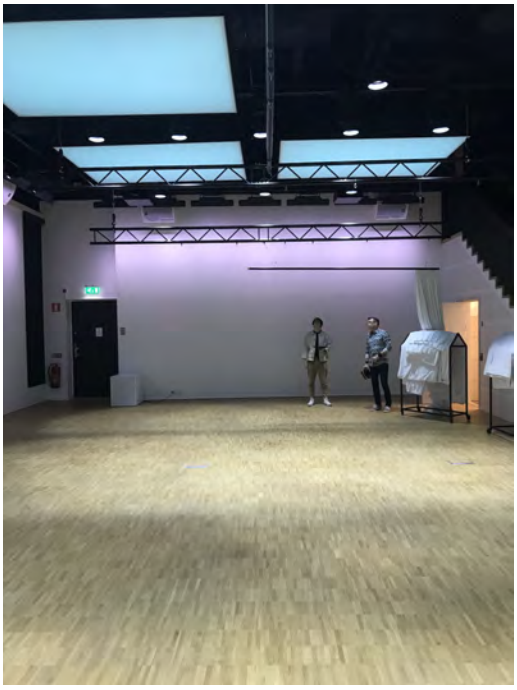


Figure 5.4: The AWL Studio.

5.5.2 The AWL Studio

In the search for an exhibition space, we asked multiple companies. Unfortunately, most did not reply or replied negatively. Through a coincidence, we were offered a studio room at AWL in Gothenburg. The room is approximately 180 m^2, has a ceiling height of 4m, and is equipped with controllable lights and ceiling rigs (Figure 5.4).

The Studio is owned by Akademiska Hus and is supposed to be a learning space for students to realize projects. As the room is under-booked due to COVID-19, we were offered to use it for free.

5.6 Material Gathering

As we knew the project would rely heavily on material, we looked into different options and opportunities.

5.6.1 Reuse

With a limited budget and high ambitions, we investigated options in how to reuse parts from electronic waste. Old Liquid Crystal Display (LCD) monitors came to be an essential resource for this project as it contains plastic sheets that can be expensive, hard and time consuming to procure or recreate.

5.6.2 Kollision

We asked Kollision if they could lend us some lighting equipment to get started. They agreed to that and shipped seven professional DMX light fixtures to us. Two Eurolite LED BAR-12 6000 K 12 × 1 W (Figure 5.2a), a light bar with 12 1 W LEDs spreading a cold white light. Light intensity, strobe frequency, and music control can be controlled using DMX. A small interface allows the user to select from what DMX channels it reads, the lights powered with 230 V are connectable with a DMX three-pin connector. We also received two no-brand LED RGB 45 W wall washers (Figure 5.2b). A wall washer is a light designed to wash walls with light. Color, strobe frequency, and light intensity can be controlled over DMX; similar to the first lights a small interface allows adjustments to what channels to read. Also, this light is powered with 230 V and is connectable with DMX three-pin. The last three lights are 36 W LED RGB wall washer lights (Figure 5.2c) from Rise Optoelectronics made for outdoor use [84]. Instead of typical DMX three-pin connectors, these lights have a waterproof four-pin connector. D+, d-, and ground are similar to the DMX three-pin, but the fourth pin carries 24 V DC.

5.6.3 RISE

We reached out to Gunnar at RISE to see if they happened to have any DMX interfaces that we could use to output DMX from a computer. They did not have any commercial products for this, but Gunnar happened to have an old project where he built a circuit with an RS485 breakout board and a microcontroller to output DMX data. We then started to read about how to create a DMX interface using MAX485 ICs and microcontrollers. Gunnar was kind to lend us two prototype circuits from this project. Both circuits included a TTGO T7 v1.3 ESP32 development board and an RS485 breakout board. ESP32 is series of microcontrollers with a Wi-Fi and Bluetooth combo chip [85].

The acquisition of these had an essential role in future work.

5.7 Project Management

We implemented different project management methods to provide structure to the project.

5.7.1 Scheduling Tasks

We implemented a digital Kanban board in the productivity software *Notion* to structure our todo-list and keep track of finished items. We initially used four columns; *no status*, *not started*, *in progress*, and *completed*. The digital board worked fine for the initial part of the project when most of our work was reviewing literature and building the website. When we began the physical work, we soon realized that we needed a physical Kanban board. When working physically, the digital board did not provide us the overview we needed. Opening up the digital board each time we wanted to add an item or look for tasks was too time-consuming, and was not motivating.

A physical Kanban board was implemented with sticky notes on a large whiteboard next to our workspace. As the whiteboard was filled with more and more post-its, we needed to implement a sorting system. We separated the todo-notes into five categories; *prototypes, website, report, theory, and exhibition.* The different headings helped us to easier navigate through our todos. Having the physical board next to our workspace helped us plan our days and weeks visually. Therefore we added a *today* section and a *this week* section.

Further into the project we continued to iterate on the format of the Kanban. As we reached the converging part of the conceptual exploration, prioritization became important. To include a prioritizing hierarchy in the board, we draw inspiration from the MoSCoW-method. All todo-notes were sorted into four new columns; must do, should do, could do, and will not do. In this way, we focused on the important tasks without forgetting tasks with lower priority. More and more stuff ended up in the "will not do" section.

5.7.2 Stand Up

We started each morning with a stand up meeting. During these meetings we shortly discussed where we are in the process and what we want to do that day.

5.7.3 Project Diary

To document the process, we wrote daily diary posts. In these posts, we kept a record of important decisions, milestones, problems, and reflections. To give structure to the diary, we set up a template to fill in each day. The points are; *stand-up*, *we did*, *opportunities*, *challenges*, and we want to do. We added notes about what we discussed and things we wanted to do on the board during the stand-up meeting. Under the *we did* heading, we describe thoroughly what we did during the day, including problems, decisions, etc. In the opportunity section, we condense the day's work to see what opportunities it gives us in the upcoming work; the challenges are summarized similarly. In the last section, we wrote down ideas we want to do in the near or far future. These are also written down on post-its and placed on our physical Kanban board.

6

Phase II: Conceptual Exploration

The second phase of our project was the conceptual exploration. In this phase, we openly explored the design space of working with light through physical prototyping and conducting experiments.

The exploration helped us to find possible design directions but also to draw the limits of feasibility. We built various light sources during this phase and engaged with different forms of artificial and natural light to train our perception of light. By working closely with physical and digital materials, we created our own ecosystem of lights. Our framework allowed us to engage with the real representations of discrete calculations and bridge the gap between numbers and emotions.

We conducted initial explorations into how natural light situations can be discretized and represented in the virtual and physical space, how lamp shapes can be used to not juxtapose with dynamic light, and how physical inputs can interface with the control of light in the digital domain. It is to note that we did not exhaust any of these topics. Our prototypes and experiments are merely sketches of possibilities in a design space of light.

During this phase, we also investigated how to make our process public, not only to share our generated knowledge but also to spark conversation and get insights into other peoples' perception of light.

6.1 Project Website

For this reason, we developed a website on which we published found knowledge to make people interested in artificial lighting and provide a virtual space for people to converse about light. Our website is inspired by how the *One Shared House* website by Repponen and Pereyra acts as an inspirational beacon and a collection of knowledge about one topic [86].

As our project is not done in collaboration with a company, the website anchored it and made it official. It served as a great tool to validate our intentions to the people and companies we contacted during the project.

The website also includes interactive elements that hint at possible interactions with light. Furthermore, the *Light Playground* from our previously conducted work is included as a sub-page of the website.

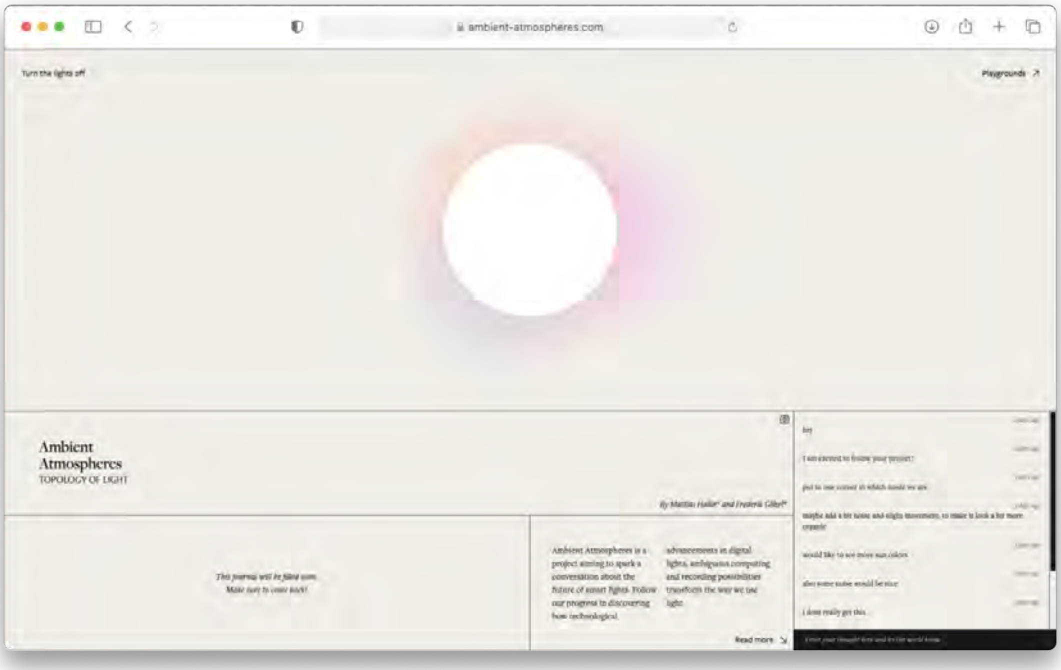


Figure 6.1: Design of the Ambient Atmospheres project website.

6.1.1 Visual Design

Designing the website was the first part of an aesthetic exploration to define the visual identity of our project. We used the collaborative vector graphics editor *Figma* as a tool to quickly iterate through different ideas and explored visual qualities like colors, fonts, and layouts. By combining these elements, we explored levels of playfulness and seriousness in the design (Figure 6.1). We continued using the final visual language throughout our process, and it therefore also defined the aesthetics and the feeling of other artifacts we designed.

The design we decided on is inspired by old scientific research journals and books. The website combines elements from those with modern flat design and interactive elements. We use *off-white* (white with a hint of yellow) as the background color and *off-black* (black with a hint of blue) as the foreground and text color. All elements are placed in a grid with clear lines dividing them. To prevent the page from feeling static or boring, we included dynamic and interactive elements, most prominently the *Ambient Sun*.

The *Ambient Sun* is an animated graphic reflecting our idea of creating an atmosphere by combining different colored lights. The *Ambient Sun* consists of four blurred colored circles slowly moving in a random pattern resulting in different colors and gradients. In the center front of the circles is a completely white static circle.

In contrast to the colored circles and the off-white background, the white seems to radiate light. The website contains a button to switch the light off. By pressing this, the light will "turn off", resulting in the background turning black while the sun remains the same. With this small interaction, we aimed to nudge people into thinking about how lights look different depending on the context.

6.1.2 Chat

To provide a virtual space for people to discuss artificial lighting and allow interested people to engage with us, we added a chat functionality to our website.

The chat allows people to write anonymous text messages without logging in. Each chat message contains a timestamp and a link to the page from which it was sent. The link allows other people to jump to the same context that the message was written to better understand its meaning.

We decided against including names, not only to reduce the threshold for users to engage but also for privacy reasons and to make the chat feel like a message board. To prevent the sending of offensive words, we implemented a simple swear word filter. We thought about adding a function to upload images to allow people to share light atmospheres they found. We decided against this to prevent the upload of inappropriate images. If people wanted to send us pictures, they could still do so through our Instagram account.

While the chat allowed people to provide input into our design process, most people just wrote small comments on the website's different features or content. Even though we did not plan or wish for a participatory design process, we still hoped for greater engagement through the chat.

6.1.3 Journals

As a tool to communicate gained knowledge in the exploration and prototyping phase, we created a journal on our website. The journal articles were written and published in irregular intervals, and topics were chosen on what we were working with or what we were discussing at the moment.

Even though we knew we wanted the journals to be well-formulated, focused on one topic, and directed at a public audience, it took us about two weeks and multiple iterations to decide on a writing style. We probed into the directions of formal and tutorial-like texts before settling on a more relaxed and informal tone. The writing style still communicates clearly but is softened by small jokes and irony.

Each journal has a header image that represents the content of the journals (Figure 6.2). All header images have transparent backgrounds and are in a line-drawing style to keep a similar style between the journals. We did not set such a limitation for the in-text images as they are supped to illustrate the concepts we are explaining. The layout of the journal page includes a sidebar with comments, links, and silly remarks. Some journals include not only text and images but also other media like podcasts or links to other websites for further reading. Initially, we had plans to add interactive elements similar to the *Playground* to the journals to provoke readers to play with light settings or physical simulations. However, we decided against this as the journals worked well without these elements.

In the beginning, we struggled to write the journal entries in a good way; therefore, we decided to write a silly story to get in the habit of writing. While we did not publish that story as the first journal, it helped us get started and was later rephrased into one of the entries. While we wrote that first story collaboratively, we decided to split the work of writing. From then on, each week, one of us was responsible for writing a draft of a journal that the other one would then edit and polish. Writing the journals helped to clarify topics as it forced us to write our thoughts in a condensed and structured way.

In the end, we published the following four journals:

- Have you heard about Frederick the mouse? [87]
- What is light? [88]
- Two Playful Hackers [89]
- What is an Atmosphere? [90]

A pipeline was created inside our website that converts markdown, a lightweight markup language, files enriched with metadata into journal pages. While this helped us have the same layout on each journal page, markdown is not the best format to structure text if one wants to influence the placement of images or sidebar items.

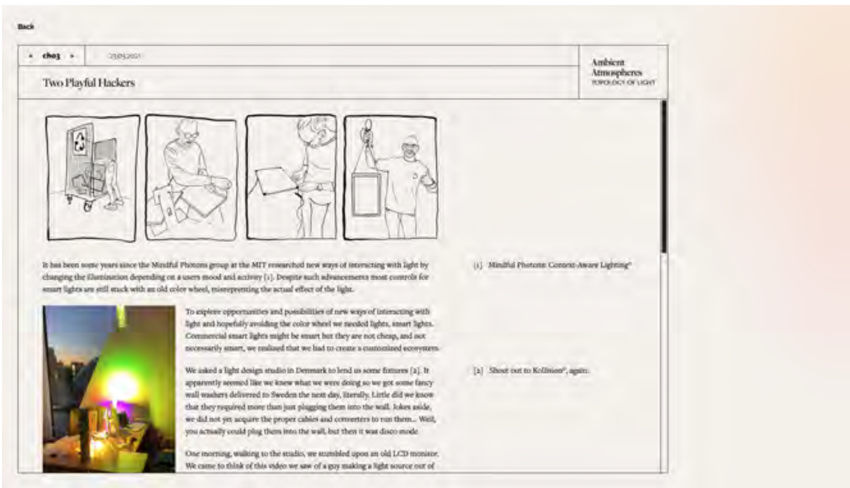


Figure 6.2: The Ambient Atmosphere website journal page.

6.1.4 Playground

In a previous project, a virtual *Light Playground* was developed to explore artificial light settings [37]. The *Playground* enabled people to explore artificial atmospheres even if they do not own a smart light. The *Playground* also contains a chat functionality similar to the one on our website. We decided to make the *Playground* part of our website and link the chat systems together for this thesis.

The *Playground* is written as a web application using the JavaScript framework Vue.js. The back end is implemented in the programming language Go and hosted with the website on our virtual server at the cloud infrastructure provider *Digitalocean*. As we wrote all the code, it was easy to change parts to enable other software to interface with it. The mechanic of the *Playground* was later used in the process as an input device for many of our experiments. In that sense, the *Playground* was used as an extension from virtual to physical space. The interface is a draggable circle in a rectangular field (Figure 6.3). Users can move this circle to manipulate the animations and colors.

Figure 6.3: Draggable circle from playground GUI.

Technically the *Playground* uses WebSockets, a computer communication protocol, to connect to a relaying server between phone and website. Each message is a JSON object, a lightweight data-interchange format, containing information about the x and y position of the draggable input. The values are normalized between 0 and 1.

6.2 Social Media

As an accessible place for us to share photos, we used the social media platform *Instagram*. We created a dedicated account for our project with the handle *@ambient.atmospheres*. On this account, we posted images of our process at irregular intervals. We also used our account to let people know when a new journal article was posted. As most users regularly log in to their accounts to see new images, it worked as a notification system. We used an off-white background in those images to differentiate the posts about new journal articles from the regular photos.

Many people used the platform to send us news about light inventions or interesting light phenomena that they found. A side effect of our *Instagram* was also that our project became accessible to people outside of the academic design circle.

Using *Instagram* as a platform for image sharing during a design process worked great as the overhead is minimal. Unfortunately, the network is quite saturated, and it is not easy to stand out and reach a larger audience. We also hoped for an even bigger engagement from other people, most users that wrote us were friends or colleagues.

6.3 Photography

During our process, photography was used; not only to document experiments and prototypes but also to save interesting light situations.

Some of the light situations we captured as images acted as inspiration for later explorations. Especially pictures of illuminated cloud formations in sunset settings. Through the act of taking photos and constantly looking for changing light situations, we became more aware of the light surrounding us.

Taking photos of natural and artificial light situations turned out to be difficult as the cameras either captured not enough of the details or automatically over-adjusted and saturated colors too much. The realization that every image is just a pseudo-representation of the real world led us to think how different representations of one atmosphere would also be interpretations and not a mirror of the truth.

Initially, we planned to use photography even more and as a diary tool to take a photo daily. We did not do this as it turned out that our work already made us aware of changing light situations, and we took many photos even without the set goal of one per day.

6.4 Guest Lectures

We were asked to present how we use speculative design as a communication tool in an RtD process in a course about designing user experiences. For this presentation, we prepared and condensed material from our process. The presentation served as a mediating artifact by communicating our design research approach. The presentation slides can be found in A.3.

6.5 Control of Light

During the project, the need to control light in an informed way occurred. For this, we used different technologies depending on the context. We explored using physical inputs as light control as well as multiple digital tools. To embed complex algorithms in the light design, we created our own light platform called *openSOL* (Open Studio of Light).

6.5.1 Color

During the early explorations with the *Ambient Window* prototype, we realized that the representable colors by the LEDs are limited. Even though the LEDs are controlled with 8bit RGB colors and should represent more than 16 million colors, only a fraction of these can be shown in reality. As our screen is transparent but with a white tone, the “off” color is white as well. Dark colors are therefore difficult to represent. This problem can be overcome partly by using RGBW lights. In RGBW lights, the red, green, and blue diodes can tint the white light instead of creating it. Lighting up the window in one color with contribution from the white LEDs while having some LEDs without the white light results in areas perceived darker than normal and looks like shadows or holes.

6.5.2 Physical Control

We used various physical inputs to control our lights through the project, some of them we built ourselves. This section will describe some of them in detail.

6.5.2.1 Potentiometers

Early in the project, the need arose to change the light in one of our prototypes. We were searching for colors that we liked when expressed with LEDs. The original workflow for this was to choose a color in an image editing software. Extract the RGB components and write them in the program of the light controlling device. Upload the code to the device and run the code. This loop was too long to explore colors quickly.

Therefore we added three potentiometers and an LED strip to an Arduino, an electronic prototyping platform. Each potentiometer controlled one of the RGB components of the LED strip. Through this, we could explore colors in real-time.

6.5.2.2 Light Control Board

We reached out to Ljud- och Bildgruppen (LoB), a committee within Chalmers Student Union that rents out sound and lighting equipment. They were kind to lend us a simple 6-channel DMX control board along with a couple of DMX cables. The control board allows us to explore the parameters physically of the borrowed DMX lights before we set them up digitally.

6.5.2.3 Roller Blind Chain

While thinking about different ways of controlling lights through physical interactions and playing with curtains, we had the idea of utilizing the string of window blinds as input. The use of window blinds already has a set affordance of changing light. Users expect to change the room’s light situation by pulling the string.

To create a prototype, we used Lego, plastic interlocking building bricks. These allowed easy and quick experimenting with different dimensions in gears, wheels, and construction. A shaft encoder was used for input as it converts angular position and motion to a data output signal. The encoder was connected to a Lego shaft which in turn was connected to a system of gears. As we did not have access to a real roller blind chain or wheel that would lock on to it, we had to try out a few ways to prevent the rope, replacing the chain, from sliding. Various Lego wheels were tried, with and without the rubber tire, with varying results. In the last iteration of the roller blind chain prototype, two wheels with rubber tires were mounted closely together (Figure 6.4); this prevented the rope running between them from slipping.

The rope was threaded through a Lego beam to keep it in place and prevent it from slipping off the wheel. Different combinations of gears were finally used to adjust how different motions and speeds in pulling the string affected the lights. We found that the shaft encoder did not track the angle correctly if the string was pulled too fast. The prototype was mainly tried out as an interaction mode of controlling the brightness of one of our light sources. We did not explore this concept further, even though it showed great potential as we only had a limited amount of time.

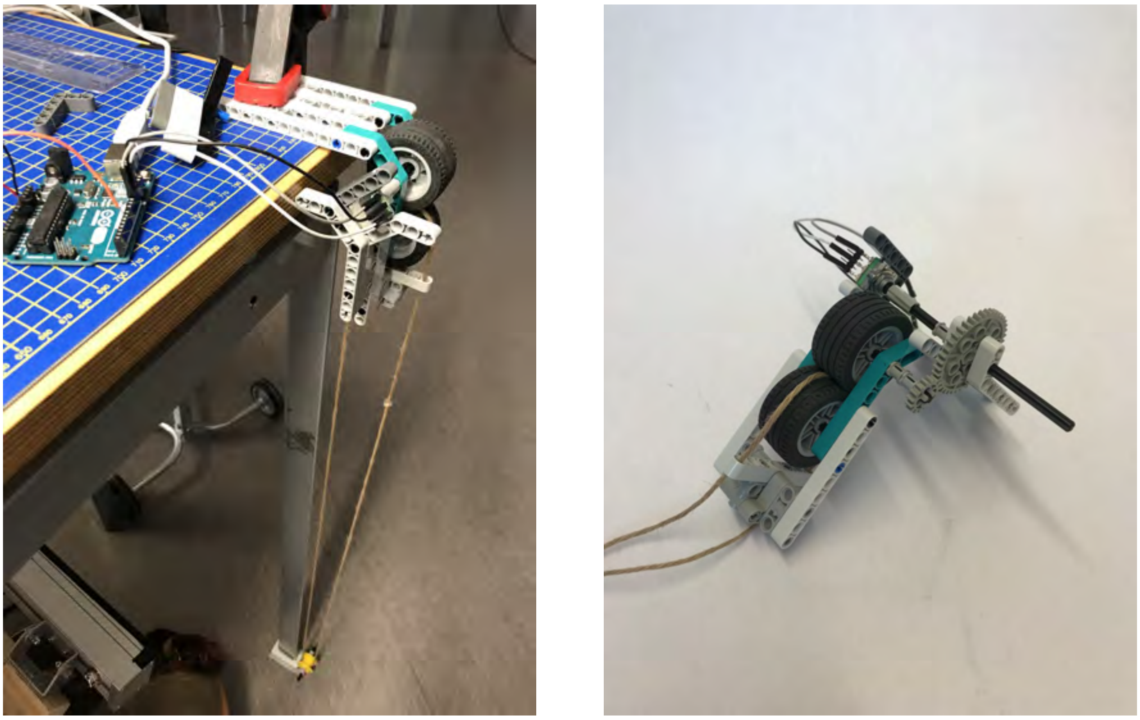


Figure 6.4: Late iteration of the roller blind chain prototype.

6.5.3 Digital Control

To allow for more advanced control of the lights, we implemented various digital tools. In this section we will explain interfaces, protocols, softwares, and devices we used to control our light digitally and remotely.

6.5.3.1 Hacked Playground

As the first digital control of our light sources, we used the *Playground* on our website. As we developed the whole software, including the back-end, it was relatively easy to interface with our API to let users control light sources through this website.

For that, a WebSocket client was implemented on the light sources. This client registers on the server with a previously chosen session id. The user can then control these lights by going to a specific URL with the same session id set as a query parameter.

The design with a fixed session-id per experiment allows a smooth and obstruction less process for users to gain control of the light. We used a QR code that contained the correct address of the *Playground* with the session-id set. In this way, users only had to scan the code to control the light source.

6.5.3.2 DMX Protocol

We were constrained to use the DMX protocol to control the light fixtures we borrowed from *Kollision*. As it is commonly used for lighting control, we used DMX to control our own lights as well.

6.5.3.3 Art-Net

We early realized that we would need many cables to connect all lights to the host computer and looked into different exchange protocols for light data.

One of the most commonly used protocols is Art-Net. Many commercial light control software can output signals in this format. We also got the recommendation to use Art-Net in an interview with Olesen and Nielsen from *Kollision*. Art-Net makes use of the UDP messages over IP to send data from a controller to a light source efficiently. The fact that Art-Net is built on top of the TCP/IP family allows it to be transmitted through any physical network supporting these. For example, Ethernet or Wi-Fi. As we wanted to have the most flexibility of the placements of our lamps, we decided to use Wi-Fi as the transmission medium.

To control DMX lights, we build a node based on a LILYGO TTGO T7 V1,3 MINI 32 ESP32 Wi-Fi board that receives Art-Net packages over Wi-Fi, translates them into DMX packages, and then sends these to a DMX output via a MAX485 IC (Figure 6.5). MAX485 is a low-power transceiver for RS-485 communication [91]. The circuit is contained in a box to make it more durable. This program is only implemented in C++ to support Arduino-based chips.

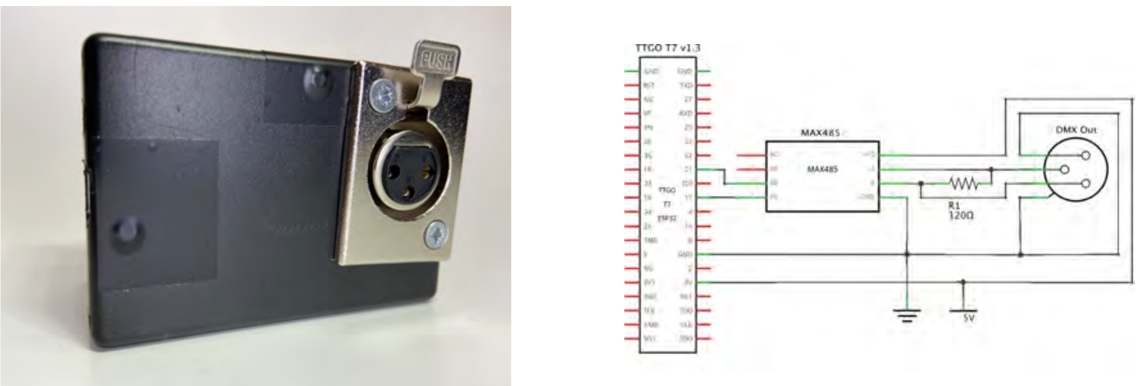


Figure 6.5: Circuit diagram of the Wi-Fi to DMX node and the box containing the circuit.

To control self-built lamps based on NeoPixel LED strips, we created a small program that receives Art-Net packages over Wi-Fi, unwrap them into DMX frames, and maps these to the correct output format for the specific LED strip. As we are also using RGBW LEDs, the program has a flag to change between RGB and RGBW and an option to define the length of a data frame. This program is implemented once in C++ and once in Python to support Arduino-based microcontrollers and Raspberry Pis.

6.5.3.4 Open Light Architecture

Open Light Architecture (OLA) is an open-source software package that translates between different protocols used in lighting design and can send and receive these via a multitude of channels.

The main program of OLA is the OLA daemon (olad) which converts between different protocols and directs traffic depending on configuration files and plugins.

Olad provides an interface through a website. In this interface, users can define which light universes exist, if they are in- or output, and what protocols they should use. The interface also contains a simplified light control through which every universe channel can be controlled manually. We used this feature a lot to test if traffic from our host computer reached the lights and also as a tool to debug our light sources.

OLA provides different client libraries to interface with the daemon programmatic. We used the Python interface to write programs that send data into OLA and let OLA deal with the communication with the lights.

As all the light sources that we build supported Art-Net, we only used this protocol in OLA. In the later stages of the project, we wanted to let OLA run on a Raspberry Pi. We, unfortunately, ran into version conflicts and did not make OLA work on a Raspberry Pi. Therefore we implemented our own Art-Net sender module in Python and skipped OLA.

6.5.3.5 OpenSOL

At a stage where we had multiple lights, we looked for a software controlling them all at once. There are several (stage) lighting software, commercial and open-source ones. Most of the programs were either targeted at stage lighting and therefore too restricted in use or commercial software that was too expensive.

We also had the requirement that the software should run on its own on a separate computer for a more extended period to deploy prototypes independently from our computers.

We started writing our own small programs that calculated the colors and sent them to the lights through OLA. With the advancement of our project, we wrote a multitude of these scripts, and we realized that some elements were always reoccurring. Therefore we decided to write our own control software.

We wanted to be able to quickly ideate different simulations but also different in- and output methods. Therefore, we made sure to engineer a modular software to support our changing needs without the need to rewrite many parts. Instead of creating an opinionated rigid structured code, we created a library of different tools that can either be used altogether or individually.

The tool is written in Python and is structured in multiple sub-modules. These group classes and functions together regarding their purpose.

Input
To receive input from separate programs, for example, user input from an interface, we created a structure that allows easy addition of different input sources. So far, we support incoming data through WebSockets. We added a WebSocket client as we were using our website's *Playground* as the user interface for most simulations. This client connects to a WebSocket server of a different program, receives the updates, and translates them to the internally used format.

We also implemented a WebSocket server where clients can connect, mainly used for GUI implementation.

GUI
At a later stage of the project, we decided to include a GUI for *openSOL* (Figure 6.6). The interface is built in Vue.js, and due to the nature of the reactive framework, it is relatively easy to add different input modes. The GUI so far supports the changing of variables in sliders and color pickers.

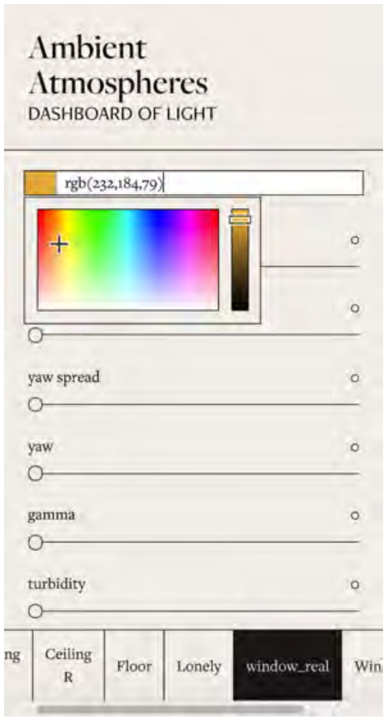


Figure 6.6: OpenSOL graphical user interface.

Output
At this stage, we only support two different output modules. For the longest time of the project, we used OLA. Therefore we implemented an output module that uses the OLA client library to communicate with olad.

We also wrote our own Art-Net output module to send messages directly to a client, either through Multicast or Unicast.

Simulation
The Simulations in*openSOL* are implemented similar to a pattern commonly found in game engines. A loop is running at all times and updates each object in the simulation (each lamp) about every 16.66 ms so that a framerate of 60 frames per second is achieved.

Each simulation can contain custom logic to update "world" variables that will be received by each lamp, for example, time of day.

Lamp
Each lamp with its own logic is implemented as an own class. In each frame, the logic is updated, and the lamp outputs the resulting data. We implemented several different lights and models during prototyping. The instances of the lamps are given IDs. During the update phase, they receive all the inputs targeted at their ID or targeted to the global scope "world". Doing so allows the lamps to react to user inputs but also to programmatic changes defined in the simulations.

Packer
To create the DMX frames independently of the output format used, we created a packer. This class collects all the data from all lamps and inserts them in DMX frames that the output modules can then send.

Patch
To let the packer know which lamp should be placed in what DMX channels and universe, each lamp is wrapped with a patch that contains the needed information.

Misc
In addition to the mentioned components, we also implemented various helper methods to convert between numerical ranges to mix colors, create gradients, smooth values, detect stale values, and more.

We needed a function that maps values in a normalized space to values in the same space but does so in a non-linear fashion. We found the *normalizable tunable sigmoid function* (Figure 6.7) [92], [93]. This continuous function allows a tunable mapping and can therefore be easily changed to allow linear mapping but also nearly every other easing function. When the parameters are changed to the extremes, it can even be used as a step-function. Another advantage of this function is that by changing two more parameters, the center's inflection point can be moved, allowing the scaling of values non-symmetric.

To smooth between values in the time domain, we implemented two methods. PID controllers or proportional–integral–derivative controllers are often used in mechanical engineering and especially robotics to control movement. This algorithm smoothly interpolates between two states quickly, but the transition is not exceptionally smooth.

Another algorithm we used is similar to the forward Euler method. We integrate a constant acceleration over time and scale the velocity by a constant value to simulate drag. The velocity is then added to the position resulting in smooth transitions between values. The side effect is that the velocity for values close to each other will not be too fast.

6.5.3.6 TouchDesigner

While we used*openSOL* for most of our project, we decided to use *Touchdesigner* for the last experiments and later the final exhibition as it allows the creation of complex media systems through a graphical node-based interface. It supports working in 2D

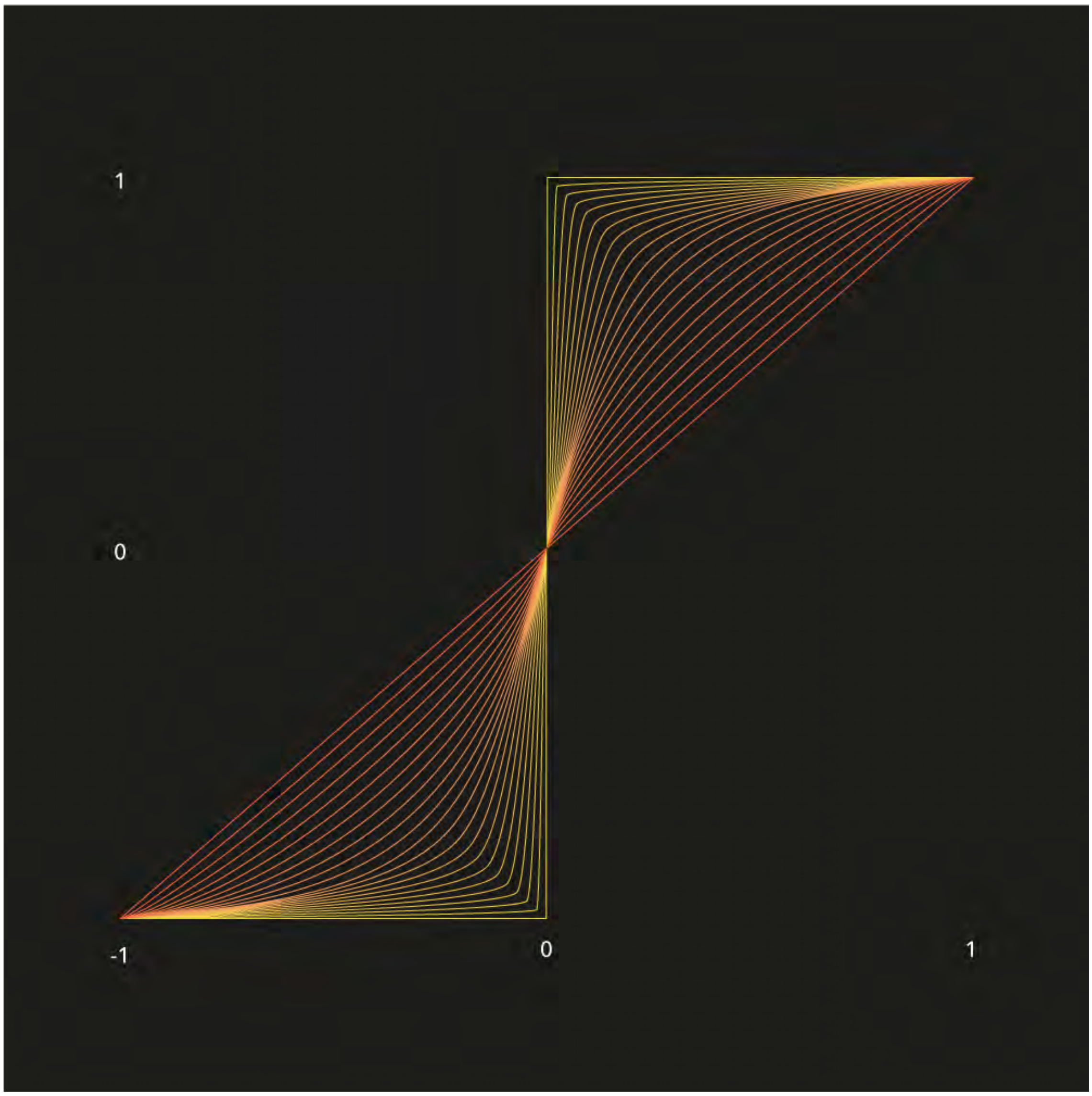


Figure 6.7: Some of the possible easing functions representable through the NTSF function.

and 3D space but also through channels in a time-based space. It furthermore supports a multitude of in- and output protocols.

We used *Touchdesigner* mostly to sample points from generated images, depending on the input, and outputs the gathered colors to Art-Net over Wi-Fi. Open Sound Control (OSC) was used as the input format, as many desktop and phone applications support it.

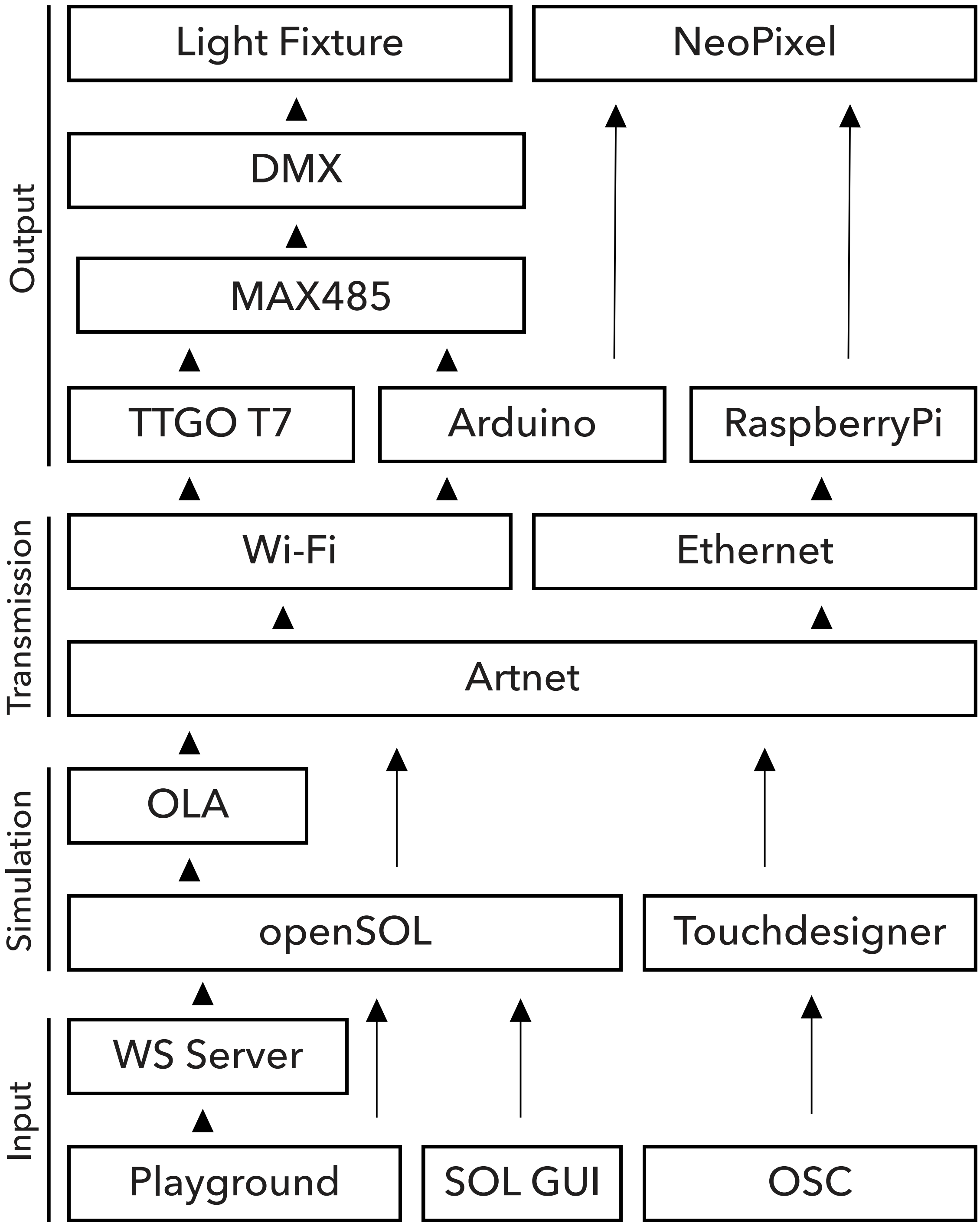


Figure 6.8: The flow of data throughout our software architecture.

6.5.4 Structure of Code

An overview of the whole structure of code and the data flow in our project can be seen in Figure 6.8.

6.6 Sunset Simulation

To probe into the representation of authentic atmospheres through digital means, we tried to implement the probably most photographed light situation: a sunset.

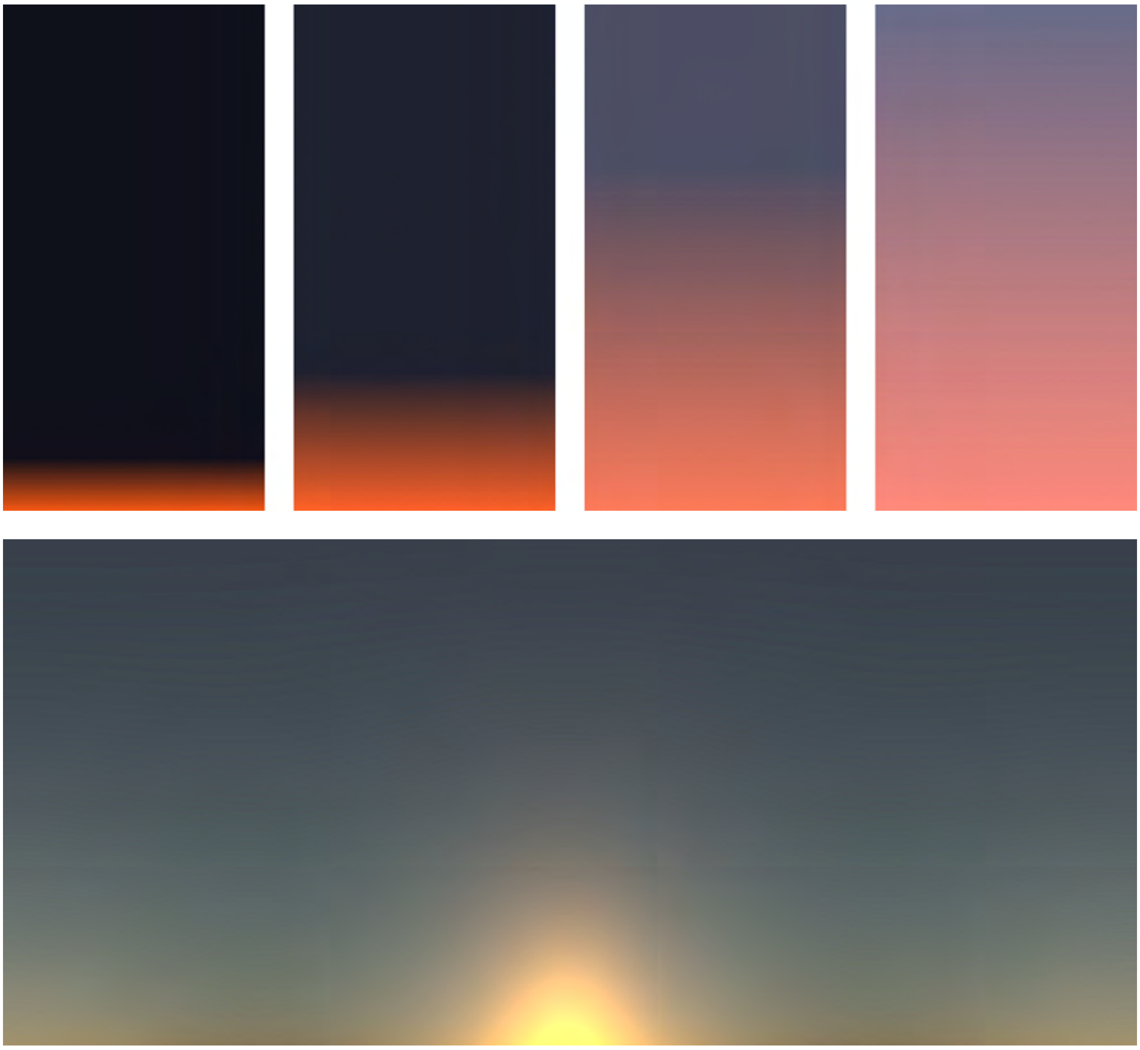


Figure 6.9: Frames from the original sunset based on mixing gradients (Top). Snapshot from the simulated sunset based on physical properties (Bottom).

6.6.1 Gradient

Based on an algorithm from our previous work we used gradients to simulate the colors of a sunset. By blending multiple gradients, we achieved smoothly fading colors on three axes (Figure 6.10).

Sky gradient or pitch: This gradient is mapped vertically to the LEDs by linear interpolation.

Time: This gradient transitions from lighter colors during the day to black at night.

Turbidity: This gradient fades between a saturated orange sunset and a relatively monochrome sunset that fades from blue to black.

The blending between the different colors is implemented with a simple linear mix of each color component. While we do the color mixing in the RGB-color space with one byte per color, using other color spaces, such as HSL, might result in a more natural transition of colors.

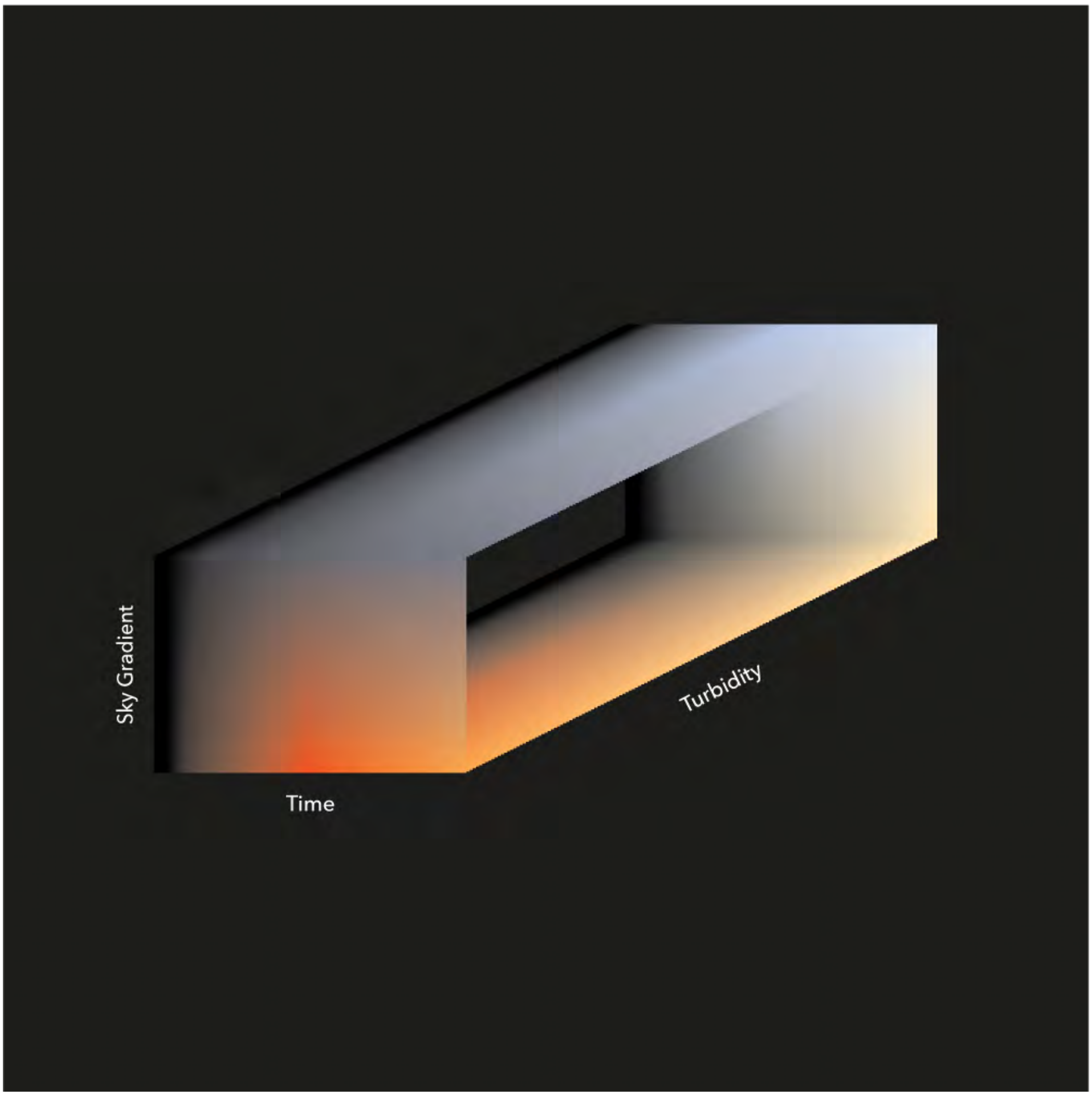


Figure 6.10: A cut through the color space of the gradient sunset.

6.6.2 Physical Model

While the gradient model worked and resulted in beautiful color transitions, it did not feel like an actual sunset as the colors and transitions were too perfect to be authentic. There was no noise or unexpected colors like one would see in an actual sunset. Furthermore were the colors randomly chosen and had no connection to real-world light settings.

To create a more realistic implementation of the sunsets that could be changed easily depending on real-world properties, we looked for algorithms representing real skies. We found different algorithms, primarily used in computer graphics for 3D rendering or games.

The two most used models are by Preetham *et al.* and Hosek and Wilkie [94], [95]. Instead of implementing these models ourselves, we created an abstraction layer on top of the open-source library SunSky [96]. We wrote code to interface from our software stack, *openSOL*, with the library written in C++.

6.6.3 Playing With Code and Sunsets

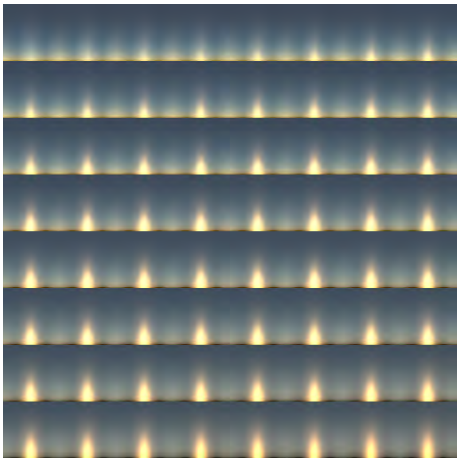


Figure 6.11: Sun position model sequence.
Time 6:24 AM, 0° 0' 0" N 0° 0' 0" E, Ground Albedo (0,0,0), Turbidity 1-9 in steps of 0.5

We developed a small test program that generates images for varying inputs to explore how the changing of values results in different sunsets and light phenomena. This quick iteration also made it easier to see the change in sunsets than directly outputting the lights in our lamps. Interestingly it is quite hard to see differences between different subtle changes without direct comparison. Furthermore, it is quite hard to mentally map the lights to the corresponding math to understand if the models are correct.

To explore even more light situations, we generated overviews of different parameters, for example, changing the turbidity but keeping other parameters the same (Figure 6.11).

In the process, we explored different representations of the sky-dome. Mappings like spherical or panorama are quite common in computer graphics. However, we explored some more unusual ones, such as an algorithm in which every pixel column in the image is mapped to a time of the day (Figure 6.11). Alternatively, an extension to this where the sampled column moves with the sun. Some of the algorithms resulted in quite artistic expressions. Even though they do not represent a “real” light phenomena, they still carry an artistic and poetic value. In some cases, this helped to overcome the interpretation of the images as sunsets and to see them as something new and allowed focusing more on how the images feel and what colors and patterns there are than to see them as typical sunsets.

6.6.4 Translation to Light

To represent the sunset in our light sources, we sample values from the sunset. For each LED, we sample a point in the sky hemisphere. By slightly changing the pitch of the view angle for each LED in a column and the yaw angle for each column, we get a 2D fragment of the skydome in the light source. Figure 6.12 shows a simplified version resulting in a 1D representation of the sky.

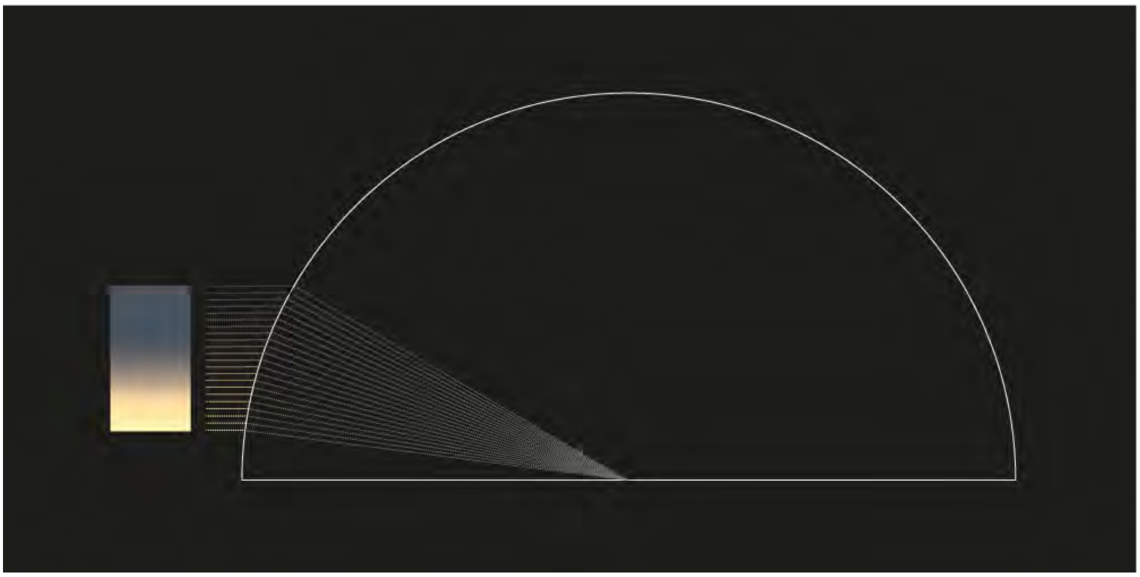
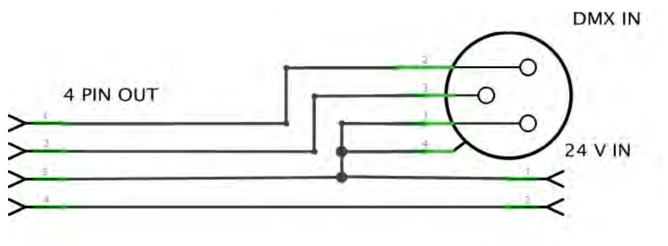


Figure 6.12: Simplified sky sampling.

6.7 Professional DMX Lights

This section describes experiments using professional light fixtures and required preparations.

(a) The box containing a DMX to four-pin circuit.



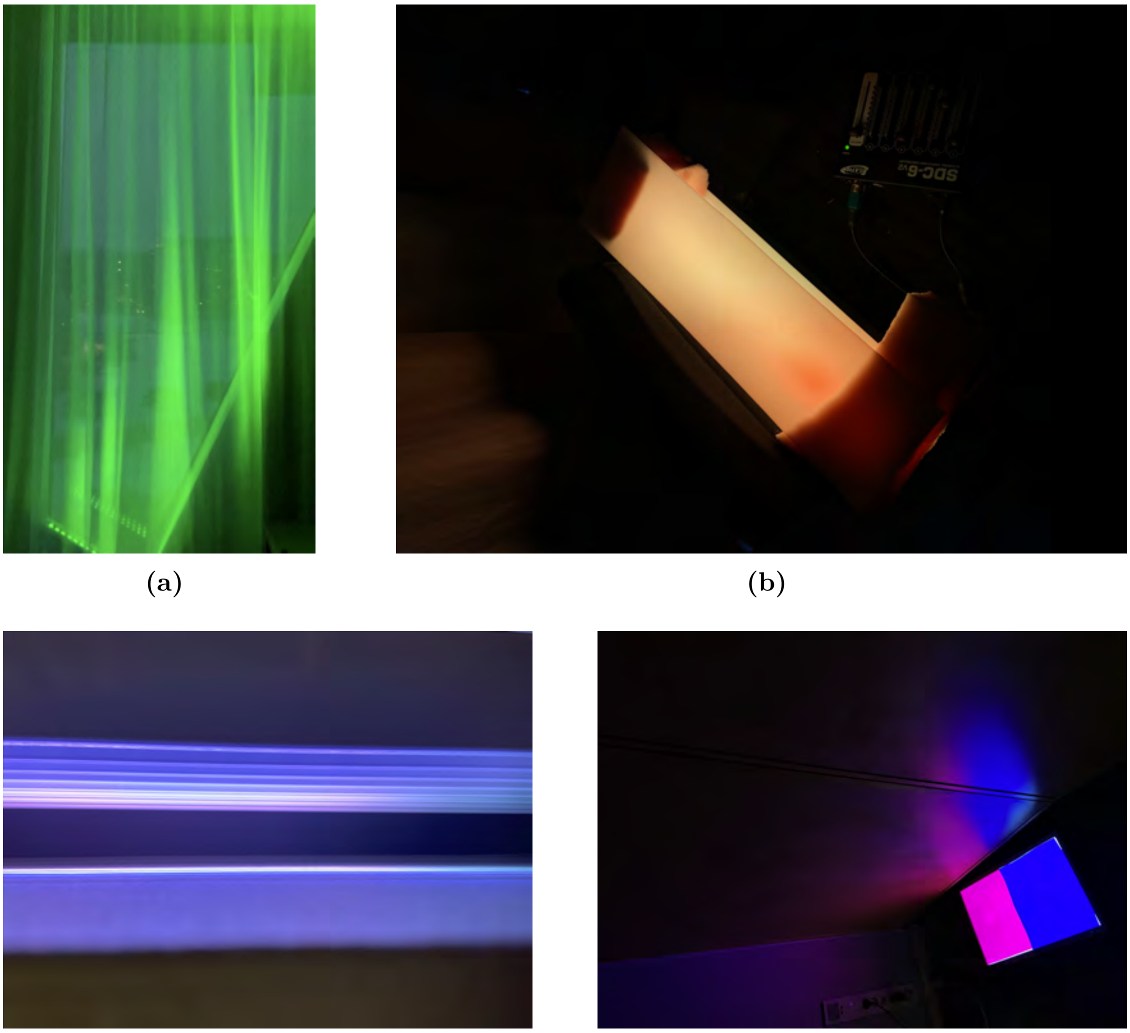
(b) The DMX to four-pin circuit.

Figure 6.13: The DMX four-pin adapter.

6.7.1 DMX to Four-pin Adapter

We received three light fixtures with no regular DMX inputs but instead a waterproof connector with four pins. We had no way of utilizing these lights without the connector and could not find a commercial one, so we built our own.

The four pins of the lamps carry the DMX signal on two channels and 24 V DC power on the other two. To accommodate this cable type, we created a circuit that takes in a DMX signal and 24 V and outputs the four channels (Figure 6.13b). To secure the circuit, we placed it in a box (Figure 6.13a).



(a) (b) (c) (d)

Figure 6.14: Various projections, reflections and diffusion of light.

6.7.2 Colored Curtains and Radiant Radiators

As our first engagement with light, we explored how different materials and structures influence the creation of colors and patterns. For this purpose, we used one of the DMX-controlled LED wall washer lights (Figure 5.2b) and directed its light onto different materials.

One of the first observations we made was that the light from the lamp we used was not single-colored. The lamp consists of a series of LED lights where each controllable unit has a red, green, and blue LED. As these LEDs are relatively far apart, their light is not always seen as their mix but sometimes as a gradient between the colors.

This was especially noticeable when shining the light through a curtain. The folds of the curtain reflect the different light colors with varying intensities; therefore, gradients of colors emerge (Figure 6.14a).

Another notable observation is how light textures emerge and change when the light is directed through a pattern. We lit up a wall by directing the light through the bars of a radiator. As the radiator has a reflective white color, the light created an interesting pattern (Figure 6.14c).

In addition to the previous explorations, we tried different surfaces to diffuse the light. This removed some of the mentioned light interference (Figure 6.14b).

6.7.3 Sky Replica

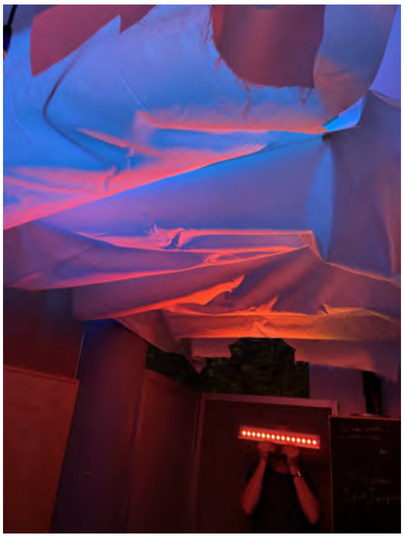
Inspired by how sunsets project their light on clouds in the sky, we started thinking about how an artificial interpretation might look. A big piece of white fabric was attached to a wooden frame to mimic the wavy and flowing cloud formations. On each of the two short sides of the frame, we mounted a DMX wash light. The whole rig was then mounted to the ceiling in our darkroom.

We used the light control board borrowed from LOB to control the lights and explore different color combinations. In addition to the colors, we experimented with different angles on the wash lights. By pointing them upwards, the light reflected from the ceiling and lit the fabric with soft gradients. When the light was pointed directly onto the fabric, the folds in it blocked the lights differently, resulting in sharper color transitions.

To recreate the sunset from a previously taken photo (Figure 6.15c) we set one of the lights to a blue tone and directed it to the ceiling to mimic the indirect light from a blue sky. The other wash light was directed onto the fabric with an orange tone to mimic the color of the setting sun. This resulted in a pattern similar to the one seen in the cloud illuminated by the sun. Figure 6.15a shows how the prototype has a different expression depending form what side one looks at it.

We also moved one light under the hanging cloth to simulate a sun setting. The result can be seen in Figure 6.15b.

(a) Images of the sky replica prototype in an attempt to mimic the sunset from figure 6.15c.



(b) Sky replica prototype lit up in a combination of indirect light from the ceiling and direct light from below.

(c) Image of a vivid sunset with an interesting cloud formation.

Figure 6.15: The Sky Replica prototype.

6.8 Ambient Window

During the Preparation phase, we found different sources of inspiration. One of these was Perks and his Youtube channel DIY Perks [97]. Perk's videos are focused on repurposing old technology to create new inventions. In one of his videos, he uses parts from a disassembled monitor to create smooth and bright light sources [98].

6.8.1 Layers of a Monitor

Inspired by the idea of up-cycling otherwise unusable technology, we decided to do the same as Perk and disassembled a broken monitor. During our project, we disassembled multiple different screens and salvaged parts. This is a general description of the parts found:

An LCD monitor consists of a frame, an LCD panel, backlighting, and electronics for control and power.

The parts we were interested in were the backlighting layers. Behind the LCD panel are several sheets of plastic to diffuse and direct light produced by light sources at the side of the screen. The light sources used differ depending on the monitor. Most common in modern screens are LED lights. In old monitors, halogen lamps are often found. These contain toxic materials and need to be handled with care and recycled separately.

The plastic sheets that direct and diffuse the light are slightly different depending on the monitor model. All screens contain a roughly 7 mm layer of acrylic plastic that contains a pattern of etched dots. These dots direct the light from the side where the light sources are to the front. Different monitors have different patterns. Some have a higher density in the center and the edges to reflect the same amount of light over the whole surface. Through experiments, we found out that the etched dots in the acrylic sheets only refracted the light coming from two sides, most often the long ones, of the window. The light from the other sides has nearly no effect on the illumination of the screen.

The first layer results in a pattern of light dots; a diffusion layer is used to diffuse the light. On top of this, a prism sheet straightens the light direction to the front, making it appear brighter and reducing the view angle [99]. Another diffusion layer is placed on top of the prism sheet.

6.8.2 Technology

In the video, Perk uses a non-addressable white LED strip. As we wanted to change the light and explore different colors, we attached an addressable RGB LED strip with 60 diodes per meter to the side of the thick plastic sheet. Addressable means that each diode on the strip can be controlled individually. By stacking the diffuse and the prism sheet on top of each other and securing the layers and LEDs with electrical tape, we were able to create a secure light artifact.

The beam spread angle and distance between the diodes results in an unlit area between the diodes closest to the edge (Figure 6.18). To hide this, we masked it out using black electrical tape.

6.8.2.1 Control

To control the LED strip, we first used an Arduino Uno. As the Arduino's 5 V pin can only handle ~0.2 A, we used a second 5 V 6 W switching adapter to power the LED strip. The required current is roughly 3.48 A (~60 mA * 58 LEDs).

Later we replaced the Arduino with a Raspberry Pi to be able to control the *Ambient Window* over Wi-Fi. We experienced flickering in the LED strips when the cable connecting Arduino and LED strip was longer than 1 m. Therefore we conducted a series of experiments to solve this.

We first assumed that the data signal got corrupted because it lay close to a 230 V power cable. Therefore we tried to insulate it with metal foil, but this resulted in no difference in flickering.

On the website of the LED strip producer is a warning that users should add a resistor in front of the data input and a capacitor between +5 V and GND [100]. We added these elements, but this resulted in no difference in flickering.

We also tried different cable types, but it made no difference in the signal.

Finally, we realized that the LED strip is powered with +5 V and the data signal from the Raspberry Pi is only +3.3 V. This results in a noisy signal that is misinterpreted by the LED strip, and therefore it flickers. Unfortunately, we had no way to step the voltage up. Finally, we got a tip from Gunnar Oledal to use the first LED in the strip as a buffer. This works by inputting GND and Data into the first LED but reducing the voltage to 4.3 V through a signal diode [101]. The second LED then receives normal +5 V and GND and the data signal from the first diode, which is now also 4.3 V (Figure 6.16). This is within the margins of allowance for 5 V powered LEDs.

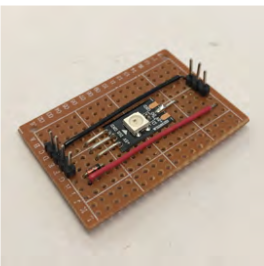
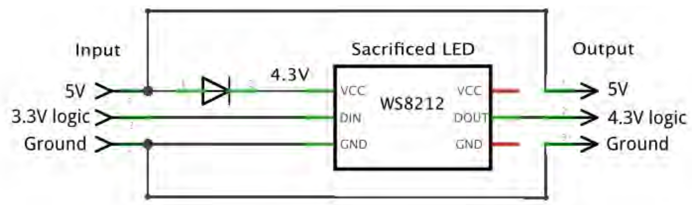



Figure 6.16: Image and schematic of sacrificial diode hack.

This experiment worked but required an additional LED in front of the LED strip. We used this for most of our process but changed to a dedicated step-up circuit for the final design.

Figure 6.17: Bright areas appearing in in areas under pressure.

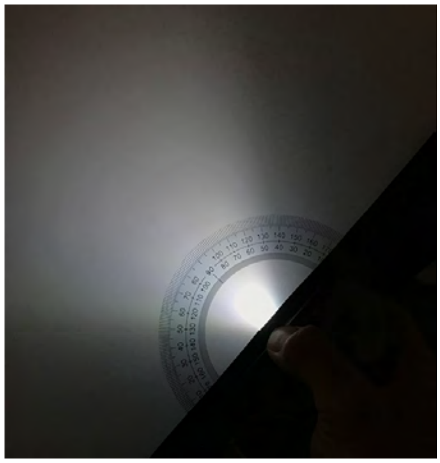


Figure 6.18: Spread angle of Neopixel LEDs.

6.8.2.2 Water Adhesion

A problem in the *Ambient Window* prototype assembly was bright areas appearing where pressure was accidentally added (Figure 6.17). It likely happened between the acrylic sheet and the prism sheet. The bright area would disappear when the prism sheet was raised and then lowered again. We considered how to prevent this from happening. The affected area appears brighter than the rest of the surface, so we started experimenting with attaching the surfaces. One theory we had was that we could accomplish a unison surface by removing the air behind the layers. Inspired by how adhesion sheets are applied to Ultimaker 2+ 3D printer, we wet the acrylic surface with soap water and then applied the prism sheet on top [102]. A plastic scraper was then used to sweep out water and air bubbles.

Initially, it seemed like it would work, but after finishing the process and adding lights to the sheet's side, we realized that did not resolve in the finish we were looking to get. The surface could be described as evenly uneven. We decided to exclude water adhesion and live with the few bright areas that would appear.

6.8.3 Experiments

Multiple experiments were carried out using the *Ambient Window*.

6.8.3.1 Gradients

One of the initial explorations using our first *Window* prototype was the creation of gradients. We used the mentioned potentiometer input to change the colors on each side of the *Window*. This resulted in interesting gradients.

At this point, we realized how far the representation of colors diverges from screens and LED strips. The RGB value representing a color on a screen is not directly translatable to an RGB LED; one reason for this is that the diode cannot represent black. Black on a screen is accomplished by reducing the brightness to zero; doing so on an LED results in the absence of light.

6.8.3.2 Move a Dot

We programmed different patterns and animations to explore the fidelity and visual representation possibilities of the *Window* prototype. In one of these algorithms, we tried to simulate a virtual circle that moves over the surface. We did this by assigning each LED an x and y position between 0 and 1 and calculating the distance to a moving point in this space. We tried two visualizations of this distance: Scaling the brightness in relation and turning the LEDs on if they fell in the radius around the point.

The LED strips we use for the frames have 60 LEDs per meter. Therefore, there is a distance of 16.6 mm between each LED. The spread of each LED is about 80° (Figure 6.18). The distance together with the spread angle turned out to be too sparse to show the moving circle.

6.8.3.3 Yo-Yo Window

One of our first interactive experiments was to let people distant from us control our *Ambient Window* light source. This experiment was similar to the *Yo-Yo Machines* from the *Interaction Research Studio*, even though we were not aware of this at this point [103].

To have the *Ambient Window* visible at all times, we hung it on the wall next to our workplace. We programmed it with a sunset that was changeable through a hidden page in our playground and handed out links to people we knew.

We collected feedback by talking to the people controlling the light. The received response was that it was hard to anticipate what changed as the visualization on the screen and real-life were not the same.

We felt that it was nice to have a piece of decoration that contained subtle hints when people were thinking about us or tried to communicate with us. Cox refers to this as peripheral interactions [104].

As this version of the input did not yet include smoothing behavior, some movements, especially when people moved the input handle fast, resulted in flickering light, which we perceived as annoying.

6.8.3.4 Sunset Window

To explore the idea of using a phone as the input device to control the *Ambient Window* further, we decided to let more people control it. For this purpose, we built a double-sided light *Window* and hung it behind a glass partition inside our working space. In this way, it was visible from the public library but not physically reachable.

By hanging a poster with a description of our project and the request to send us their thoughts next to the *Sunset Window*, we hoped to collect feedback. Even though we did not get any feedback through our website, the experiment helped start conversations with different bypassers and made them curious about our project. As one of our main goals is the start of a conversation about light, we see this experiment as a small success.

Through this experiment, we also had to face different technical challenges and increase the fidelity of the *Sunset Window* and the input so far that people could use it.

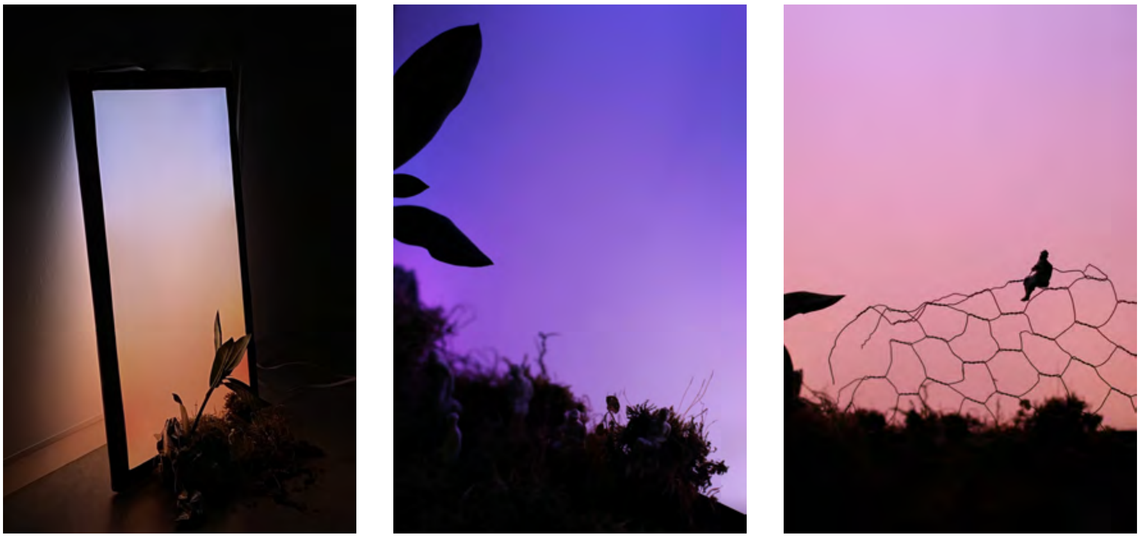


Figure 6.19: Photo shoot using the window prototype as backdrop.

6.8.3.5 Gradient Sky Photo Shoot

Gamboa reached out to us with the idea of using our window with the *Sunset Simulation* algorithm as a backdrop in photographs of scale models in a modeled environment. Different environments were built using plants, moss, grass, bricks, and chicken wire (Figure 6.19). We prepared a *Window* prototype with the sunset algorithm through *openSOL* and placed it behind the models. The *Window* light illuminated the modeled environment resulting in interesting light phenomenons.

As we so far focused on generated gradients through the sunset simulation, we were missing a way of easily change the colors in the window. After this experiment, we decided to look for good ways of controlling the *Windows* in an informed way.

6.9 Ceiling Tile

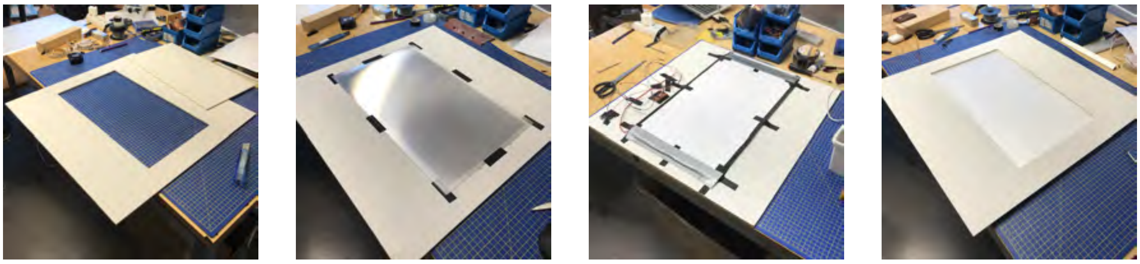


Figure 6.20: Process pictures from constructing the Ceiling Tile prototype.

Based on the *Sunset Window*, we further thought about different places such a light could be useful. The rectangular form reminded us of ceiling tiles that are often used in office buildings. In our building, they are used in the restroom. First dismissed as a joke, we quickly realized that the restroom might be an excellent place for such a light and especially for people to try it out. Participants would spend some time at this place anyways; the room can be darkened so that the only contributing light is the *Ceiling Tile*, and it is common to use the mobile phone while in the restroom.

The *Ceiling Tile* was created from a 590×590 mm foam board sheet. A rectangle was cut out in the middle of the square with a 20 mm margin to the plastic sheets (Figure 6.20). This was done to hide the unlit cone that appears close to the LED strip. The plastic layers were attached with electrical tape, one by one.

Since this prototype was meant to be replacing a tile in the ceiling, we did not want any light to slip out in the back. We tried placing different materials behind the acrylic sheet but found that a sheet of glossy white paper resulted in the most significant increase in perceived illuminance. Placing a mirror on top of the acrylic sheet should, in theory, make the light bounce back, but it did not result in the same perceived increase.

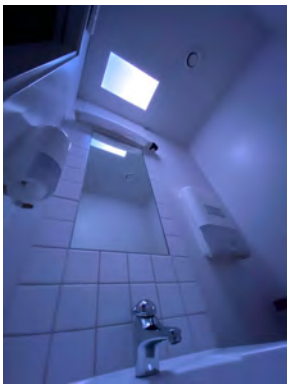
6.9.1 Hallway

Before mounting the *Ceiling Tile* in the restroom, we mounted it in an enclosed hallway in our studio (Figure 6.21). The other lights in the hallway were turned off by covering the motion sensor. A DMX wall wash fixture (Figure 5.2c) was also set up, and both lights were connected and controlled with*openSOL*. We used the sunset simulation function and gave the DMX fixture the nearest color of the gradient in the *Ceiling Tile*. Facing the DMX fixture to the wall created a nice mix of indirect light from the light fixture and soft direct light from the *Ceiling Tile*.

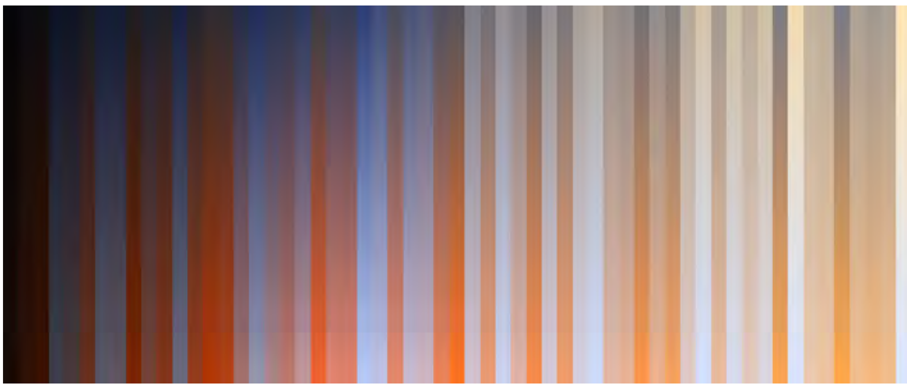
Figure 6.21: Hallway Ceiling Tile experiment.

6.9.2 Toilet Experiment

After first experimentation in the hallway and making sure that the prototype works, we put it up in the restroom ceiling in the Kuggen Chalmers Library. To prevent the normal light in the cabin from turning on, we covered the motion sensor with black tape. As our light had the exact measurements as the ceiling tiles, the installation was straightforward (Figure 6.22a).



(a) Ceiling Tile mounted in a restroom.



(b) Each slice represents a liked light setting.

Figure 6.22: The toilet experiment.

The *Ceiling Tile* was connected to the same network as a Raspberry Pi. The Raspberry Pi was used to delegate incoming data from our playground, which was used as input to the tile. Unfortunately, the signal dropped quite often and unexpectedly, which led to times in which the light would not respond to interactions. We had implemented an idle state with bright light; therefore, this did not lead to darkness in the restroom but just unsatisfying user experiences.

To make people aware that an experiment was ongoing, we added a poster on the room's door. We added a second poster on the inside of the door (A.6). The poster on the inside contained a short description of this experiment and a QR-code. The QR-code led to the *Playground's* website, which was used to control the light. In this way, people could interact with the light once they scanned the code.

To evaluate how many people interacted with the prototype and see what lights they chose, we implemented an anonymous collection of the movement patterns from the input. We furthermore implemented a heart button on the playground (Figure 6.23). With this button, users could show that they liked a light setting. An overview of the liked settings can be seen in Figure 6.22b. Each vertical slice represents a gradient of the liked light setting.

Figure 6.23: The Toilet Experiment GUI.

As the library had very few visitors, we only got sparse feedback and, unfortunately, none through our chat. In total, we had about 25 unique users, but the *Ceiling Tile* acted as a conversation starter with several people we met and made them curious about our project.

After having the experiment set up for a while, we were approached by a person from the library. They were wondering about the experiment and why we had not asked them for permission. While we at first thought they did not like that we set our experiment up in their restroom, we realized that they only wanted to know what it is to make sure that the accessibility of the restroom is not reduced. They furthermore told us that they could have advertised our project if they had known earlier.

6.10 Bendable Window

Usually, the acrylic sheet in the screens we disassembled was 7-10 mm thick, but we disassembled one screen with a 2 mm thick acrylic sheet. The thicker sheets are rigid and cannot be bent, but the 2 mm thick one was thin enough to bend. Also, unlike the previous screens we disassembled, this acrylic sheet was lit up from the short sides instead of the long ones. We took the opportunity to create a bendable version of the *Window* concept. Each short end of the 2 mm acrylic layer was clamped

Figure 6.24: The Bendable Window prototype.

Figure 6.25: The frosted acrylic rod prototype.

together between two pieces of wood and screws. The wood pieces were previously prepared with drilled holes for the LED strip, and the LED strips were attached to the wood and covered with duct tape. The LED strips were, finally, connected to each other and controlled by an Arduino.

The wood pieces made it easy to bend it into various radii. The panel lit up well, even when it was bent. The thin acrylic sheet placed between the wood pieces created a nice floating feeling.

Finally, we attached a prism and a diffusion layer to the acrylic sheet and clamped on the wood again. It looked acceptable, but the layers would stretch uneven when it was bent, causing the layers to separate. This could have been solved by adding tape on the edges, but it removes the floating feeling. The prototype has the best visual appearance when only using the acrylic sheet as there is no tape and nor visible gaps between the layers.

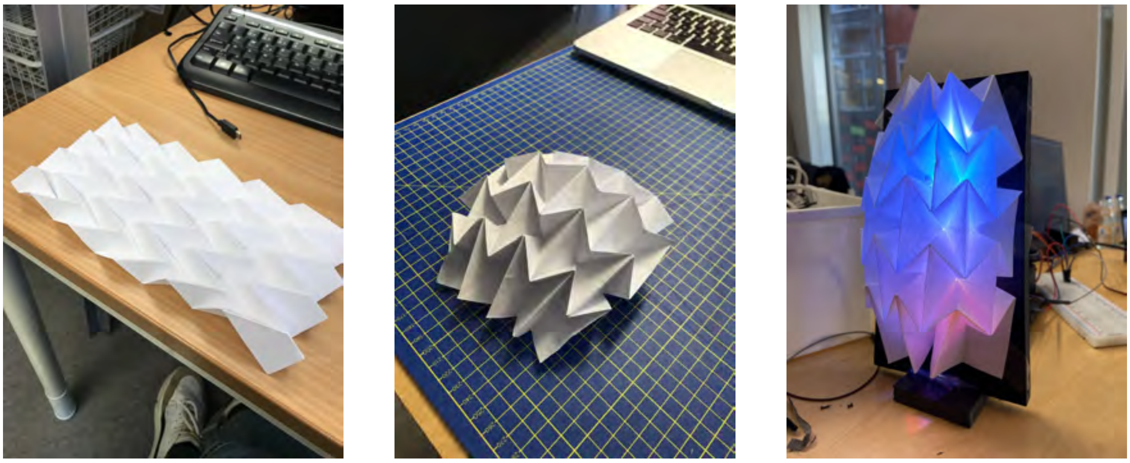
6.11 Frosted Acrylic Rod

To experiment with how light travels through glass, we created a small artifact. This artifact consists of a transparent acrylic rod of 110 mm length and 10 mm diameter (Figure 6.25). This rod is frosted on the top and about 15 mm on the sides around the top by roughening the surface with sandpaper. It is inserted into a 20 mm height wood block which has an LED attached from the bottom. As the acrylic rod had imperfections and air bubbles, the light slightly reflected even in the not frosted parts. However, most of the light was emitted from the frosted area at the top.

We thought about using artifacts similar to this one as representations of ground reflections by spreading multiple rods on the ground. As their resolution was limited to only one pixel, we decided against going forward with this. The one prototype we had built was then only used as a debug LED.

6.12 Origami

Intending to create a lamp that can change shape, we searched for inspiration on rice lamps and different origami patterns to alter the shape of the lamp-shade. Two origami patterns that seemed interesting were *Miura Ori* (Figure 6.26a) and *Glide Reflections* (Figure 6.26b) [105]. The properties of the *Mirua Ori* pattern is interesting as it expands and shrinks in the direction of the plane. The *x-axis* grows as the *y-axis* grows and vice versa. Structures with these properties are called *Auxetic structures* [106]. The other pattern, *Glide Reflections*, is more complex. Pesenti *et al.* describes it as a form of symmetry with the combination of "a reflection around a line" and "consequent translation along the same line" [107]. The disposition of the unit does not continue in a straight line. Compared to *Miura Ori*, which is a form of *V pleat* origami, the surface is flexible in all directions allowing it to be shaped into more complex forms. An example of complex shapes and dynamics that can be accomplished is the *Shrumen Lumen* project by IDEO [108]. Sphere-like shapes and can be accomplished by constraining parts of the pattern.



(a) Miura-ori pattern created with an A4 paper paper.

(b) Glide Reflection pattern created with an A4 paper.

(c) The Beating Heart prototype.

Figure 6.26: Origami prototyping.

6.12.1 Beating Heart Light

We wanted to explore how we could use the *Glide Reflection* pattern in creating a dynamic and shape transforming light source. We attached the fold of an A4 paper in an elliptic shape onto a piece of cardboard with seven Neopixel LEDs beneath. A string was connected, through a hole in the cardboard, to the middle of the folded paper in one end and a step motor via a reel on the other end. To prevent the motor from pulling too hard on the string and breaking it, we added a rubber band in the middle of the string. The motor was controlled using an Arduino Uno, and we chose a pulsating pattern for the control of the motor. The light was just set to a gradient between red and blue.

Through the colors and the contraction and expansion of the origami, it looked like a beating heart. The appreciative qualities of the artifact could have been increased with less sound from the motor.

We wanted to go forward with this prototype and expand on it or even make it part of the final exhibition as it showed great potential in transferring emotions through light, movement, and changing shape. Unfortunately, our time frame was too small to build a bigger or more polished prototype. We would probably need multiple iterations more to arrive at a state that would have been usable for the exhibition.

6.12.2 Scale-up

After creating the *Beating Heart* prototype, we continued to iterate on how we could use the knowledge gained from the beating heart prototype and scale it up. The beating heart prototype was relatively small, and we wanted to investigate what we could achieve with larger origami pieces. The previous origami folds we made were done using regular A4 paper, but to get a sense of how the dynamics of the origami changes when it gets bigger, we started folding bigger pieces of paper. We made bigger versions with the same amount of folds and bigger versions with the same size of the folds, as can be seen in Figure 6.27. The size of the paper for the big folds was 914×914 mm. The one with the same amount of folds had similar properties as the smaller version, just bigger, while the one with the same size of the folds, on the other hand, felt very fluid. The relationship of the tension built into the folds and its weight allowed it to be shaped in various ways.

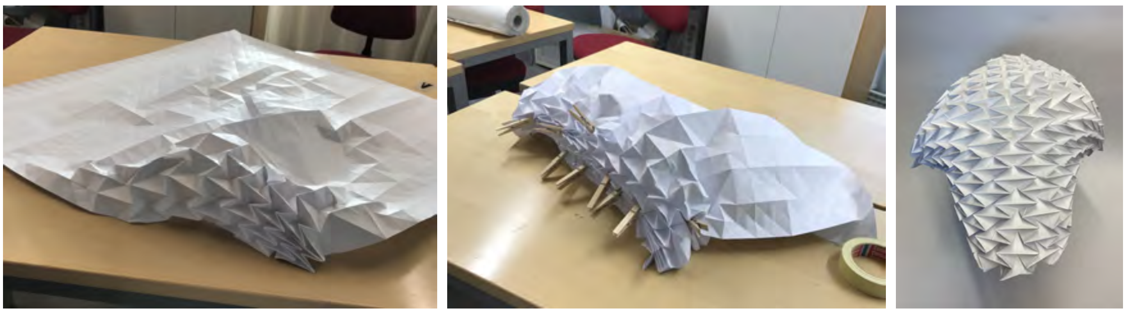


Figure 6.27: The process of making a glide reflection pattern.

With the big version of the *Miura Ori* pattern, we tried different arrangements to light up the formed valleys and mountain creases using LED strips as a follow-up and iteration on the sky replica prototype. With the big version of the *Glide reflection* folding (Figure 6.27) we played around by constraining it and applied pressure to various parts of the fold to see what shapes we could create and what constrains it.

We would have loved to integrate the same motion behavior from the heart prototype or even multiple motors pulling on different edges. We even thought about integrating capacitive touch sensors to allow users to interact with the prototype and let it shrink back when touched. We had to constrain ourselves at this time in the project as we entered the physical manifestation phase.

7

Phase III: Physical Manifestation

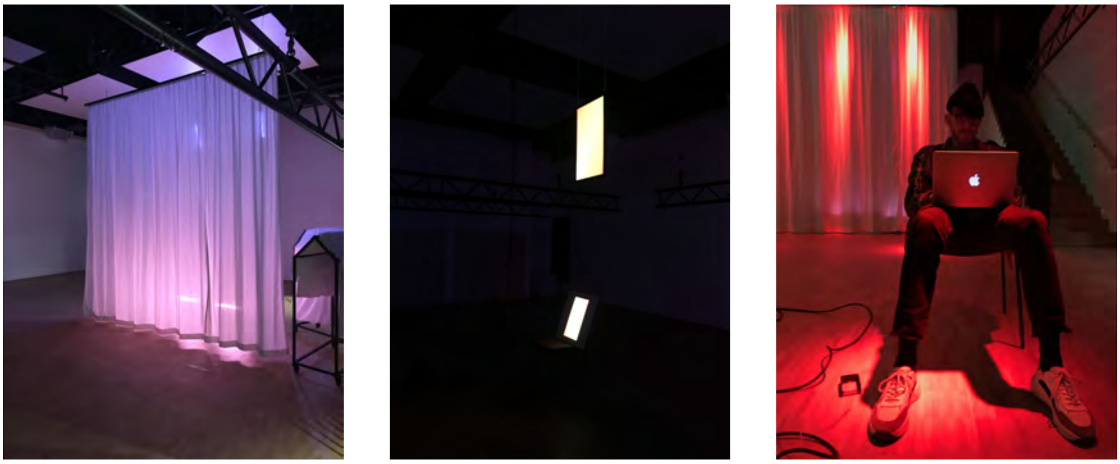
In this project phase, we used the gained knowledge from the concept exploration phase to design, build, and host an exhibition. The exhibition was used as a showroom and platform to communicate and discuss the idea of ambient atmosphere sampling and light atmospheres as memory bridges. For this, we developed an interactive installation. A series of ambiguous posters were created as accompanying artifacts to act as mirrors into our process and spark new ideas for artificial lighting.

Our knowledge of working with light and creating light technology was reflected in the final artifact: an installation with seven *Ambient Windows* and an analog *Atmosphere Player*. We used the context of an alternative reality without virtuality to make the artifacts re-interpretable by viewers.

7.1 Exhibition Space

Our exhibition was hosted at the AWL Studio in Gothenburg. The location consists of a roughly 180 m^2 hall. We visited the exhibition space early in the process and met with Jonaz Björk, the digital set designer at AWL. For this visit, we prepared our already built prototypes and brought them to the space together with the DMX light fixtures. Björk showed us around the space, introduced us to the controllable rigs in the ceiling and how to adjust the lights. He also showed other equipment belonging to the room, such as different curtains and curtain rods, power and ethernet outlets integrated into the floor, furniture, etc.

After the tour, we were given free rein to test our light sources in the room. Inspired by previous prototypes and experiments of lighting up fabric with direct and indirect light, we experimented with lighting up a 4 m tall curtain. We attached a curtain along with one of the ceiling rigs and mounted two wall washer DMX lights (Figure 5.2b) to the rig next to the other one. Two other DMX wall washers (Figure 5.2c) were directed onto the curtain from the floor (Figure 7.1a). We controlled the lights with *openSOL* through our *Wi-Fi to DMX node*. We then tried different angles on different sides of the curtain. We were able to create subtle and smooth gradients in the curtains, but there was a lot of light pollution spread into the room from the DMX fixtures.



(a) Curtain gradient in the AWL studio.

(b) Two window frames in various heights.

(c) Engaging with light.

Figure 7.1: First AWL exhibition space visit.

Next, we experimented with hoisting the *Window* prototype using the ceiling rig. The *Ceiling Tile* prototype was placed on a chair next to the window to simulate how it would look to hang the lights at various heights (Figure 7.1b). At this point, we could only control both simultaneously, resulting in both showing the same colors and patterns.

Spending a day in the room gave much value to the process. Instead of only having a mental model through numbers and functions of the room, we had the time to engage with the room and explore how our lights create different settings in context. Before, in between, and after our experiments in the room, we sat down on the floor working with other tasks. We used the built-in light system to flood the room in various colors and combinations (Figure 7.1c). We left the room with much inspiration but also anxiety about the potential of the built-in light system compared to our own. We were impressed by the built-in system and what it was capable of, but we decided to move on with our own lights as we wanted to focus on the light artifacts themselves and not the room.

7.2 Shaping the Exhibition

The shape, direction, and stance of the exhibition changed severely over time. We knew from the beginning that we wanted to keep the design space as open as possible and therefore not over-define the knowledge in the exhibition but present it in an ambiguous and inspirational way.

7.2.1 Talk with Kollision

Early in the project, we sat down with Andreas Lykke-Olesen and Rune Nielsen from *Kollision* to discuss different exhibition formats. We told them about our current ideas, and they talked about previous projects that could provide inspiration.

In the *Follow* project, they created a space having a shape of a cut open box [109]. The visitor could enter the space, and the lights would change depending on where people stand. Focusing the light to a limited area is an efficient way of creating rooms in rooms. In our proposal to them, we explained a concept where we wanted to light up a room with objects commonly found in homes (A.1). In our example, we used a bedroom. Lykke-Olesen and Nielsen proposed that we try to create a more conceptual space instead of a real room. They mentioned the *Cornell Cube*, a virtual room often used to explore render engines, as an example of a conceptual space [110], [111]. They also discussed if it would be more interesting to put other objects in there that are not as symbolic as a bed in a bedroom, such as the *Stanford Bunny* [112]. They also proposed the use of projections and projection mapping as a complement to light sources. As an example, they talked about a project they were part of called *Earth Lights and Ping-Pong with the Sun* [113]. In that project, the designers worked a lot with physical textures and projection to create an engaging environment and experience.

7.2.2 Cut Cornell Cube

Inspired by the talk with Lykke-Olesen and Nielsen, we explored the idea of building a cut-open cube and light it up from the inside. One idea was to even model this cube similarly to the *Cornell Cube* to reference 3D rendering and move it to the real world [110], [111].

7.2.3 Spatial Illumination

Another idea was to change the atmosphere in the exhibition space by lighting up the whole room. We considered hanging curtains in straight and circular curtain rods and illuminate them. We also wanted to place out different interactive artifacts in the room that also would affect the atmosphere. The interactions would result in a change of behavior of the artifact and room in total. An interactive element could, for example, be the string from the curtain blind experiment (Section 6.5.2.3)

7.2.4 Spirited Lights

Our exploration of the *Beating Heart* light led us to the idea of having many interactive lighting artifacts. We thought of seeing each artifact as an “animal” that has its own behavior but also a collective reaction to interactions from a visitor. For example, the *Beating Heart* light could contract when initially touched but later gets used to the user’s hand and then follows its movement. Visitors would need to learn how to interact with the artifacts to change the atmosphere. While we were intrigued by this idea, and we still think that this is design direction worth exploring, we realized that this concepts lacks communication of our core idea: sampling and representing atmospheres. Therefore, we decided to not follow this path.

7.2.5 History of Light

In a conversation with Gamboa, we developed the idea of having the exhibition as a museum of light. It would show past inventions of light, describe current trends like smart lighting, and show our artificial light proposals as a possible future. While this idea might have worked great to communicate our idea in a clear way, we thought that it described our concept too much as a next step in the evolution of light. We were afraid that viewers would take our proposal as the single next step and not expand the idea space on their own. One could say that this idea was too much *Showroom* and too little *Speculative* design.

7.2.6 Showing the Process

This idea diverges from the speculative nature of the exhibition even further and instead communicates our process in detail. This would have resulted in an exhibition in which we show all prototypes that we created and wanted to create. We decided against this as we would not have managed to build all prototypes in a high enough fidelity. Having low fidelity prototypes would probably not have communicated what we wanted to show. We believe that more polished prototypes work better to communicate with non-designers as the focus is not on the implementation but the complete design.

7.2.7 Alternative Reality Lab

Another idea we developed was to stage the exhibition as a testing lab of an alternate reality *Ambient Atmosphere* research project. In this lab, the researchers would have built a prototype of an atmosphere sampling device and would download the data to a device representing the atmosphere in light. While we did not choose this path, we used parts of it, especially the alternative reality bit, for our final exhibition.

7.3 Final Exhibition

The final layout and format of the exhibition is centered around an interactive installation. The installation is, in turn, surrounded by posters connected to the process. A conceptual graphic of the installation can be seen in Figure 7.3 and the layout in Figure 7.2. The main idea of this exhibiting is to evoke memories solely through light. Therefore, we call it *Bright Memories*.

7.3.1 Interactive Installation

The interactive installation consists of seven *Ambient Window* artifacts hanging in a half-moon shape from the ceiling on varying heights. Next to the formation of window artifacts, there is a pedestal with an interactive *Atmosphere Record Player* and four recorded *Atmosphere Tapes*.

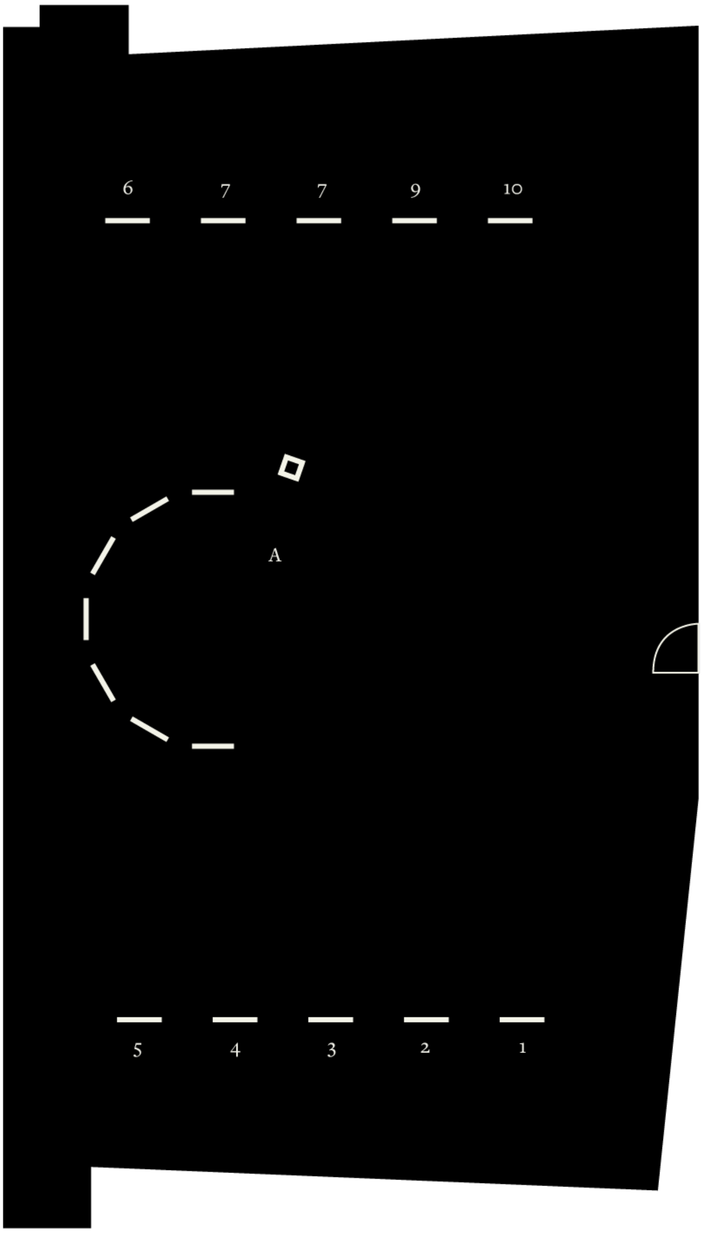


Figure 7.2: Map of Bright Memories exhibition space.
A: The Ambient Window Installation and Player.
1: About text.
2: Taken with a MacBook Pro.
3: Overcoming Reality.
4: Help! I screwed up the Math.
5: The Sunset Never Sets.
6: Creased Light.
7: Shapes Shape Shadow.
8: Framing the Light.
9: Illumination Vectors.
10: Colored Space.

Figure 7.3: Conceptual mood rendering of the interactive installation.

7.3.1.1 Final Ambient Window Artifact

The previous *Ambient Window* prototypes were made by attaching the components using electrical tape. For the final artifact, we redesigned it with more finesse. To move the focus away from digital technology, we sought inspiration in retrofuturism and mid-century modern design. We choose to use wood as a building material to enhance the feeling of a world of no virtuality. Wood is, at the same time, rather easy to work with. We produced wood frames that would fit around the plastic sheets and cover the technical parts.

The final *Ambient Window* artifact spreads light from both the back and the front, but it is not symmetrical as the double-sided *Sunset Window* iteration. The double-sided window prototype used the material from two screens; to maximize the material, we only used one acrylic sheet per screen instead of two. In this way, we did not only save material but also cut the thickness of the plastic parts by half. The less opaque diffusion layer is put on the backside of the acrylic layer, while the prism sheet is placed in the front following the more opaque diffusion. The more opaque diffusion layer was put in the front as it is a higher priority to have unison spread in the front. This means that the front and the back are not identical in this version (Figure 7.4). This is fine since the formation of the windows in the installation has a clear inside and outside.

The wood frames were made using 21×43 mm planed pinewood. The size of the plastic sheets is 310×485 mm; to allow for a 20 mm overlap, the outer dimensions of the frame were set to 360×530 mm. The wood pieces were cut in 45° using a miter saw. The acrylic sheets are 7 mm thick, but the LED strip is 10 mm wide. 10 mm wide and 20 mm deep slots were therefore routed out in the long frame pieces

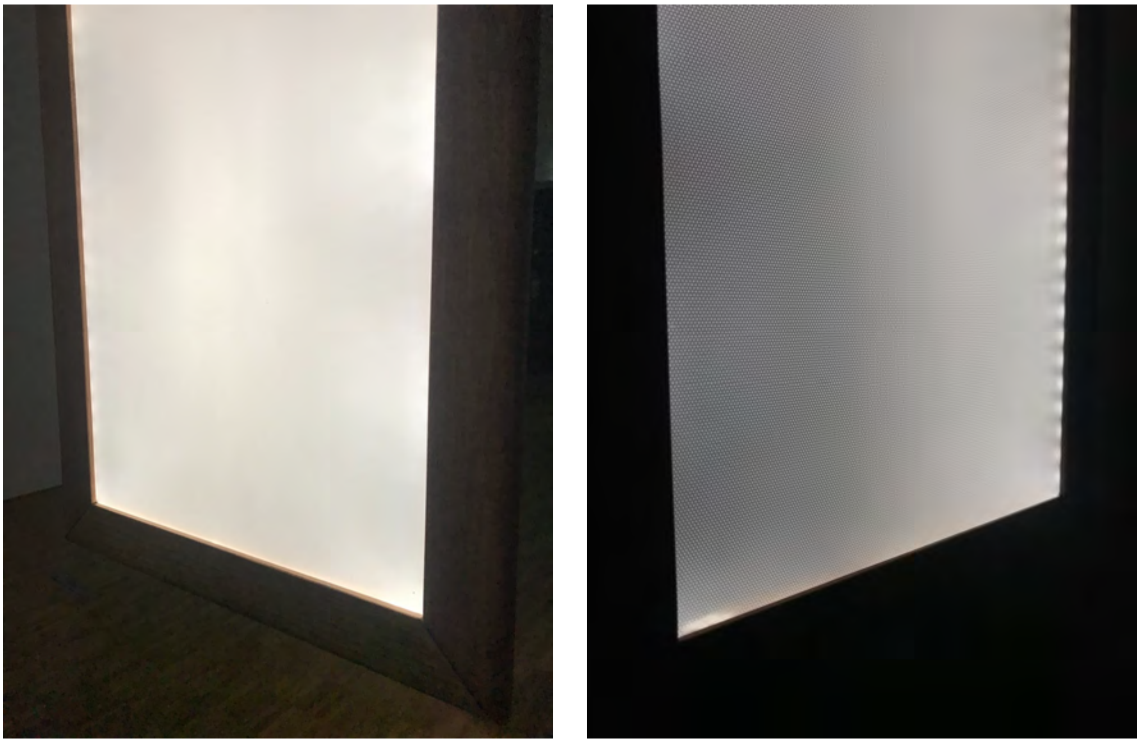


Figure 7.4: Front and backview of the Ambient Window artifact.

(a) The routed slot for the LED strips and plastic panes.

(b) A JST connector sunk into the wood frame.

(c) A stack of frame pieces.

Figure 7.5: Process photos of constructing the frame pieces.

(Figure 7.5a) using a handheld router and an 8 mm router bit. The top and bottom parts of the frame have 8 mm wide and 25 mm deep slots as it did not have to fit the width of the LED strip but had to have the extra depth for the wiring. Inspired by the mid-century modern furniture style, the outer brim of the frame was rounded using a 10 mm radius round over routing bit. A JST female connector is sunk into the top part of the frame (Figure 7.5b) and connected to a Dupont female connector on the inside of the frame to allow for a smooth assembly. For the mounting screws, ⌀2 mm 35 mm deep holes were drilled in the corners of the top and bottom pieces, therefore drilling into the side pieces. Two ⌀3 mm holes were drilled in the top piece of the frame for eye hooks. Finally, the frame was sanded using 180-grit sandpaper and treated with Herdins 711 Mellanbrun wood stain.

The final *Ambient Window* artifact is lit up by Neopixel RGBW LED strips with 60 diodes/m instead of RGB LEDs. A Dupont three-pin male connector is connected to the input side of the LED strip. A 390 Ω resistor is attached to the data cable between the connector and the LED strip.

The plastic layers and the LED strips are assembled with electrical tape, making sure that all the light from the diodes is projected onto the side of the acrylic sheet. The frame pieces are slid onto the plastic sheets, and the Dupont connectors on the top frame piece and the LED strip are connected. The frame pieces are mounted together using 3.5×35 mm Torx screws, and eye hooks are screwed into the previously drilled holes.

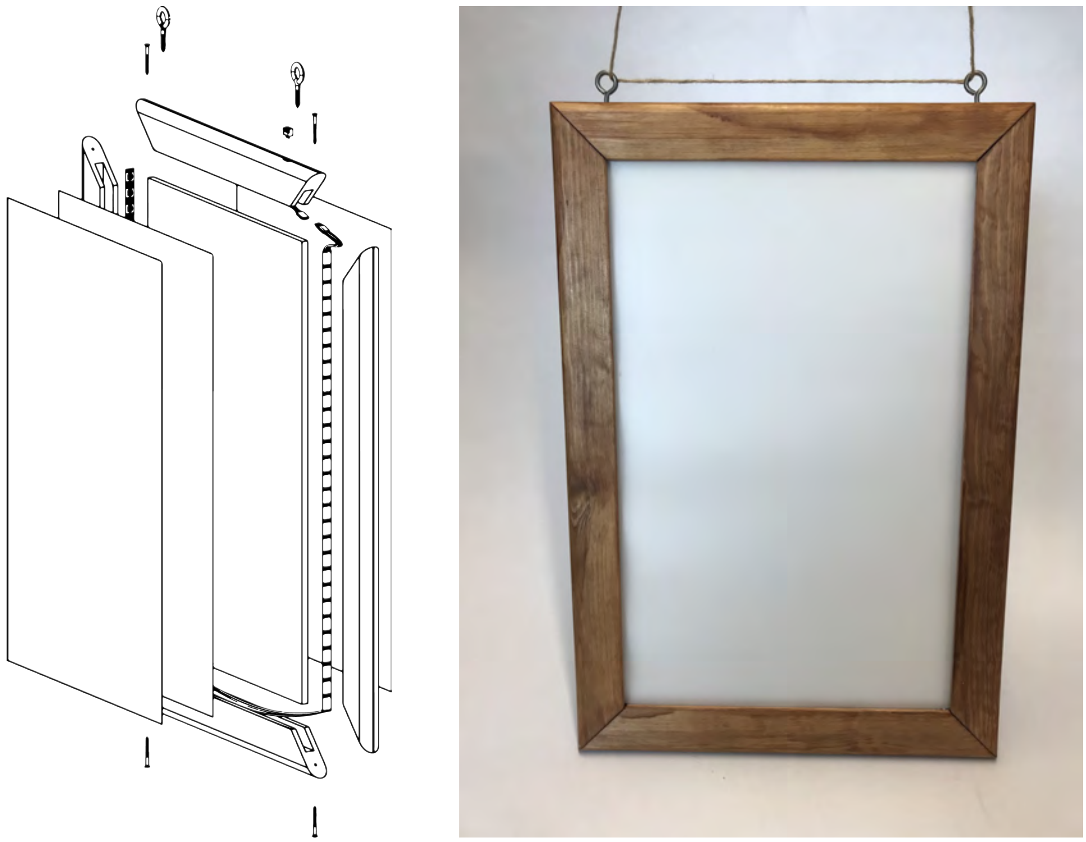


Figure 7.6: The Ambient Window artifact.

7.3.1.2 Window Ecosystem

To control the seven window artifacts in parallel, we developed a customized circuit board that would fit our needs (Figure 7.7).

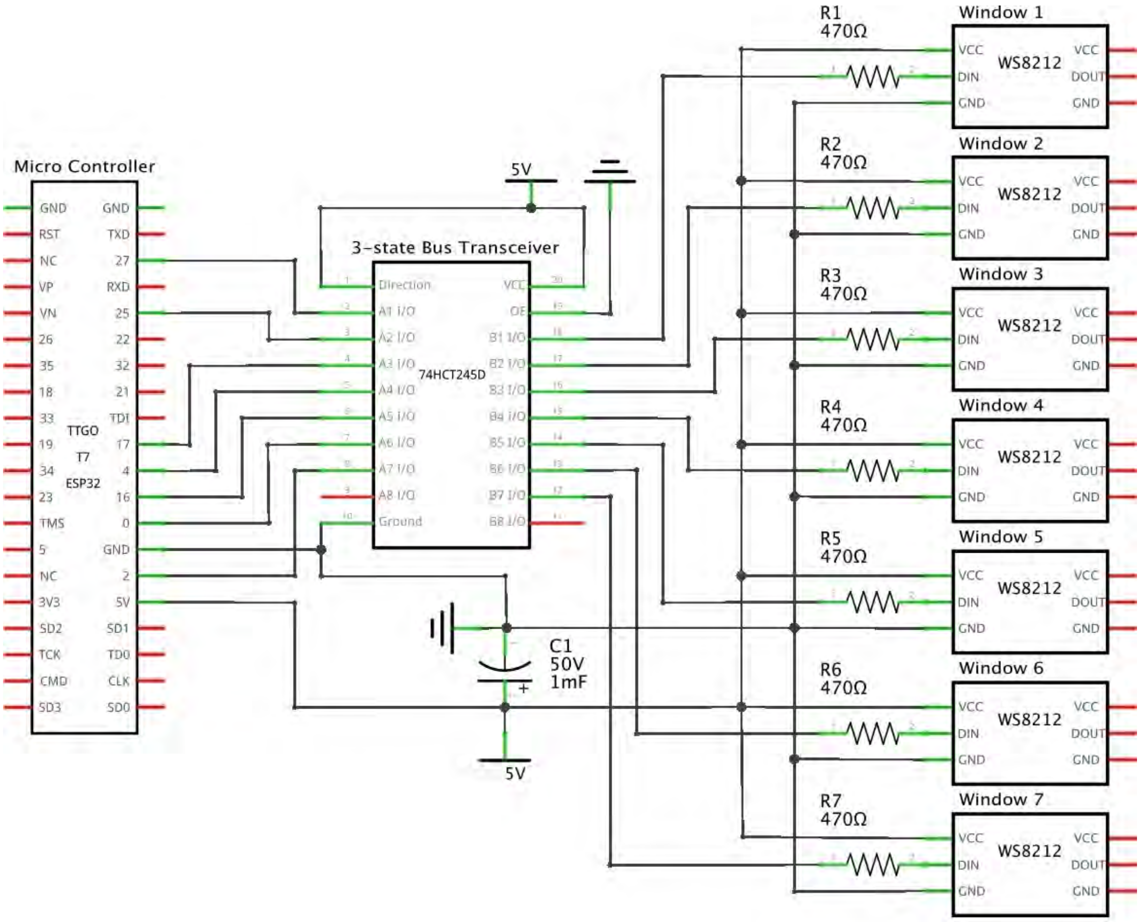


Figure 7.7: Schematic over custom made circuit board that connects the Ambient Window artifacts to Wi-Fi.

We used seven different LED strips and therefore needed seven data signals. We tried using Raspberry Pis as they seemed promising in the first experiments, and we had several of them. Once we connected all the LED strips and sent different data to all Raspberry Pis, the LEDs started to flicker. After various unsuccessful experiments such as overclocking the Raspberry Pis, sending the data at different rates, and pushing new data only when changed, we decided to replace the Raspberry Pi with a microcontroller.

The microcontroller was the TTGO t7 v1.3. On this board, the data transfer for all seven LED strips went nearly perfect, but it only worked with the FastLED library, which does not support RGBW [114]. Therefore, we had to include a hack to enable RGBW. Furthermore, was it required to disable interrupts for the FastLED library to speed up the data processing.

To step up the data signal, provide power to the Raspberry Pis, or later the TTGO, and power the LED strips, we built a module out of cardboard that contains the circuit board and place for the controlling units to attached. The circuit board takes 5 V in and provides it to the LED strips. A capacitor is used to buffer sudden voltage changes. The data signal can be fed on one side, and on the other side, eight three-pin connectors output the signal, +5 V, and GND to be used by the LED strips. To step up the signal from the Raspberry Pis and TTGO to +5 V, we used a Tri-State Bus Transceiver (74HCT245D). We experimented with placing the transceiver close to the LEDs or at the other end of the cable, but it made no difference.

The complete module was later attached to the ceiling rig in the exhibition and connected to all the *Ambient Windows*.

7.3.1.3 Atmosphere Record Player

The interactive piece of the installation is a wooden device that can replay captured atmospheres called the *Atmosphere Record Player*. The atmospheres are stored in *Memory Cards*, wooden cassette tapes that fit into the record player. Each *Memory Card* has a unique built-in hidden resistor. The *Record Player* measures the resistance in the cassette using an ESP32 microcontroller and sends it over Wi-Fi to the light controlling computer.

Like the frames, is the *Record Player* inspired by mid-century modern furniture and its rounded shape and wood joints. The player consists of five parts; two leg frame parts, one wood front panel, one wooden tape slot, and one plastic spring.

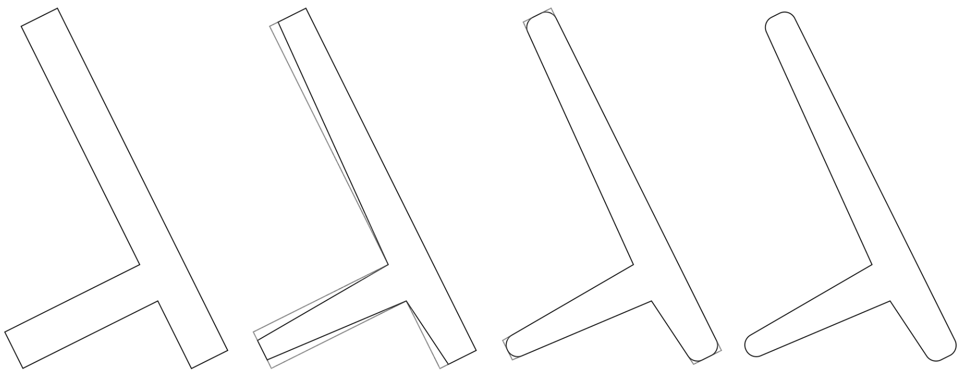
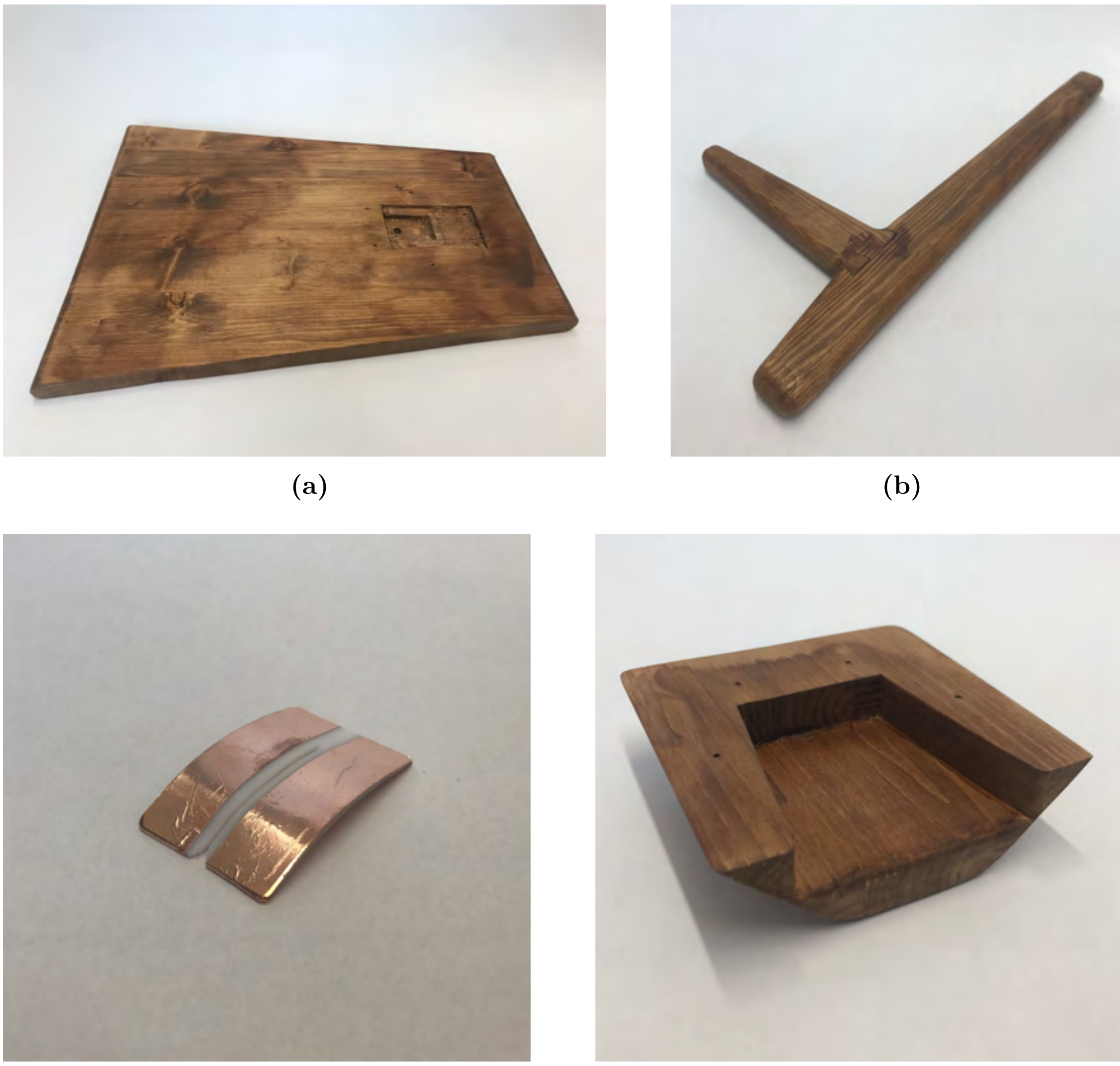


Figure 7.8: Drawing the leg frame outline.

The *Record Player* is designed to look and feel neat and light to reduce the feeling of hidden technology. It is built upon a tapered rectangle to provide a solid base without making it bulky and direct the attention to the top part of the player (Figure 7.9a). The legs both work as feet for the player but also as a frame to the wooden front. This provides sturdy construction and adds an aesthetic element that connects to the inspirational period. We designed it not to need any visible screws as this would affect the aesthetic properties. Different shapes of the legs were explored with CAD, paper sketches, and mock-up models (Figure 7.8). In the final version of the legs, we went with a straight and consistent shape.

Each leg was built using two pieces of 21 × 43 mm planed pinewood, the same as the *Ambient Window* frames. The two pieces of wood were connected with an angle of 90° using dovetail joints (Figure 7.9b). The slots were routed using a dovetail router bit, and the pieces were assembled using wood glue. The outline was then drawn on the side of the leg frame. The long part of the leg frame has a straight front and a tapered back (Figure 7.8). The leg piece of the frame is tapered on both sides by removing 10 mm on each side on the tip and creating a diagonal line to the base. The outline of the leg frames was cut out using a band saw, and the edges were lastly rounded using a 10 mm round over routing bit.



(a) (b) (c) (d)

Figure 7.9: The different parts of the record player.

The wood front of the record player is cut out from an 18 mm pinewood sheet. The base was set to 300 mm and the top 200 mm to make the sides slanted enough. The top and the bottom edges were rounded with a 10 mm radius, but the long sides were left straight as they would get connected to the leg frame. ⌀8 mm holes were drilled into the side of the wood panel for wood plugs to fit in. A 50 × 80 mm area in the top part of the panel is chiseled out (Figure 7.9a) to fit the plastic spring and a ⌀8 mm hole in the middle for the cable.

A plastic spring ensures a stable surface connection between the record player and the atmosphere tapes. The spring is made using a 1 mm thick acrylic sheet; for the spring, a rectangular shape of 50 × 80 mm is cut out from a 1 mm thick acrylic sheet. A curved shape is accomplished by heating the plastic with a heat gun and squeeze it between two wooden pieces. Each side of the acrylic piece is covered by copper tape, and one cable is soldered onto each copper surface on the bottom of the piece (Figure 7.9c). A cable is finally soldered onto the copper tape on the backside of the spring.

The tape slot is made using two pieces of 18 mm pinewood. The bottom part had the slot cut out (Figure 7.9d), and the other piece is glued onto the bottom piece. After the glue hardened, all sides except the one with the slot were tapered in 45° using a miter saw, creating a pyramid-looking shape. The edges were finally rounded using an electric sander to give it a softer look. All wood parts are finally treated with Herdins 711 Mellanbrun wood stain, the same as the frames.

The spring is placed into the chiseled part of the wood panel with a piece of electrical tape holding it in place, and the cable was threaded through the hole. The tape slot is attached on top of it with screws from the back in previously drilled holes. This made it easy to disassemble it and adjust the spring.

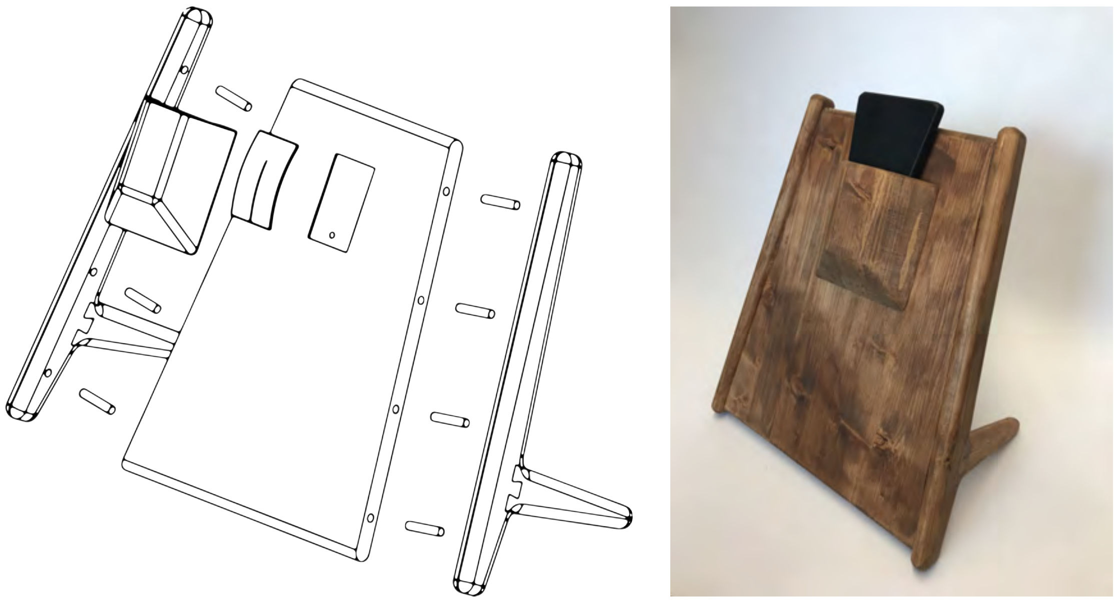


Figure 7.10: The Ambient Record Player.

7.3.1.4 Atmosphere Memory Cards

The *Atmosphere Memory Cards* are cut out from 12 mm thick MDF board (Figure 7.11). The edges and corners are rounded using a sanding machine; the edges directed into the record player have a bigger radius than the other edges. The

Memory Card is coated using black spray paint. A 5 mm deep, 8 mm wide, and 30 mm long slot is routed out 25 mm from the short side of the tape. 13 mm wide strips of Copper tape are attached in parallel from the routed slot, around the bottom edge, and up along the other side. Unique resistors are soldered between the copper tape strips in the routed slots. The slots and resistors are covered with hot glue, and a printed label sheet is finally attached over the whole side with the covered slot.

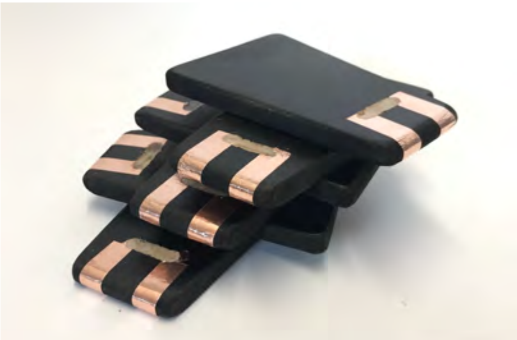


Figure 7.11: The Ambient Atmosphere Memory Cards.

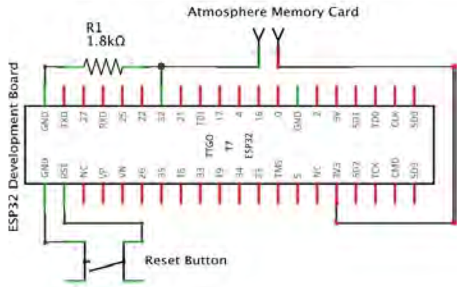


Figure 7.12: Schematic of the Atmosphere Processing Unit.

7.3.1.5 Atmosphere Processing Unit (APU)

A circuit with an ESP32 development board is set up to measure the resistance between the cables running from the record player through the table (Figure 7.12). The measured resistance is sent to the IP address of the computer controlling the lights. A reset button is connected to the circuit to easily be able to restart the microcontroller in case of hang-up.

7.3.1.6 Pedestal

The *Atmosphere Record Player* is placed on top of a customized IKEA Lack table. Five holes are drilled through the table; four for attaching the record player to the table and the fifth for the cable. The *APU* is attached on the inside of one leg using electrical tape and the reset button is attached on the outside of the same leg. The cable from the record player is connected to the *APU* using a two-pin JST connector. A black table cloth is placed on top of the table, hiding electrical components. A hole is made in the table cloth for the cable, and the *Atmosphere Record Player* is finally screwed to the table through the table cloth.

7.3.1.7 Composition of Windows

Seven window artifacts are hung in a half-moon shape from a rig in the ceiling (Figure 7.13). The rig has a radius of ∼180 cm, and the *Ambient Windows* hang 62 cm apart. The height from the floor varies between 40 cm and 260 cm in an irregular and organic shape. Cables are connected to the *Ambient Windows* and twined up along one of the strings. On top they are connected to the custom PCB (Figure 7.7) that in turn is connected to 5 V DC.

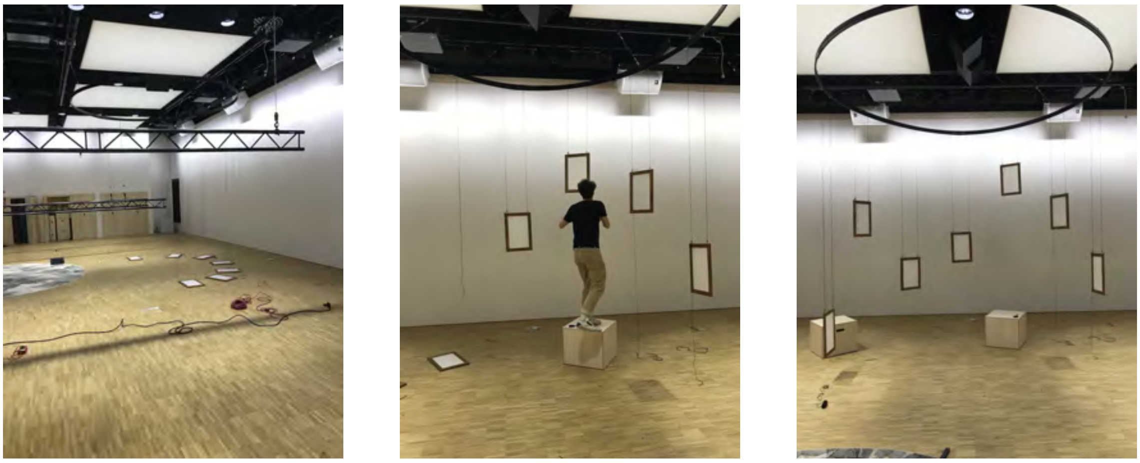


Figure 7.13: Hanging the windows in the exhibition space.

To define the area of the hanging Windows we added a rug. This circular gray rug had the same dimensions as the ceiling rig and therefore perfectly framed the space. The rug also served as an inviting area for people to sit or lie down.

7.3.2 Interactive Tech

We used *Touchdesigner* to create the digital back-end of our installation. The created node network renders different scenes of light depending on the input from the player device (Figure 7.14). If no memory disk is inserted, it fades to a warm white.

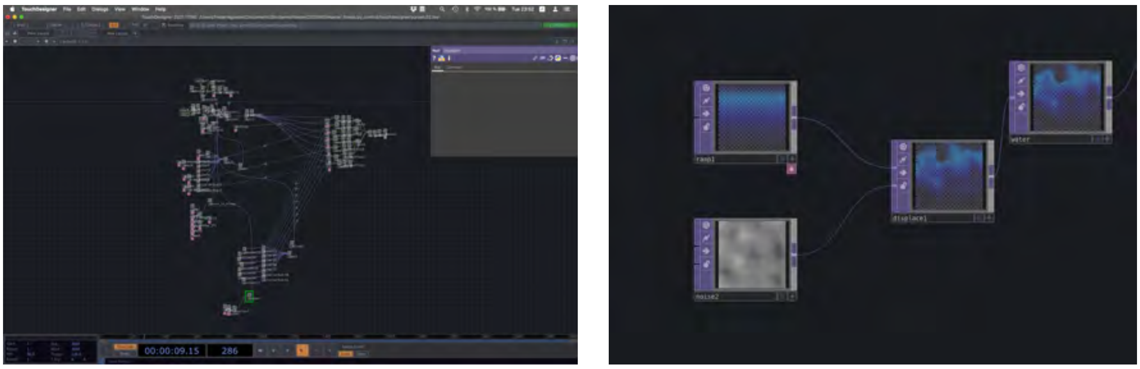


Figure 7.14: The whole Touchdesigner interface and the nodes for the Lost GoPro atmosphere.

The *Player* device sends the measured resistance from the *Memory Cards* via OSC to the computer on which the simulation is running. We export the rendered scenes by sampling depending on virtual positions for the LEDs. The sampled points are then transformed and arranged in the correct order and sent to the light devices via Art-Net.

We integrated the physical *Sunset Simulation* from the conceptual exploration phase as one of the memories. To interface with the library, we wrote a plugin for TouchDesigner that renders a 2D panorama view depending on the input parameters of time, turbidity, and location. This panorama is then sampled like a regular 2D image.

Figure 7.15: Sun moving across the sky in the Saltholmen memory.

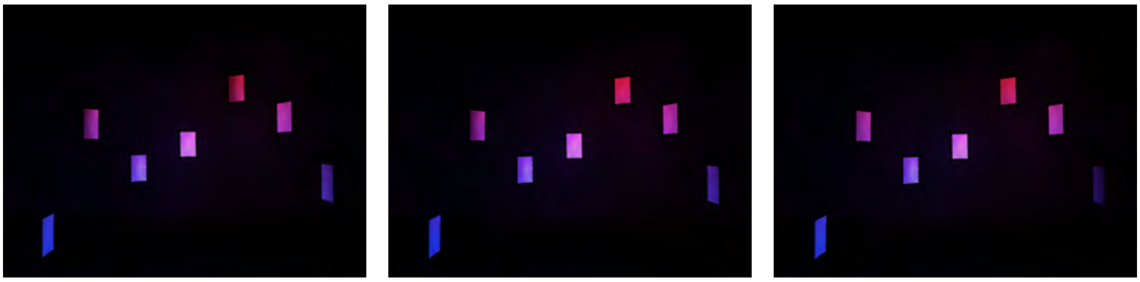


Figure 7.16: Flickering lights memory from Tokyo.

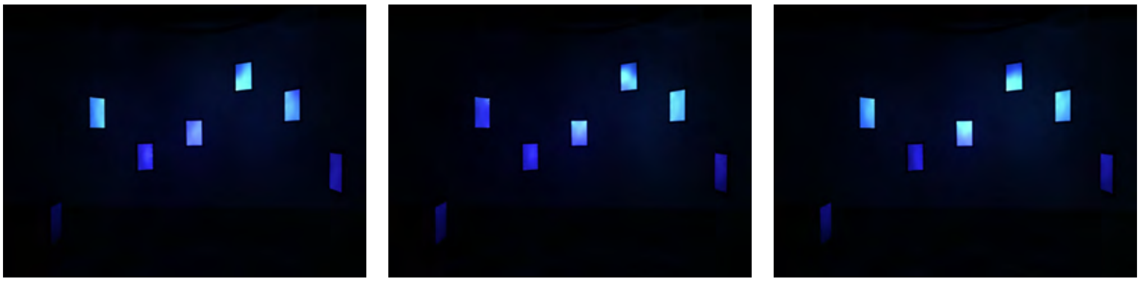


Figure 7.17: Underwater animation from the Lost GoPro memory.

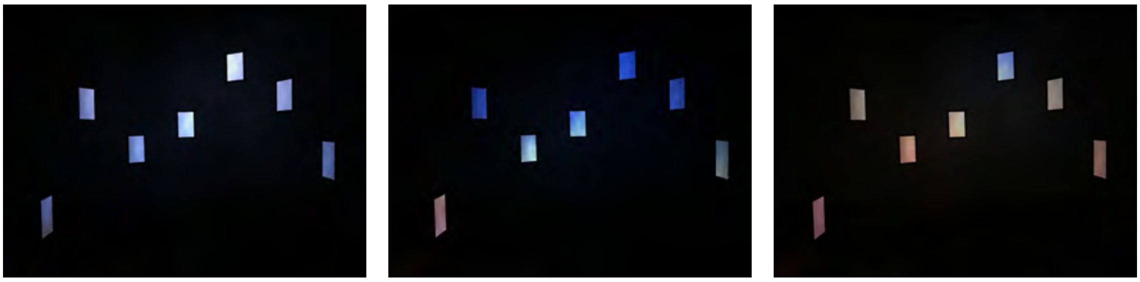


Figure 7.18: Saturated sunset memory from Branäs.

7.3.3 Light Simulations

We designed four different light animations for the exhibition.

7.3.3.1 Saltholmen

The first light setting for the exhibition is the one we later came to call *Saltholmen* (Figure 7.15). This animation is made using the physical sun model. We animated the sun to move from the bottom right in a curve through the windows ending in the bottom left window using the physical sun model. The animation is slow and smooth and is changing very subtly. We made it slow to let the visitor feel how the subtle changes affect one's mood.

7.3.3.2 Tokyo

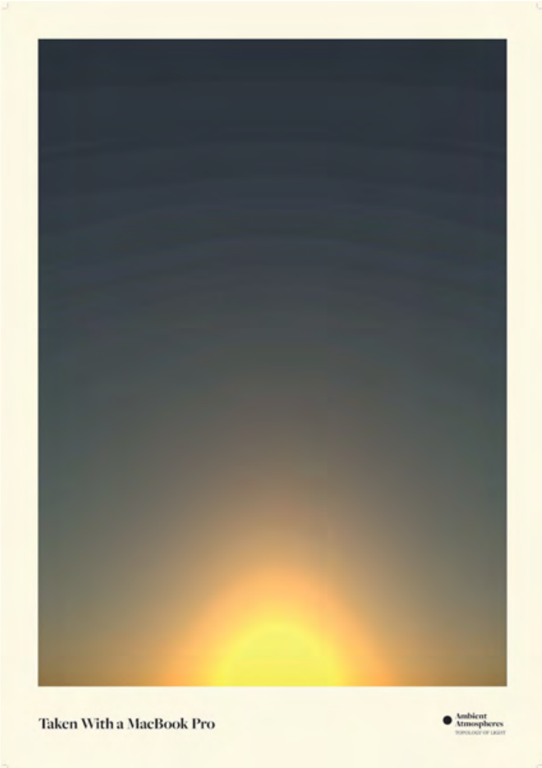
To show how different extreme colors, compared to the soft gradients in the sunsets, can look like we created a scene with very vibrant shades between red and blue (Figure 7.16). To add more of the feeling of a real place, we added flickering to simulate old neon lights. With this simulation, we want the visitors to feel how small and subtle details, as flickering signs, can help one to connect the scene into an authentic setting.

7.3.3.3 Lost GoPro

While thinking of possible unique light phenomena we wanted to explore, we thought of water. The way water moves and refracts the light inspired us to explore how we could resemble this. While experimenting, we created an animation of different blue tones moving in each other. We felt that this was quite an accurate representation of the feeling of being under water. We extended the animation by having a fade from light to dark blue in the vertical direction. The addition of light moving spots on the top simulates sun rays shimmering into the water (Figure 7.17).

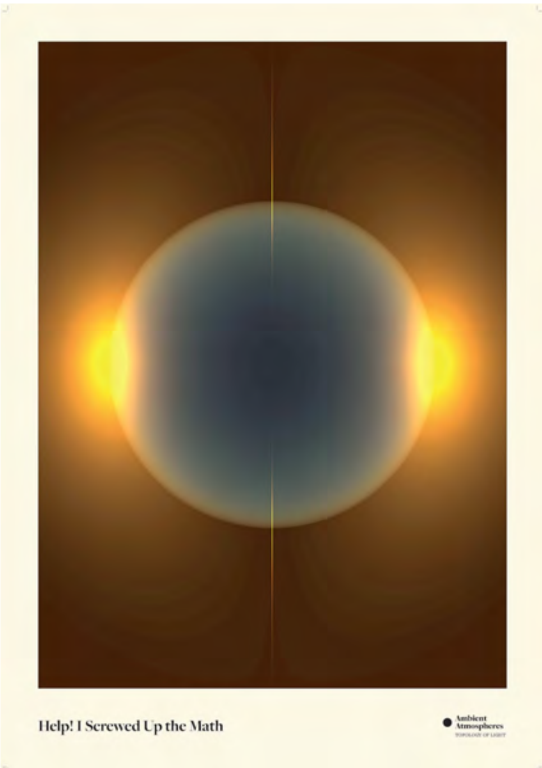
7.3.3.4 Branäs

We felt that the *Saltholmen* sunset did not succeed in transferring the natural feeling of a sunset. Therefore we created a more vivid simulation (Figure 7.18). We based this algorithm on the *Gradient Sunset* from our exploration phase but changed colors and the movement to map it better to the seven available *Windows*.



(a) Taken with a MacBook Pro

(b) Overcoming Reality



(c) Help! I Screwed Up the Math

(d) The Sunset Never Sets

Figure 7.19: Exhibition posters.

7.3.4 Posters

To communicate parts of our process and create creative engagement with the exhibition visitors, we created a series of posters. We used the posters to communicate some of the ideas we worked on that did not end up in the final exhibition by disconnecting them from the original context and feeding a discussion in a different direction.

These posters are intentionally left without descriptive texts to increase the ambiguity. Each poster contains a large-scale graphic of one of the topics we worked with during the project and a heading that hints at its meaning. To not make the exhibition too serious and easier to relate to, some headings are puns or remarks in a non-serious tone.

7.3.4.1 Taken With a MacBook Pro

The graphics of this poster is generated using the sun position model used in the project. The heading of the poster hints at the fact that the image is generated using a computer. This connects to our research on how to generate and recreate light settings and atmospheres using discrete data.

7.3.4.2 Overcoming Reality

This image is a spherical projection of a sunset, but the algorithm is changed so that the image also contains information under the horizon. The turbidity is, in addition, outside the valid range resulting in vibrant colors.

7.3.4.3 Help! I Screwed Up the Math

This graphic is, similarly to the previous poster, a spherical projection of a sunset. The algorithm generating this was accidentally written so that it would generate two sunsets at the same time. We corrected the code but found this representation interesting.

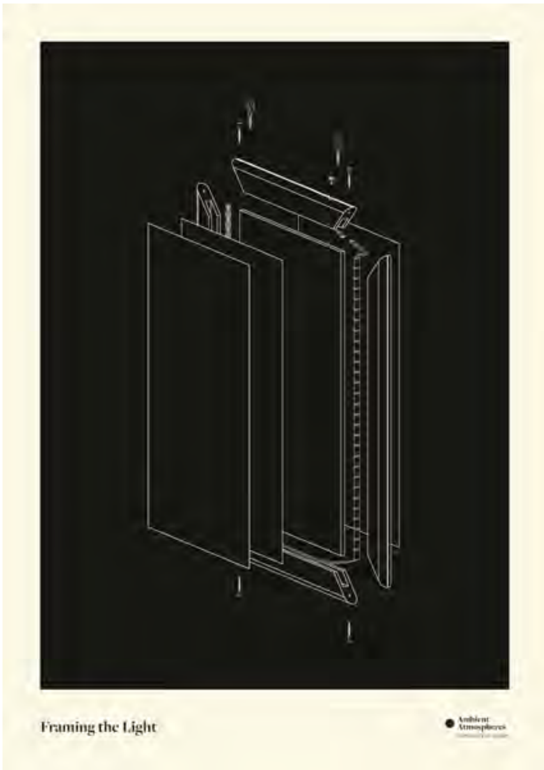
7.3.4.4 The Sunset never sets

This poster's title is a play on the fact that the name sunset is not actually correct. The image shows slices of the sky over the time of a day. By moving the virtual camera with the sun's movement, the image appears as if the sun is at all horizon positions at the same time.

(a) Introduction Page

(b) Creased Light

(c) Shapes Shape Shadow



(d) Framing the Light

Figure 7.20: Exhibition posters.

7.3.4.5 Introduction Page

The first poster contains a description of the exhibition, the project, and the researchers. The text can be found in A.8.

7.3.4.6 Creased Light

Creased Light is a reference to the folds of the origami shape. The graphic is a photograph of the big origami fold we did during the conceptual exploration. We did not move forward with our origami concepts for the final light artifact, but it was a part of the process that generated much response through our social media channels. With this poster, we hope to create new perspectives on how lampshades can be changed dynamically.

7.3.4.7 Shapes Shape Shadow

Shape shape shadow is a re-connection to one of our initial goals with this project, ambient light sampling. During our early research, we read about various ways of sampling light data. One paper that we found interesting sampled information about light direction and intensity by analyzing how a formation of hollow cubes creates shadows [28], [115]. This sampling device had more value than generating numbers as it is relatively easy to understand the concept. As quoted earlier in this report, “light can not exist without darkness” [3], this rendering illustrates this synergy.

7.3.4.8 Framing the Light

The *Framing the light* poster is an exploded view of the central artifact of the project, the light window. With this poster, we want to convey how we tried to have a transparent process by revealing the different parts and structures. We also played with the words to mediate how we in this project try to frame the future of artificial lighting and intelligent lights.

(a) Illumination Vectors **(b)** Colored Space

Figure 7.21: Exhibition posters

7.3.4.9 Illumination Vectors

We are taught that light travels in straight lines, but Lynes illustrates how light from different sources spreads through and illuminates space [5]. This illustration inspired us to think of light not as straight rays but as fields of illumination that interact with each other.

7.3.4.10 Colored Space

Kalff represented atmospheres visually by drawing graphical maps with zones in different colors [6]. With these maps, they show how one can light up different parts in a room in different ways to create direction. Brighter colors in the center pull the attention to the middle of the room, while the opposite creates a distraction.

Figure 7.22: The Bright Memories exhibition brochure.

7.3.5 Brochures

In the first evaluations, we realized that we needed to add at least a small layer of explanation to the exhibition to at least explain our thoughts and interpretations. Without this, people were lost in the space of speculations and did not know in what direction they should think and therefore did not come up with more profound interpretations. Images of the different posters were added in a brochure together with a short version of the text from the exhibition description poster (Figure 7.22 and Appendix A.7). In the brochure, each poster has a short descriptive text hinting at the context and purpose of the graphic.

7.3.6 Advertisement

Advertisement material was prepared to spread the information about the exhibition.

7.3.6.1 Press release

AWL asked us to formulate a press release that they could use to advertise the exhibition in their channels; it can be found in Appendix A.4. Creating a press release helped us a lot by forcing us to condense our work and formally describe it. Having a press release showed to be advantageous as we could use it in different contexts to communicate our project.

7.3.6.2 Event and Timeslots

The current restrictions limit the visitors in the room to eight people. Time slots of 30 minutes every hour, six persons per slot, were created to respect the restrictions and allow the visitors to visit in peace. AWL offered to handle the booking through their event page.

To advertise the exhibition we made a Facebook event. The event included information about the exhibition and how to book time slots.

7.3.6.3 Social Media

The event was marketed through various social media channels to reach a broad audience. We contacted different Instagram accounts connected to Chalmers and Gothenburg. People connected to the interaction design master program were informed through our common communication channel. The event was also marketed in different Facebook groups.

7.4 Exhibition Evaluation

To evaluate our exhibition we used cued testing with inspiration from focus groups [77], [78].

Participants were first asked to walk through the exhibition space on their own without us being present. We gave them this time to create their own interpretations and encourage playing with the lights without feeling observed. We scheduled between 5 and 10 minutes for this phase. Some participants asked us to explore a bit more before joining them, and we extended the time accordingly.

After that time, we joined the participants in the exhibition space and started a semi-structured interview while moving through the space. We first asked about general feedback or any thoughts they had.

After that, we moved to the beginning of the poster series and asked for associations and what the posters convey. At this point, we slowly moved along the posters. If the participants did not start to focus on one poster, we encouraged them by asking questions about a specific poster.

We continued the talking while moving to the second row of posters. Here we asked similar questions but also how they thought these posters relate to light or light technology. We also asked questions about their interpretation of the separation and grouping of the posters.

Finally, we moved to the center of the exhibition, where the installation was hanging. There we asked the participants to insert a memory they thought was the most interesting. After they inserted it, we asked why they chose this memory and how it makes them feel. We also asked about real-world applications that they see and scenes they would like to capture. At this point, the conversation naturally evolved, and we continued with an unstructured interview. The complete interview script can be found in A.9.

We believe that this combination of cued testing, focus groups and undisturbed engagement with the exhibition enabled the participants to pre-discuss questions and reflections with another person on the same knowledge level. This allowed the participants to support and reflect on on each other's thoughts during the semi-structured discussion. We, furthermore, think that this helped to reduce the friction of starting open conversations with different directions.

7.4.1 Participants

We evaluated 15 people in six groups, divided into four pairs and two groups of three people. The age range was 24 - 37, and most of the participants were designers and architects, but also people with other backgrounds, such as an art director and students in textile product development and software engineering. While this sample groups is relatively small and only covers a small demographic group, it was knowledgeable in the area of work, and we believe that we were able to gather a lot of relevant and interesting feedback.

7.4.2 Visitors

Although the interaction with the visitors of the actual exhibition was not as formal as the conducted evaluation before the opening, we collected interesting feedback from a much more comprehensive demographic range.

7.4.3 Thematic Analysis

The evaluation sessions were transcribed and iteratively sorted into different groups using the digital canvas tool *Miro*. All direct comments on the posters were put to one side and the rest to the other. Many comments were directly related to a specific poster, so each poster received its own group; the other poster comments were grouped into fitting themes.

The comments regarding the lights and memories were color-coded depending on what memory the comment applied; to keep track of what memory the emotions or reflections were connected to. Together with the rest of the comments, they were grouped into a lot of small groups. Similar groups were put with each other, forming themes. The different themes were lastly reviewed and rephrased into summarized texts. The following are themes found:

7.4.3.1 Exhibitions as a Conversation Starter

By conducting semi-structured interviews in the exhibition space, we were able to collect the thoughts and associations of visitors. The content we gathered was analyzed with a thematic analysis, and the topics found are described below.

7.4.3.2 Exhibition Itself

Several interviewees analyzed the exhibition itself in terms of accessibility and user experience. While this feedback was not what we were looking for, it still helped us justify some decisions.

Initially, we did not have any brochures to explain the posters, but the first two groups of participants expressed that they did not understand the direction of the posters and that they wanted more to dive deeper into the topic. Based on their feedback, we made the mentioned brochures. This turned out to have a positive effect as multiple groups mentioned that they tried to understand but also extrapolate the posters in a way that was more directed towards light and our research.

We had thought about having cubes to sit on in the exhibition space. We finally decided against this to invite the visitors to walk around and explore the light at different positions. This showed to be effective as many participants said that they liked to walk around. It was also mentioned that the rug encouraged participants to stand in the middle.

Some groups extended the exhibition by playing a guessing game with the atmospheres. One person would stand in the center of the lights while the other inserted a disk. The person in the center would then try to guess or describe the place the atmosphere represents. This process might be an interesting evaluation strategy in a future project.

In general, most participants enjoyed visiting the exhibition with another person they could talk to and explore with; some participants mentioned that they would also appreciate visiting alone as they might have been more aware or have led to a more immersive experience.

7.4.3.3 Spatial Experience

Nearly all visitors appreciated the layout of the exhibition. They described that the posters on the left invited to a natural start that continued on the opposite side and that the centerpiece drew the attention in a good way.

Many participants thought the space had a sacred atmosphere and had the same feeling as a beautiful church; one participant commented that "...it almost had this sacred feeling. The feeling of when you go into a beautiful church. You automatically quiet down and be aware of the volume of sound and so on". This feeling was increased by the fact that the room was quite empty and silent. Participants seemed to become more serene and calm in the space, and we noticed that they talked slower and in a low voice.

7.4.3.4 Confusion

Even though all participants liked the exhibition and had thoughts about light, there was still some confusion. Especially in the beginning, when we did not have the brochures, many participants were confused by the meaning of the posters, one participant mentioned that "a lot of question raised but a few were answered".

Some participants also missed that the *Branäs* and *Saltholmen* tapes were sunsets and thought it just showed static light. They only realized that when the tapes were inserted for a while, one participant said that "it took quite a while before it changed so we took it out and placed in another one instead".

One person also mentioned that they were not thinking about the future of light as they do not know what the future is.

7.4.3.5 Posters

All the participants enjoyed the posters and liked the aesthetics and fidelity of them. Many participants mentioned that they would like to have one at their home, "I would like to have them at home, very nice".

7.4.3.6 Difference Between the Sides

Different groups mentioned their perceived difference between the left and the right side of posters. They assumed that the left side showed different visualizations of light while the right side showed more technical parts and the process, one participant mentioning the difference said that "Strong contrast to the posters on this side and the other, the left side is focusing on lights and the right side shadows".

Some participants were wondering about the idea behind the sides and if the right side represents the process, technology, or maybe a story. Most participants understood that this side represented math and science-related things; one participant remarked that "These posters are a little bit more strict, the other side is more fantasy".

Some participants compared the left side of posters with abstract art, others with photography, and some with paintings. Interestingly, some participants did not interpret the posters through their symbolic content but by their effect on the viewer.

7.4.3.7 Abstract Sun Representations

Taken with a MacBook Pro did not spark as much discussion as the other ones, but it set the mind of the viewers towards light and sunsets. For some participants, it also started a process of thinking about the degree of realism in the image. Is it a photo or a simulation? One participant described it like "For me this was a horizon and a sun setting".

Most participants were wondering what *Overcoming Reality* represents and created their own interpretations. Quite a few participants were reminded of a closeup of an eye and some of an embryo or another closeup of an organic thing; it was mentioned that "This makes me think of an eye in space".

After adding the brochures, participants thought more of different versions of reality or if the image represents a different planet.

Few participants understood the connection to the title of *Help! I Screwed Up the Math*, but they still had interesting associations to different topics. For example that the image shows an out-of-body experience. Some also appreciated that it was a completely different way of understanding and thinking about a sunset, one participant said “Yeah and this is sort of an out- of-body experience. Then you start thinking of sunsets in a completely different way. And understanding it in a different way”.

Few participants had direct associations with *The Sunset Never Sets*. Some mentioned that it reminded them of a chancel window behind an altar; others thought it looked like a campfire.

7.4.3.8 Duality

One reoccurring topic participants mentioned about the right side of the posters in combination with the previously seen left side was the duality of technology and art. Some participants described it as abstract and concrete. At the same time, others appreciated that even though some drawings looked technical, they did not lose their visual appearance.

Some interpreted *Creased Light* as a visualization of how light and shadow can create a pattern. Only a couple of the participants mentioned that they thought of the poster as a lamp shade or illuminating object itself; “I feel like it could created light form different angles and create emotions by being dynamical”. Participants who followed our process recognized that the shape was similar to the breathing light and wondered why we did not include this in the exhibition.

Before adding the brochures, *Shapes Shape Shadow* was glanced over quite a bit. After the brochures were added, more participants looked to see how the shape creates the shadows and how computers could read light directions from it; one participant declared that “...these are more an analysis of light and shadows in terms of objects and how light is illuminating objects”.

Nearly everyone understood that *Framing the Light* represented a technical drawing of one of our Windows. One participant compared it to an instruction manual, “More Instructive, feels like this would be an instruction manual on different things but in a more nicely layouted way”. For some participants, this poster was especially interesting as they tried to understand the technology of our project.

It was interesting that even though most participants associated *Illumination Vectors* with the flow of photons, they thought that it is the distribution in the exhibition space or our *Ambient Windows*; one participant commented “Was trying to understand if the illumination vectors was connected to the actual physical screens. Or is it an artistic way of showing something from a physics standpoint. Not sure, but i like it”. One person even saw it as an electronic circuit. Another one said that the lines and the motion carried emotions in the same way as the light.

Colored Space also carried very different associations. Some participants connected this poster with a brain scan because of the pattern. One participant thought that it could maybe see the different brain regions activated by different lights. The poster inspired one person to move through the room to see how different positions feel. Some persons also thought about how the different light moves the focus in the room. One person thought of fingerprints or animal paws.

7.4.3.9 Light

The light installation pulled the attention of all the visitors.

7.4.3.10 Color

Some participants were surprised by how solid colors can convey feelings and how different colors completely change the room.

7.4.3.11 Preferences and Motivations

When asked about their favorite light settings, most participants mentioned the *Lost GoPro* or the *Tokyo Night*. They explained that they liked the saturated colors and the relatively fast-moving animations; for example, one participant emphasized that "This one makes me happy".

Some participants also strongly liked the *Saltholmen* memory. But in contrast to the previous, their rationale focused more on the name and the associated place than the light itself, even though they said that the light is an expression of how Saltholmen, in reality, feels. At least one person expressed that even though they liked the *Saltholmen* memory, they were underwhelmed.

Some also mentioned that there is a difference between light and color. The sky in the summer is blue, but the light is still orange. While this is something we thought about, we were not able to overcome it in the exhibition.

Some participants also appreciated that the sky was represented as a gradient as this felt very natural to them; for example, "The color of the sky is not uniform, the gradient describes it well. Both from a single time stamp but also across the day. Blue sky during the day but if you stay til the evening the warm lights will appear".

7.4.3.12 Awareness Increased

Interestingly some participants mentioned how their perception changed the longer they were in the room. While they did not notice any difference in color in the *Saltholmen* memory, they were able to see the movements and transitions after a while. Some also explained that they became more aware of how the light reached participants and how the own position changed the received light.

7.4.3.13 Wanted Colors

We asked the participants about one memory they would like to have recorded; many participants answered personal memories of places or places they would like to be. Some did not know how the light at this place was but were certain that it was special and different. One participant explained that "I usually think of objects and persons when I think of light. Maybe a sunny day at our family cottage. If I could move that atmosphere here, that would be very cool. The light is hard to describe. I am sure that somehow it is different". Some would like a sunset at a certain place that felt special to them.

Others described more universal experiences, such as a fire in a winter cottage or cars crossing by. One interesting mention was the idea to record the light in dreams. The person was unsure how this would look like but thought it could be a mix of artificial and natural lighting.

Others wanted very strong colors, such as ice-like blue tones, a very strong sunset, or a walk in a forest. Multiple persons expressed that they wanted different settings with green tones.

One person wished for different uses of the Windows and wanted to see more symbolic content in them, for example, by using the lower Windows as grass in a memory of a spring day.

7.4.3.14 Movement

Nearly everyone appreciated the movement of the windows, and participants thought it made the atmosphere more real. Some participants especially appreciated the significant movements and transitions of the *Tokyo Night* and *Lost GoPro* memory. One participant commented that "The flickering added a little action" on the *Tokyo Nights*, another participant commented that "I like how they change, especially the bottom one and the top one because they change the most" on the *Lost GoPro*.

Only one person commented on the direction of light and how different things look when the sun is at different positions. One participant mentioned that the sunlight in Singapore illuminates the city in an unfortunate light that makes everything look bland.

7.4.3.15 Associations

Many participants talked about how the light brought up different memories or associations. One participant recalled a memory, "*The Lost GoPro* made me think of Ebba that dropped her camera in high school". Another participant thought of a different context, "The dark blue that we saw the last in Branäs makes me think of when we are out sailing since you don't have the light from the city". Most participants associated a personal memory with the light setting, mainly with a positive event or memory. Only one person said that they did not like the *Lost GoPro* memory, or at least did not feel any connection to it, because it reminded them of the ocean, which they do not have in their home country.

One person said that it was more the memory of someone else than of themselves. Many other participants associated the atmospheres with more broad objects or scenes and not concrete memories.

One discussion point that arose a couple of times was that the naming of the tapes might have influenced the perception. This could also be seen in the fact that some participants extended our visualization in their heads. They thought the *Saltholmen* one contained breaking waves even though we never included this.

However, the names were also misleading and created expectations that were not fulfilled by the atmospheres.

Different participants also spoke about the experience as transportation. They felt that the atmosphere moved them to a different place, and they were really feeling the atmosphere. One participant said “It makes me miss that kind of life because we don’t do that anymore (corona). This is a good thing during these corona times. It actually brings this feeling of that place”.

7.4.3.16 Affective State

Participants described different emotional responses to the lights. Many participants said that the *Lost GoPro* and the sunsets made them feel peaceful, happy, and good. One participant expressed it as “Very peaceful. I feel calm”.

Tokyo Night evoked more of a stressed and energetic feeling. Interestingly participants still liked it. One participant described it as “This is bringing me back to life in a way. My senses are coming back”.

Interestingly it mainly was the movement in the frames and not the colors that participants associated with specific emotions or affective states. The slow movement of *Saltholmen* and *Branäs* memories were experienced as calming and relaxing.

Some participants mentioned their previous mood before coming to the exhibition and how it was changed. One person said they could not enjoy the exhibition as much as they had to go back to work soon. Others said that the exhibition helped them to restore energy or lighten up a monotone day.

7.4.3.17 Constellation

Several participants expressed that they highly appreciated the form of the installation. They liked how the frames in the circular shape created an illuminated space in the center of the room. Multiple participants told us that they thought that the limited amount of frames and therefore “resolution” actually helped to convey an atmosphere as the brain filled in the gaps with meaning; one of them said, “I like how the one in the bottom left was more of a warm color and it really merges even though the space in between is not there, but in your mind, you create that space”.

One person was confused about the symbolic content of the frames. They were wondering what part of the scenery the frames displayed. Another person wondered where they should stand. The opening in the circle of frames evoked the feeling of a natural standpoint to them, but they also liked to stand in the center of the lights.

7.4.3.18 Sparked Minds

In the open discussion, participants mentioned different directions their minds wandered. One person noted that they work with energy projects at the moment and therefore thought about the history of light and how the perception of different light colors changed over time and is different depending on culture; "... lighting has been historically a big part of households when we moved from candle and fires. Energy-efficient lighting had a bad reputation for a long time".

7.4.3.19 Interaction

Many participants praised the physical input and the way of interacting with light. They also liked that it was made out of wood. One person mentioned that it is a nice contrast to the fluidity and velocity of light "It is a nice counterpoint to the lights which is fluctuating in a high speed while the wood is something that you crafted. I can see different relationships to time. It is slower and it takes a while to craft this kind of thing while light is very fast. It becomes a nice counterpoint. If it was a touch screen it would have been different". Wood is slow and rigid. Participants also liked the memory cards as they evoked the feeling of real and tangible storage for a memory. The same participants also said that a digital touch screen input would not have been as strong.

7.4.3.20 Sound

Different participants had different opinions on sound in the exhibition. While some wished for sounds connected to the memories that make the experience even more immersive, others were thankful that we did not include sound. One participant said "I actually think it could have been a good move to not have music, i was adding my own music in my head. You work a bit harder to fill in the gaps a bit yourself". One group heard background noises of construction work and thought it was part of the exhibition. They liked how the sounds accidentally connected to the lights.

7.4.3.21 Summary

As one can see, different topics of conversation were sparked. Therefore it seems that there is a genuine public interest in artificial lighting. Several participants expressed that they would like to have a light like ours or even a future iteration in their home and that the idea of having recordings of atmospheres appealed to them. The variety of feedback shows how universal but also personal light is.

We believe that our exhibition succeeded in making participants aware of the power of artificial lighting, and we hope that the conversations and discussions will sustain even after our project closes.

8

Results

The result shown in this chapter is divided into two parts. First we present our final artifact, the exhibition Bright Memories. In the second part we present an annotated portfolio of our created artifacts and their contribution to our design process. We structure the annotated portfolio by extracting strong concepts and grouping the annotations within these. These annotations present considerations when *working with artificial light as a design material* and thus answering our research question. By doing so we also give examples of considerations *when using digital and physical tools to support the artificial light design process at different stages* and reflect on *what value can be provided and supported by different mediating artifacts in an RtD process.*

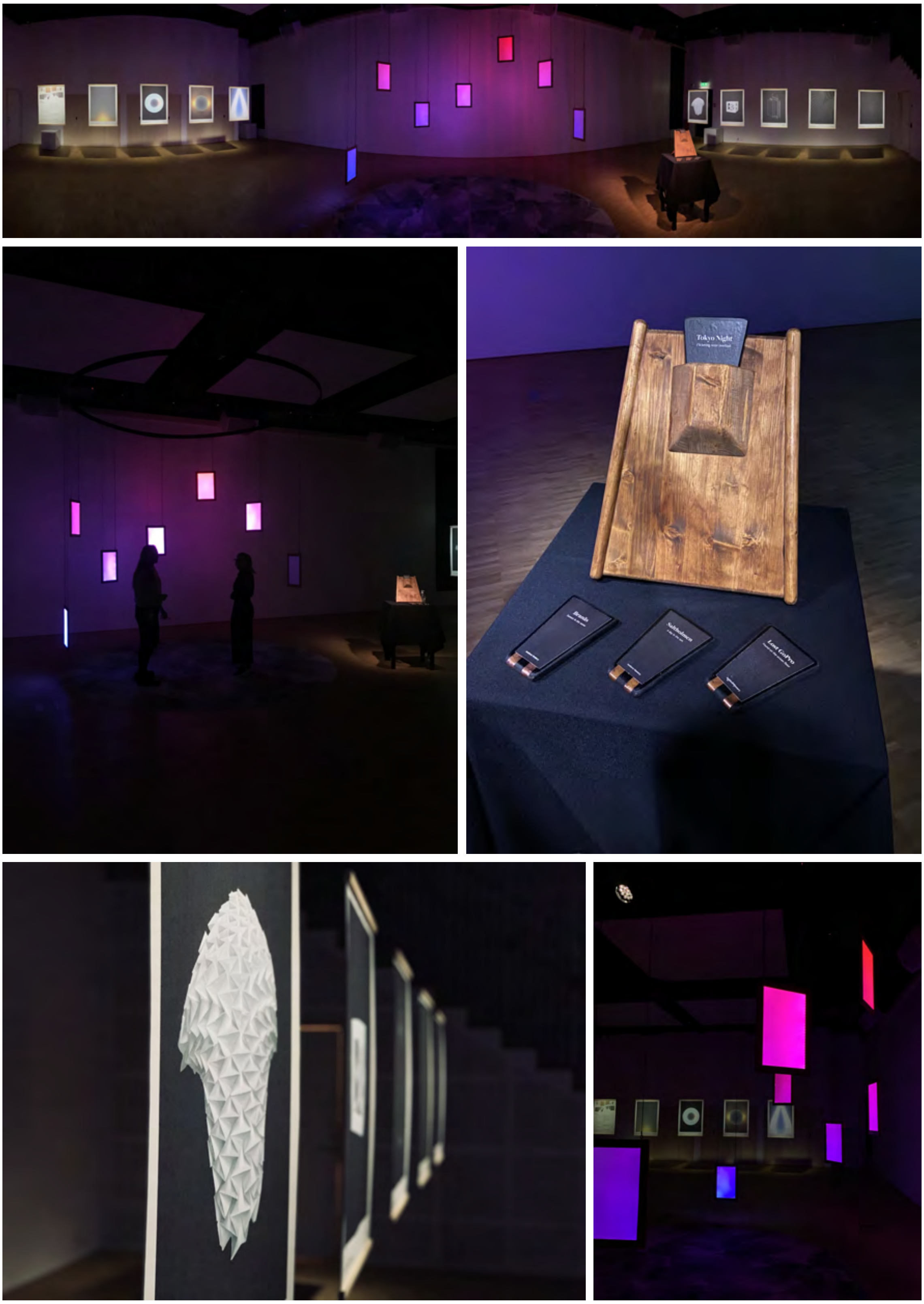


Figure 8.1: The Bright Memories exhibition at the AWL Studio.

8.1 Bright Memories

A part of our contribution to the field of artificial lighting is manifested in our exhibition *Bright Memories*. The exhibition consists of an interactive installation exploring light atmospheres as memory bridges and a series of ambiguous posters (Figure 8.1).

The installation consists of seven light sources resembling windows (Section 7.3.1.1). These *Ambient Windows* are arranged in a half-circle and hanging at different heights to describe fragments of an illuminated space (Section 7.3.1.7). The installation can be interacted with through a wooden *Atmosphere Player* device (Section 7.3.1.3). Viewers can insert one of four *Atmosphere Memory Cards* (Section 7.3.1.4) into the player to change the atmosphere played through the Windows (Section 7.3.3).

The installation is a speculative design contextualized in an alternative reality in which no virtuality exists. Therefore, the visitors could overdraw the technical processes and define the exact implementation and meaning of the exhibited devices themselves. Crafting these *Ambient Windows* and the *Atmosphere Player* device out of wood makes them look like mid-century artifacts, supporting this stance further.

The posters contain large images and an interpretable title as stimuli to provoke new thoughts in the visitors (Section 7.3.4). Four of the posters describe interpretations and visualizations of light situations in different abstract ways. The other five posters show different parts of our design process. Some of these show how to think of light differently, while others represent prototypes we created. To offer guests a way to understand our thoughts behind the posters and what knowledge they contain, a *tri-fold brochure* that visitors can bring home accompanies the exhibition (Section 7.3.5).

Figure 8.2: Association Range. How close to our core idea the feedback was.

Through the act of hosting the exhibition, we learned how designers could use a physical manifestation of an idea to communicate knowledge and spark a conversation during an RtD process. The exhibition was successful in sparking several conversations about the present state and the future of artificial lighting. These conversations were held with other designers but also participants outside of an academic context. A multitude of ideas was discussed, from pragmatic market-oriented applications to hedonistic speculations.

Different participants from our evaluation pointed out that the light situations did evoke memories and associations. Some reported being reminded of very personal memories. Others described more broad associations. For example *being underwater* in the *Lost Go-*

Pro memory. In contrast to such associations, some participants mentioned that the title of the memory cards might have influenced them and that without it, they would not have been that much affected.

A lot of participants mentioned how the movement of the light influenced their feeling; the flickering light of the *Tokyo Night* memory was described as stressful by some. Others described it as energetic. Some participants described the slow fading movement of the *Branäs* and *Saltholmen* memory as calm or happy. Similar was the movement of the *Lost GoPro* memory described even though people reported that this had an even stronger effect. In general, participants reported that faster movement made them feel more intense emotions.

Similar to that, people mentioned that more *vibrant colors* created more significant emotional responses. Many liked our use of *gradients* as it made them understand the light as something more natural. But some people also reported that some settings seemed to be not as realistic because the light filling a space is not necessarily the same color as the objects in it. For example, a sky is blue, but the light from the sun still warm white.

Multiple participants mentioned how they liked the *tangible interaction* of the installation. They liked the concrete tangibility of the artifacts and that the *Memory Cards* actually felt like one could store a memory inside them. Some participants also appreciated the choice of wood as a material and that it felt very crafted. The tactility and the hiding of the technology were also appreciated and made multiple participants wonder how it works.

The conversations we led also hinted towards success in transmitting the idea of ambient atmosphere sampling. Some participants asked us if we really went out to these places and recorded them. Others described how they would like to have an *Atmosphere Player* in their home. Some even extended the idea and proposed to have atmosphere sommeliers that create special settings for people.

The topics discussed in the exhibition should in no way be seen as scientific validations but as points of interest in our design space. We believe that these show how far an exhibition can serve as a ground to invite non-designers to engage in a design space. It allows different people from different backgrounds to discuss different topics. Sparked conversations can revolve around the original idea, technical implementations and implications, marked speculations, but also completely different topics. We believe that our stance of keeping the installation and the posters ambiguous, not loading them with a predefined meaning or function, helped create these different discussion points.

The exhibition also served as a focal point in our process. While the open and unstructured explorations were fruitful in generating a multitude of ideas and prototypes, we needed a point to converge to. As we did not have any problem to solve or a product to design, we needed a context where we could place the final design. An exhibition showed to be a perfect candidate for this. It left enough space to not be forced in any direction of design while still requiring polished artifacts to communicate knowledge. In that sense, it condensed our explorations towards a single point of knowledge.

8.2 Considerations When Working With Artificial Light

During our process, we created a series of prototypes. Only a fraction of these were used in experiments. Other prototypes acted as tokens pointing in different directions of the design space of working with light, and still others were used to communicate our design intents to a public audience. In addition to the prototypes itself, we created different technological solutions to control, or support our work with, light.

The following is an annotated portfolio containing these prototypes, the exhibition installation, and the technologies. To make the gained knowledge embedded in our designs accessible to future researchers, we extracted intermediate-level knowledge in the form of an annotated portfolio and strong concepts. Each concept is illustrated by the artifacts embodying these qualities.

8.2.1 Making Light Tangible

(a) Ambient Window artifact. **(b)** Opaque plastic diffuser. **(c)** Frosted Acrylic Rod artifact.

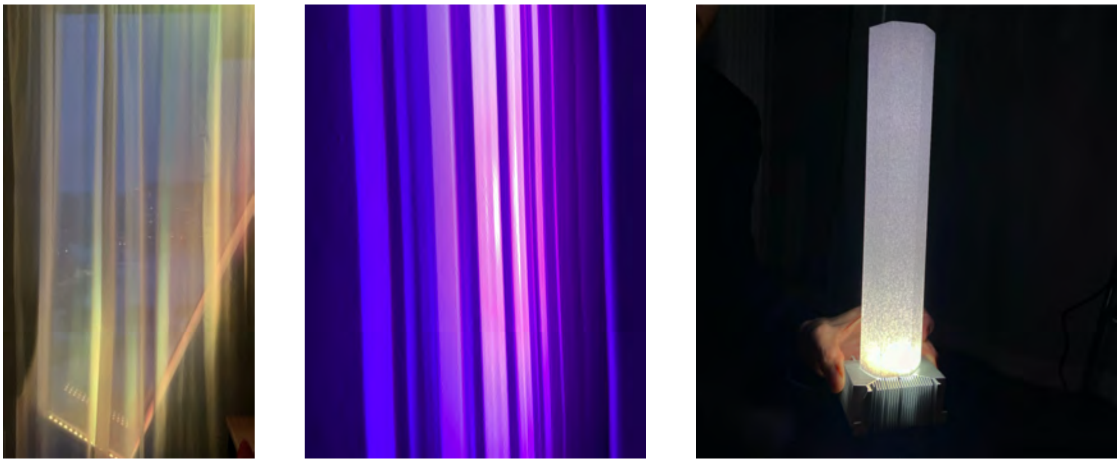
Figure 8.3: Surfaces making light tangible.

Light is inherently dependent and strongly formed by the surfaces and materials it interacts with. Through specific compositions of light and material new compound elements can be created. The *Ambient Window*, our furthest developed prototype, shows this. The two LED strips in the prototype are not visible, nor are the etched dots on the surface (Figure 8.3). A viewer only sees the solid wooden border and then a smooth area of gradient light. The light fills out the plastic panes, and these become the illuminating surfaces.

Another example of this can be seen in Figure 8.3b where the plastic is smoothing out the distinct light from the light fixture. Wiberg and Robles describes this arrangements of physical and digital materials as computational compositions [58]. As we carefully crafted the composition between stained wood, smooth plastic surface and artificial light we achieved an artifact with a distinct but authentic "texture".

In the *Frosted Acrylic Rod* artifact, something similar can be seen in how the rod becomes a tangible representation of the light (Figure 8.3c). Even though this one LED is too weak to illuminate the space, a multitude of them can create interesting patterns. Here the plastic, wood and light are not yet completely in harmony and the designs "texture" looks somewhat juxtaposed.

8.2.2 Mixing Physics



(a) Shimmering Curtain.

(b) Colors refracted through a radiator.

(c) LED paper pillar.

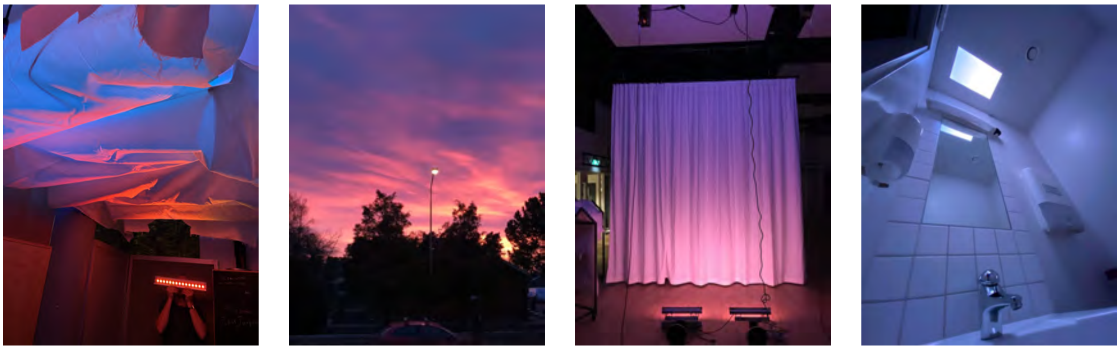
Figure 8.4: Physical mixing of of light.

Different materials interact differently with light. In our initial exploration with *Colored Curtains*, one could see how different colors of light were reflected differently and resulted in interesting gradients (Figure 8.4a). Moving the curtain will change the texture of these reflections in interesting ways, in that way light can be manipulated by changing a physical property that is not directly linked to the light itself.

In the *Radiant Radiators*, patterns were created by the reflections from the heating element (Figure 8.4b). Similar to the curtain example the light form the individual diodes will refract in different angles and this can be an opportunity in creating interesting patterns.

In Figure 8.4c a piece of paper is lit up by a high power LED. This shows how the structure of a material can also help to create patterns. Therefore working in reverse to how opaque sheets of plastic remove them (Figure 8.3b).

8.2.3 There is no Fill



(a) Sky Replica artifact. (b) Vivid sunset. (c) Curtain gradient. (d) Toilet experiment.

Figure 8.5: Concepts representing natural light using gradients.

In our work of trying to resemble natural and authentic light situations we found that it is hard to represent natural light phenomena with solid colors. Light interacts with the space it inhabits but also every other light source and itself. Therefore light creates gradients and complex patterns through objects and other things interacting or interfering with it. Controlling two lights can already result in complex compound light settings. This can be seen in all our prototypes building on top of the *Ambient Windows*. In the *Sky Replica* we illuminated fabric that was attached to a wooden frame (Figure 8.5a). In that way we simulated clouds illuminated by a late sunset (Figure 8.5b). One can see how the light interacts not only with the fabric but also other light sources to create patterns and gradients.

Figure 8.5c shows how we tried to replicate a similar sunset by lighting up a 4 m tall curtain using DMX light fixtures; here, especially gradients are visible.

In the *Toilet Experiment* the whole room was changed with our light source (Figure 8.5d). We noticed that the gradient lights looked more natural than solid colors, not when looked at but when seeing the illuminated space, especially when standing directly under the light source. By receiving partly blue, partly orange light one owns hands looked similar to being in the shadow on a warm summer day.

8.2.4 Shape Changing Lamp Shade

In the *Bendable Window* (Figure 8.6a) and the *Origami* prototypes (Figure 8.6b and 8.6c), we experimented with how shape-changing lamp shades can change the appearance of the light but can also work together with the light to make its effect stronger. Especially by combining moving qualities of the shade with animations in the light strong effects can be achieved.

The *Origami* prototype is a folded piece of paper that is illuminated from the back. The prototype also had a motor connected to change the shape. In this way we could expand the surface and show one color or contract and show another duller

(a) Bendable Window artifact.

(b) Beating Heart artifact.

(c) Glide reflection origami fold.

Figure 8.6: Dynamic lamp shape artifacts.

color. But even without changing the light actively was the light changed through the different folds when moving the prototype.

The *Bendable Window* is an iteration of the *Ambient Window* with a much thinner plastic sheet, allowing it to be bent. This allows to explore how the curvature of the surface affects created gradients in the screen and what happens when the surface becomes three-dimensional.

Even though we did not implement this we though about using the moving qualities of the lights as input controls. The *Origami* shade for example as a touch input device that reacts to the proximity of hands.

8.2.5 Light Carrying Meaning

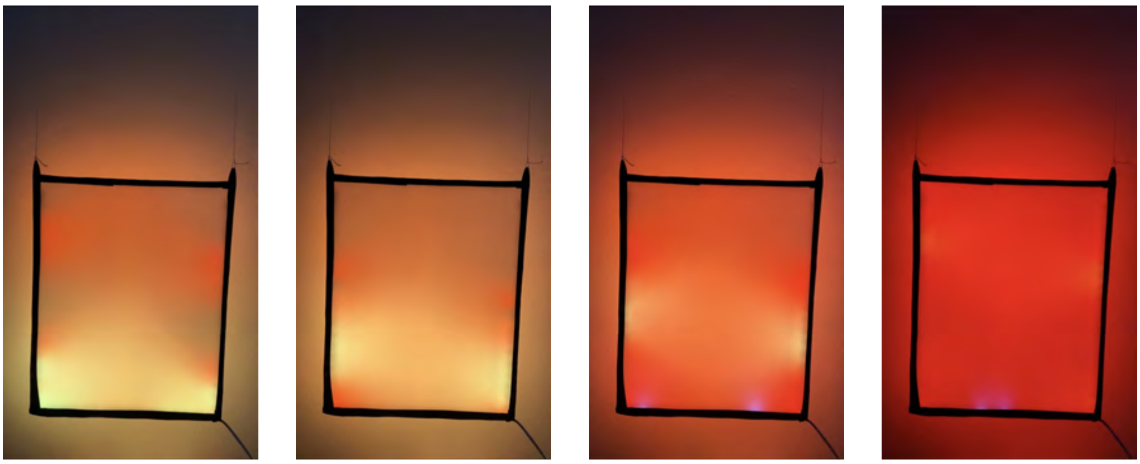
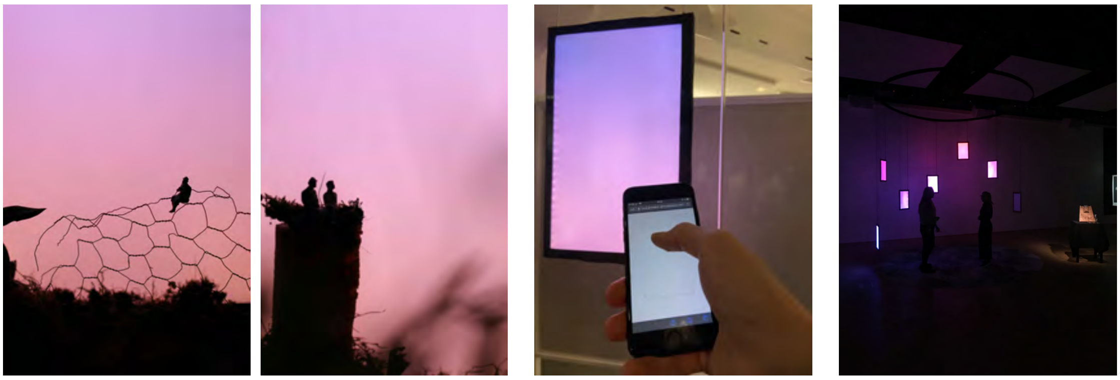


Figure 8.7: Fire animation.

Loading the light with meaning can help to resemble light phenomena. This can be done in different ways. Animation of the light can be used to mimic patterns, like the *Ambient Window* prototype resembling a fire in Figure 8.7. Figure 8.8a shows



(a) Modeled context with an Ambient Window.
(b) Communication artifact.
(c) Bright Memories exhibition.

Figure 8.8: Physical mixing of of light.

how placing objects in front can create a context and in that way a meaning. In the exhibition the expressed light situations were loaded with so much meaning, in the form of color and animation, that many people associated similar things with the same setting (Figure 8.8c).

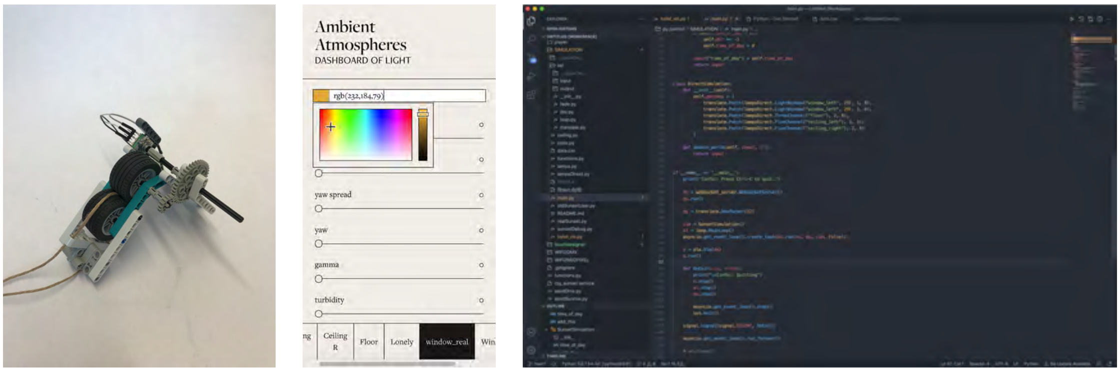
Similar thoughts were already explored by other researchers [10], [11], [116]. Most of these projects utilize more medias than just the light setting, for example projection and sound. In our opinion one needs to be caution to not overload a given scene with symbolic content as this might lead to unnatural compositions of light and material, therefore resulting in kitsch [58].

A different way in which light can be loaded with meaning is the change of light. In such a setting, the act of changing the light is already loaded with meaning and the values it is changed to do not necessarily need to carry meaning. In the original *Ambient Window* experiments, the light was used as a signal to communicate between users (Figure 8.8b), similar to how the *Yo-Yo-Machines* of the *Interaction Research Studio* work [103]. In our first prototype the controlling person did not even know to what settings they were changing the light. But the change still symbolized that they interacted with our website and though about us.

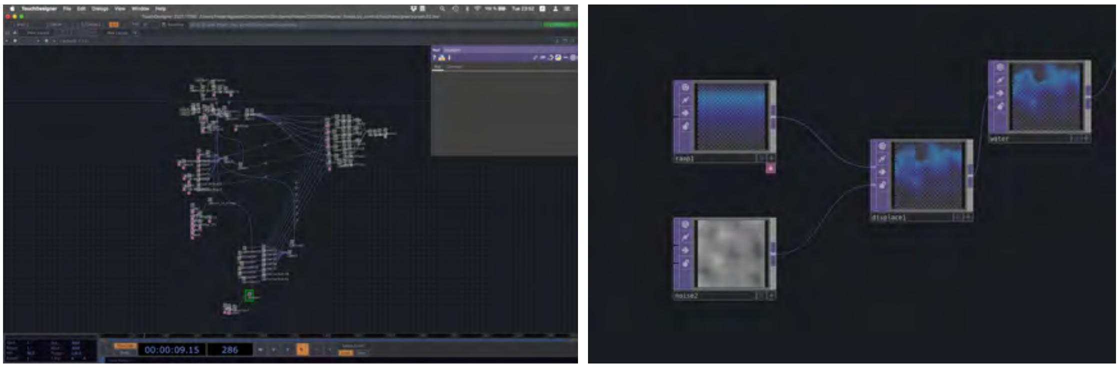
8.2.6 Control of Light

One of the main points when working with artificial light is the control of it. While it certainly is possible to control and form light completely through mechanical means, as we explored in the *Origami* lamp, we focused mostly on digital controls on different abstraction layers.

Early in the process, in the *Open Exploration* phase, we found it helpful to engage with light in a simple form without abstractions. For that reason, we used *Physical Inputs*, that change digital values, to control light; for example the *Roller Blind Chain* prototype (Figure 8.9a). This direct control enables instant iteration loops.



(a) A physical input artifact. **(b)** The openSOL GUI. **(c)** Programming the light.



(d) Visual programming interface.

Figure 8.9: Various ways of controlling light.

At the same time, this sort of control is hard to reproduce and therefore not applicable for creating fixed light scenes. Different physical controls can be mapped to different values. We used for example a Light Control Board to control DMX channels directly, while we used potentiometers to change values in a gradient and a curtain string to control the brightness of a light. Completely other, but still physical interactions, with light are described by Ross and Keyson [11]. They use complex input artifacts to describe and change the whole atmosphere of a room.

Later in the project, but still in the *Open Exploration* phase, we used *Digital Inputs* to create repeatable experiments but also to explore light in a more defined way. Digital inputs can have different formats; they can be programs with GUIs (Figure 8.9b) or headless applications (Figure 8.9c). An advantage of having digital inputs is that these can be designed independently of the artifact. In this way, one program can be used to control a multitude of prototypes.

To quickly create different simulations in the whole *Concept Exploration* phase we used programming. But we used it also in the *Physical Manifestation* phase to create final, long running programs. *Programming* can be used instead of, or in addition to, digital inputs. Through programming, designers are entirely free to implement any simulation or design they want. However, programming comes at the cost of taking time and energy from the designers. It was a great addition to the process as programming is one of our core skills, but it still required much work to implement everything correctly.

To overcome the complexity of programming, *visual programming* can be used (Figure 8.9d). This allows the designers to focus on what they want to express and ignore syntax. Furthermore, can some of these programs show the intermediate states or even visualize how a light setting will look. We especially recommend it to designers that do not have the programming knowledge to write their own programs. We used visual programming only in the *Physical Manifestation* phase as we did not have previous knowledge of it, but we do think it can be helpful in previous phases as well. A limit of using *TouchDesigner* is that it needs to run on a high-end computer which can make long and remote experiments difficult.

8.2.7 Getting to Know Light

Photography can be a great tool for observing light without having to create it. We noticed that the simple act of taking photos already increased our awareness of light situations (Figure 8.10). Even though photography is not explicitly mentioned by Höök we believe there is a strong connection of how they describe the process slowing down to get to know a design material [47]. For us the time of taking photos or even just calmly looking at light phenomena helped to train our light appreciation skills.

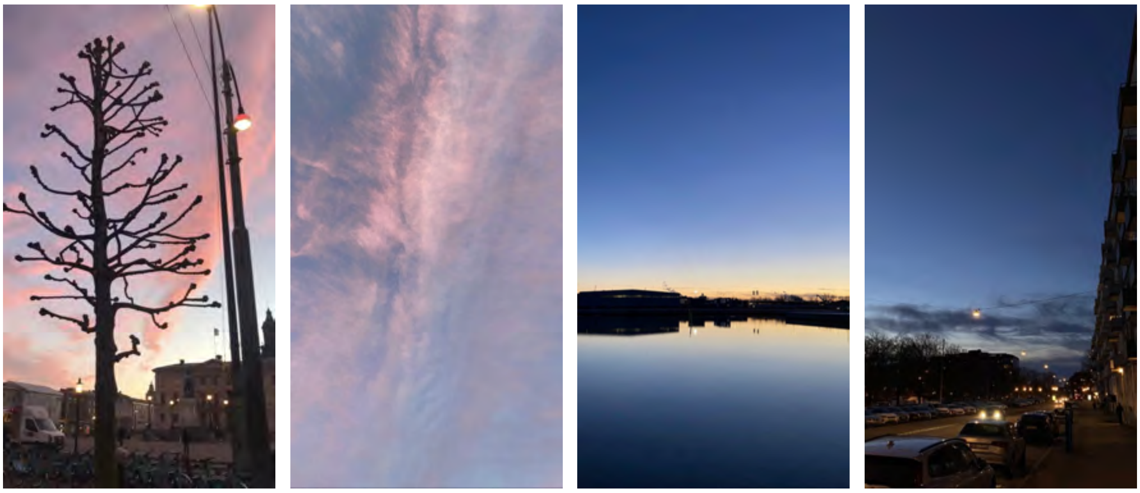


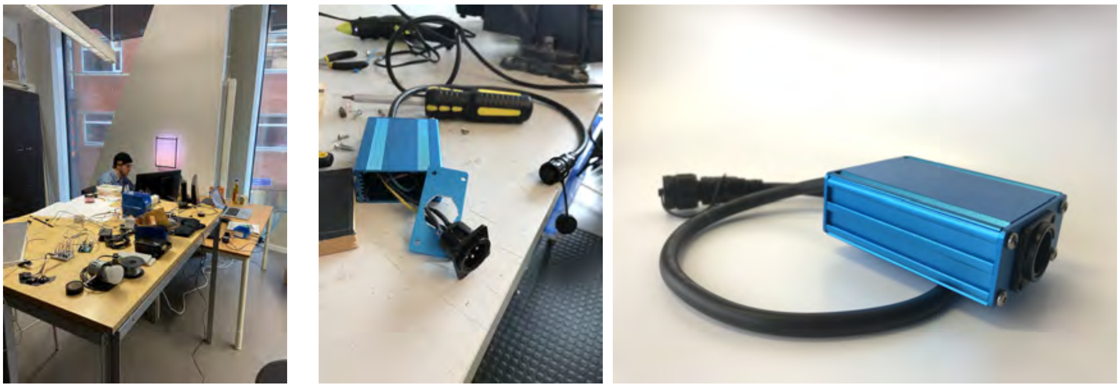
Figure 8.10: Photographs of interesting light phenomena.

Auto-ethnographic methods and descriptions of one's own mood can be valuable to explore how light affects humans without conducting formal studies. We used this *first-person* approach to explore how light changes the ambiance of a room.

Visualizations can help to get a feeling of how a design looks without actually creating it. Even though it is challenging to get the light behavior realistic, it can be of good use to show how something will roughly look. We used visualizations to get a feeling of how our installation might feel (Figure 7.3). In the end, the room looked very different but actually carried a similar atmosphere in it. While we used simple visualization methods, like sketching, throughout the process, we used renderings only in the last phase of the project as the time they took did not fit into our fast explorative workflow.

8.2.8 Physical Work

(a) Interior and exterior of the DMX to Wi-Fi node. **(b)** Sacrificial diode hack.



(c) Playful mess. **(d)** DMX three-pin to four-pin converter.

Figure 8.11: Iterative Prototyping and Playful Hacking.

To create the physical manifestations of lights *Iterative Prototyping* is needed. As light is so complex, there is nearly no way of knowing exactly how a design will behave in the real world. Therefore prototypes with increasing fidelity can help to understand the behavior of light and its interaction with the material.

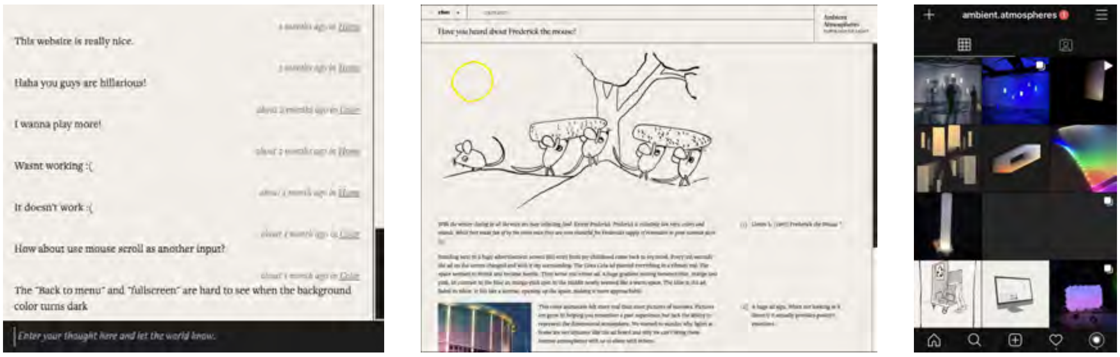
Playful Hacking can, in the same way, support the design process, especially as a generative tool to find new ideas [68]. Many of our designs were born through playful hacks on previous designs. Having a dedicated studio space made it easy for us to jump between writing and building (Figure 8.11c).

As light control requires communication links between the digital and physical world it is helpful to prototype in an applied technical way that allows to create such interfaces. We for example had to create many different tools as we did not have the budget to buy them. Figure 8.11a show a Wi-Fi to DMX node that made it possible for us to control professional light fixtures over Wi-Fi. Figure 8.11b is a sacrificial diode hack used to step up data signal voltage from 3.3 V to 4.3 V. We also built a DMX three-pin to four-pin converter box (Figure 8.11d); it was necessary to control some of our borrowed light fixtures, we did not find such a device on the market.

8.2.9 Communication of Light Ideas

As light and especially complete atmospheres are hard to describe in words we found it helpful to use artifacts to communicate ideas and insights. These artifacts had different shapes, fidelities and roles in the project.

Some artifacts served a conversational purpose. The *Ambient Window* (Figure 8.3a and 8.8b) and *Ceiling Tile* (Figure 8.5d) artifacts served as mediating objects, embedding our knowledge and exhibiting our ideas. We used these prototypes for experiments in a public context. While we were able to spark first conversations through these prototypes, a more in-depth study is needed to explore the impact further. While they did not generate the feedback that we wished through our website, they led to discussions with persons walking by.



(a) The ambient-atmospheres.com Chat.

(b) A ambient-atmospheres.com Journal post.

(c) Ambient Atmosphere Instagram feed.

Figure 8.12: Communication platforms.

Other artifacts communicated knowledge and invited to a discussion. These are not limited to the scope of artificial lighting but could be used in any design context. We created a *Project Website* with an integrated chat (Figure 8.12a) and *Journal* (Figure 8.12b) system as a platform for discussion and exchange of knowledge. This website worked great as an anchor for our project and showcased our ideas to early stakeholders. Unfortunately, the chat system did not result in any exchange of knowledge and did not help create a discussion. The journals, in contrast, resulted in engagements of page viewers and sparked some conversations.

The *Journals* published on the website were concretized outcomes of our process. Through this manifestation in written form and targeted at a public audience, the journals forced us to verbalize our thoughts in a clear and accessible form. We used

Social Media to share images of our process (Figure 8.12c). We furthermore used it as a platform to communicate news about our exhibition or released journal posts. In transferring this superficial knowledge, the social media channels succeeded.

Having a *Transparent Process* proved to be valuable in opening up a design space for others to follow. During this project, we used multiple tools and methods to communicate and share our knowledge.

Most of the artifacts we created helped the *Communication* between us but also to externalize ideas and perceive them in reality. This helped to explore the feasibility and impact of our concepts. These prototypes also served a generative value as we found new ideas through these by snowballing.

The *Colored Curtains* and *Radiant Radiators* experiments (Figure 8.4a and 8.4b) at the beginning of our process kicked off a whole path of thinking about how light interacts with different surfaces, finally resulting in the *Sky Replica* (Figure 8.5a), which in turn explored the feasibility of directing light on the material in a way that it represents a real sky.

The *Bendable Window* (Figure 8.6a) was based on the same concept as the *Ambient Window* but explored if it still works when the surface is not straight but bent. The *Frosted Acrylic Rod* (Figure 8.3c) and *Origami* (Figure 8.6b and 8.6c) prototypes both explored different directions of representing light in material but were not further followed. In the case of the acrylic rod because the concept did not seem interesting enough, and in the case of the origami because it seemed too complex for the time frame.

9

Discussion

In the following chapter we will discuss our process model the *Triple Diamond* and our research approach *Playful Hacking*. We will further discuss in how far our communication though public channels served our project and where we see our work in relation to previous research. In addition will we give learning that we found while working with light. We will then discuss how COVID-19 effected our project before we propose future iterations and reflect on accessibility and cultural differences.

9.1 Triple Diamond as a Process Model

In planning our process, we decided on a *Triple Diamond* process model instead of the commonly used *Double Diamond*. We think that this model worked great and that it supported the exploration of a new design space.

Having most of the theoretical and scientific parts done in the first phase enabled us to concentrate fully on the explorations in the second. This does not mean that we did not read new literature in the second phase, but we already had a solid understanding of theories connected to the design space. Some of these served as justifications to even start the explorations (most of the papers about light sampling); others were used in a generative way to create new ideas.

The second phase completely focused on explorations that were not connected to a particular use case or context (except light). While this worked great to explore the space of possibilities, it became hard to condense the explorations in the third phase. We had to remove many ideas and prototypes from the final exhibition as we did not have time to create all prototypes in a polished way.

In general, the *Triple Diamond* showed to be an effective way of working but might be even better suited for a longer project.

9.2 Playful Hacking as an Approach

Early on, we decided to use prototyping and *Playful Hacking* as our primary approach to conduct research. Through this, we were able to work closely with the material, and we engaged with it in a direct manner. While this approach worked great in the diverging phase, *Open Exploration*, of the project and helped us explore many different design directions, it became apparent that this approach suffers when time is limited. One has to condense the research to one point. We were required to leave many (all except one) of our prototypes out of the final exhibition as we did not have time nor money to create polished versions. Furthermore was it difficult to relate all the prototypes to each other. As the design space was so broad, the prototypes explored very different ideas and did not necessarily support each other's stance.

Prototyping as the primary research activity also has the limitation that there is no defined end goal. For us, only time and budget limited the space of explorations. When applying the same strategy outside of a university project, it might be advisable to set a defined goal to have something to work towards at the beginning of the project. Our process might have resulted in a more scientific research contribution when certain time slots were reserved for this kind of work. It is quite easy to chase ideas and prototypes instead of reflecting on how these add value to the research.

9.2.1 Money

Even though the final exhibition required less money than we received a budget for, we were constrained by money. At the beginning of the project, we wanted to acquire different materials. As we could not acquire these through our studio, we had to build our own interfaces. We decided not to use cables and transmitted data via Wi-Fi instead. While this limitation of budget and resources forced us to learn the low-level technology of light, it required much time that could have been spent on explorations of the light design itself.

When working with limited resources, *Reusing Material* is a good way of getting started when prototyping is used as an ideation tool in RtD. However, it might require some creativity to figure out what to search for and how to use it. In our case, we mainly salvaged non-electrical components from old electronic devices, primarily monitors. Deconstructing old monitors showed to be very valuable as the materials found in it are hard to find as off-the-shelf.

After learning how the different plastic layers work in a monitor and their properties, we could have acquired them new. Acrylic sheets of the wanted thickness could have been bought, and the small cavities on the surface could have been etched using a laser cuter. Using old monitors not only saved money in buying prism sheets, diffusion sheets, and acrylic sheets but also save time in cutting and preparing them.

9.2.2 Generated Knowledge

Most of our generated knowledge is manifested in different prototypes and experiments. This knowledge might be hard to extract for researchers with a different background and do not have the same pool of knowledge.

The experiments with these prototypes were done on an ad-hoc basis without quantitative evaluations. For us, the focus was on trying our artifacts out in a real-life setting and not so much on generating data. Therefore the effects of experiments are hard to describe. In retrospect, it could have been valuable to evaluate the prototypes in a more formal setting.

9.2.3 Ethics of Experiments

Most of our experiments were conducted in a context accessible to the public. Sometimes at places that we did not have the approval to use. We name this method *Guerilla Evaluation*. Conducting experiments at places that we did not have the approval to utilize is obviously ethically debatable. We justified this by having the artifacts behave passively as long as bystanders did not interact with them. We furthermore did not collect any person-related data and only provided an optional platform (our chat) for participants to send feedback or engage with us. We also ensured that lights we deployed in public spaces did not flicker to prevent seizures or other ill effects. By implementing idle states, we regulated that our lights would fall back to relatively bright settings to mirror the behavior of lights that we replaced.

9.3 Making it Official

Choosing to make the project and process public was a big commitment and required much time in maintaining a polished and sharp front. Nevertheless it helped us in the project at various stages to have such a public stance. The gains and struggles are discussed in the following two sections.

9.3.1 Transparent Process

We set out to have a *transparent process*, and while we succeeded in opening and publishing parts of our process, we did not get as much input as we wanted. As our research was conducted individually without any research project or company, it took some effort to make people aware of our project. We tried to utilize our website and the implemented chat as a platform for discussion. Unfortunately, this failed as we were not able to start any interesting discussion. During some of our projects, it was even “misused” as a tech support chat. Journals that we wrote had some effect on conveying knowledge to the public. Unfortunately, the writing of these articles took a long time, and we could only publish a subset of the topics that we wanted.

In general, a *transparent process* might be better aimed at larger research groups with the time and resources to communicate through their channels and build up momentum over a longer time.

9.3.2 Official Material

AWL requested a *Press Release* that their marketing department could use to market the exhibition in their channels. As neither of us had ever prepared a *Press Release*, we contemplated how such a thing should be prepared. By sitting down and putting it together, we, once again, had to define our project to fit a specific context which forced us to define it for ourselves as well. We spent some time on making it visually pleasing as we thought it might be of use in the future (A.4). Having a press release was useful when stakeholders asked for material about us and the exhibition similarly as the website worked during the conceptual exploration phase.

Having official material prepared allows focusing on other things to avoid unnecessary interruptions in the work when asked about our project by external parties.

9.4 Related Work

Light has been researched on and designed with in many different projects. Many of such projects are focused on pragmatic attributes, like the *Mediated Atmospheres* project increase the concentration [10], [117]. Our project instead focused solely on hedonic qualities. Furthermore did we only use non symbolic light while many projects use composed medias of sound, light and images [10], [11].

One attribute that we did not explore as far as we wanted is the directionality of light (direct vs indirect). Zhao *et al.* showed, in the *Mindful Photons* project, that changes in that can result in different experiences [19].

In general we think that we have been successful in mediating the atmospheres of rooms through our prototypes. We were also able to achieve this while maintaining good computation compositions [58] which we saw lacking in previous projects that tried to change atmospheres, for example the *Roomba Mood Ring* [21].

9.5 Light as a Design Material

Working with light as a design material showed to be more complicated than we thought. To control lights in an informed way, one needs a solid platform, both in software and hardware.

Artificial lighting needs technology to be created. Building this technology takes a long time. Therefore, researchers have to find a balance between the technical complexity of building their own light sources, which allows complete control, with using commercial or pre-existing lights, limiting the possibilities. The same applies to the software side when working with light. Using pre-made software can save time, but it also limits the possibilities of what can be expressed.

When using light as design material, one must also understand that the complexity does not grow linearly with the number of light sources. Each light interacts with all other lights and adds, therefore, extreme complexity. Limiting the control to a set of variables that in turn drive the colors showed to be a good trade-off between control and complexity even though it reduces the level of detail that can be shown.

Working with light also requires learning a new skill-set of appreciation. Previous knowledge in graphical design can be of use, but as light does not translate perfectly from screen to real-world, researchers need to learn a new language to express how light settings feel.

We both realized during the project that our appreciation for light situations was dramatically increased. With different experiments, we discovered how often similar light situations occur in natural settings. We got especially fixed on sunsets and light situations in the sky. In this way, we became Frederick the mouse [1].

9.5.1 Gradients

One observation that we made relatively early in the project is that gradients make things look real. This is especially true for light. In the real world, most light is mixed light from different sources, reflected and broken by the environment. When illuminating a space with only one color, an artificial feeling often arises, but when using two or more colors harmonizing together and creating soft gradients, more authentic and emotionally effective light situations can be created.

9.5.2 Physical Input

Through the exhibition, we also learned how valuable a physical input to engage with light is. People generally appreciated that we did not use a touch interface or phone to interact with the *Windows*. They felt that the physicality of the disk transported the idea of a memory very well and that the wooden Player device was a great contrast to the intangible nature of the light.

9.5.3 Photography

Photography is not only an excellent tool for documenting and communicating purposes; it also made us both more curious and creative in distinguishing interesting light phenomena. Through image processing, we experimented with how to change the symbolic content of a picture. Constantly searching for interesting color patterns and gradients also led to a greater appreciation of unique constellations of daylight. A person even mentioned that she appreciated our increased interest in beautiful skies.

9.6 COVID-19

Conducting a thesis during a global pandemic resulted in complications and difficulties but might have been favored at some points.

Finding a space to work in seemed difficult until we decided to use the *IxD studio*. This turned out to be advantageous as the studio contained a wood, electronic, and paint workshop. It was furthermore empty for most of the time as all other courses were conducted as home study.

Having a dedicated studio or place to work showed to be imperative for an RtD process. Our studio allowed us to have a place where we could build prototypes and even explore lights in a dark room. The close spatial relationship between these three forms of working led to a fast pace of prototyping and supported our approach of playful hacking.

An empty studio gave us many opportunities but affected other parts negatively. One of the biggest obstacles to our public experiments was the low number of participants because the building we were working in was nearly empty for most of the time. Having the experiments set up in a time with more people passing by might be more resultful. It would also be interesting to locate the experiments in a more public setting to get different groups of people to react to them.

We hoped we would find a company interested in working with us on the project, but it was hard to find a fit due to restricted access to offices and our idea being too far from commercial products. Although we received a positive response from *Kollision*, the current situation did not allow us to utilize it fully. The access to the AWL Studio is likely also thanks to COVID-19 due to underbooking of the space. Without COVID-19, it probably would have been challenging to find an exhibition space as well, as more events would have been hosted.

9.6.1 Exhibition

Hosting an exhibition during a pandemic worked surprisingly well. By having time slots, the number of people in the room was limited to a maximum of eight, including us. Limiting the number of people that could be in the space at the same time also had the effect of leaving the room relatively quiet. Multiple visitors mentioned that this helped them to feel the atmospheres.

The fact that we had time slots and we had to show people to the space created an opportunity for us to speak with nearly every visitor. This was extremely interesting as their thoughts and associations differed quite severely.

9.7 Accessibility

Working with light and especially trying to create atmospheres in darkened spaces creates a dilemma of accessibility. Brighter light sources that illuminate rooms evenly create more accessible light situations, but at the same time, they do not lead to interesting atmospheres. Our experiments tried to be accessible by letting the user (indirectly) choose the brightness. Our exhibition, on the other hand, did not offer this kind of interaction, and the whole space was only dimly lit through spotlights on the posters and the installation. Even though we did not get such feedback, this might have resulted in a bad experience for visually impaired people.

9.8 Cultural Differences

All light settings were designed by us, two European men with similar familial backgrounds. This limited cultural background might have led to the design of light settings that exhibit certain atmospheres for us and people with similar backgrounds. It might therefore be interesting to research how different humans with diverse cultural backgrounds perceive the same atmospheres. A book that describes such a different perception between western countries and Japan is *In Praise of Shadows* by Tanizaki [118]. They describe for example how western light design focuses on illuminating as much space as possible while traditional Japanese light designs leave space for shadows.

9.9 Future Iterations

During our project, we explored many different paths in the design space of light. Due to time constraints, we had to narrow down and focus on one expression of light.

In future iterations, it would be interesting to explore the other paths further. Especially the interaction of different materials with light would be interesting to explore. We created the first prototype of a moving lampshade and believed that this concept could be extended to open up a new way of working with light. Direct control of an object's shape and its expression of light might be a great interface.

9.9.1 (De)-Centralized Computing

In our exhibition, we had all artifacts controlled by a central computer. This allowed to synchronize and direct the lights from one place. However, it required the computer to be in the space at all times.

Having each artifact compute its own state and animation might be interesting as it would make the artifacts independent. It could be interesting to see if artifacts could share a common state by communicating. This could even be extended with different artifacts that have different sensors. The complexity of behaviors in the lights could then grow depending on the sensors and lights in the network.

9.9.2 Therapeutic Light

One of the visitors of our exhibition, a children and adolescents psychotherapist, was amazed by the light and argued that the light could be used to support therapies. Light settings could activate suppressed memories and feelings and be worked through with the help of a therapist. Warmer light settings could be used to create positive emotions.

9.9.3 Light Atmospheres

With the light settings and animations in the exhibition, we showed and explored first light settings and emotional responses. We created these settings in a relatively uninformed way by using our first-person viewpoint. It could be interesting to do quantitative studies to evaluate how different colors, movements, and patterns result in different memory responses and emotions. In the exhibition, for example, we had two saturated animations with fast movement and two less saturated animations with more subtle changes; it would have been interesting to see how subtle colors with fast movement affects the perceived environment.

It would also be interesting how different sensorial clues, like sound, smell, temperature, could support the transfer of an atmosphere. Especially sounds were mentioned often in the feedback from visitors.

9.9.4 Future Possibilities

This project aimed to spark a conversation about the future of artificial lighting and make people more present and appreciate light. During the project, multiple people reached out to us with tips, collaboration proposals, and ideas for further development. Through our Instagram followers sent us interesting smart lighting products and other stuff relating to our project. Explaining the project to people also made some share interesting articles and podcasts. One important example is the episode about light in the podcast *Filosofiska Rummet* which was of great inspiration early in the project [3].

The music producer Erik Friis, known as Samuraii, became interested after seeing a post on Instagram. He mentioned that he recently picked up an interest in light and wanted to hear more about our work. He explained that he wanted to explore how to add sound effects to lights instead of the common opposite. Possible collaborations were discussed, it was decided to keep in touch regarding the future.

A student from our program contacted us with the ambition of controlling our light using gesture control. Although his project did not lead to a collaboration, we were happy that our work sparked innovative and exciting ideas.

During the process and the exhibition, multiple people brought up how they could see different artifacts in their home or as a commercial product. Although this was not the goal of the research, we are pleased that people appreciate our work.

10

Conclusion

In this chapter we present the conclusions we drew from our project in regards to the research questions. We will first describe considerations when working with artificial light which answers the question: *What should be considered when working with artificial light as a design material when trying to recreate natural light situations?* As we had an applied approach to our work we also identified *What should be considered when using digital and physical tools to support the artificial light design process at different stages?*, thus answering our second research question. Through the prototypes created in our project, we managed to answer the third research question: *What value can be provided and supported by different mediating artifacts in an RtD process?*

When working with artificial light as a design material, we realized that two major parts have to be thought for: the physical manifestation of the light source and the light illumination itself. Light sources can be designed through *iterative prototyping in a physical form.* It can help to visualize the interaction of light with a lampshade through renderings, but the real design of the interaction between light and shade should be designed in reality while seeing and feeling the light.

As light is challenging to make sense of by solely imagination, it is helpful to engage with it in a constant prototyping way. Exploring the effect of different materials with lights in a tangible and real way helps develop interesting ideas.

Continuous prototyping and *playful hacking* is a great approach in generating a wide range of ideas that can be drawn from or combined in further iterations. Trying to solve technical problems when they occur generates knowledge and confidence to deal with new issues that occur. A specific example of this is how we decided to use DMX512 and Art-Net to control the lights.

As the light itself is more volatile and intangible, it is complicated to design it in an informed way. For early explorations, it is advisable to have *physical inputs* to change the lights attribute directly. These inputs do not have to influence the RGB values directly, but they can be attributes influencing a more complex setting, for example, the speed of an animation. Through this direct hand-eye coordination, the iteration cycle is reduced and allows quick explorations. This initial exploration through physical inputs is also a great way to get a feeling for how different values result in different lights and the limits of a light source.

For prototypes that are supposed to be deployed as experiments, it is *advisable to use code to control the lights*. This allows to map a variety of in- and outputs and quickly write different behaviors for the lights. Designers that have the knowledge to write their own programs should do so as it opens up a whole space of possibilities. It allows inputs from different sources, output in diverse protocols, and a code structure that fits the project. Though code lights can be directly manipulated and designers can add layers of abstractions as they wish. Commercial software can be limiting in the early phases of the project by dictating the directions or way of working with light.

Early experiments can be written in throw-away code to explore concepts quickly. Many software routines can be reused with the project advancing, and the code should become more rigid and stable. Writing code in a modular way supports this process by allowing different parts to become stable while others can still be in flux.

Code can not only be used to control the light but also for explorations of different simulations. It is especially powerful when combined with a *graphical output*. In that way, static or moving pre-visualizations of light can be done.

Programming can also be used to spark creativity and expand the own mental model. Using “wrong” simulations or using values outside the specification is especially helpful as the created images are no longer constrained to reality. Even though the created images are not representing real situations, they can still contain deep poetic and inspirational value.

When advancing to a stage in which stability is of major concern, i.e., during an exhibition, one can move to commercial light control software. There is a multitude of programs to control and design with light. While many of such programs are targeted at stage design and might therefore be too rigid, there are more open platform tools that support various applications, such as *TouchDesigner*.

Such a program allows defining algorithms visually. This is especially powerful when using advanced algorithms with multiple inputs and outputs that are hard to understand. The visual nature allows the designer to create a mental model of the process. It is also easier to spot mistakes in such a program as one can see intermediate products. When using such programs, one should be aware that they usually require more powerful computers and might not be able to be deployed on micro-controllers that are usually embedded in smaller designs.

To explore artificial light, it also *helpful to have a dark space*. Preferably this room should either be or mirror the space of the intended location. This is especially true when the light sources are supposed to be arranged in a constellation. Any change in location and relation of lights will affect the perceived atmosphere.

The use of different media and mediating artifacts during RtD can provide much value in opening up a design space, externalizing gained knowledge, and sparking conversations.

Early in the project the knowledge is limited, and the map of possibilities is unexplored. The creation of a project *website* can be seen as the first step to a more specific direction and to define the overall stance of the project. Doing so invites the researchers to define what they are doing and take time to formulate their goals. It furthermore is a first opening to the public. Doing so early in a project has shown to be valuable when contacting possible partners and stakeholders of the project as the website communicates the ambition and qualities of the project.

Using the website as a platform to publish new research findings works great. The format of journal entries written in a not completely serious tone can make the project accessible and interesting. Regularly releasing such journal entries with new insights from the research simplifies it to follow and understand the project. Making it relatable and understandable is crucial to engage people. Some visitors at the exhibition mentioned that they followed the posts from the website and that it made them curious about the project and subject.

Adding an *anonymous communication* function or chat to the project website might generate some feedback, but in our experience, it only creates a small amount of engagement, and only a fraction of that is valuable input or feedback. The amount of work that is required to create and sustain such a chat is too big for the value it might generate. In our project, nearly all interesting conversations were started either verbally in real life or through the Instagram chat.

Social media is a great tool to communicate with a larger audience. In contrast to the project website are social media channels easier to advertise as these are already used by most people. Sharing images of artifacts communicate knowledge from the process. This creates a bond from the viewers to the project. We received several messages from people who wanted to share other projects or designs in our design space.

Documentation of interesting light phenomena and settings through *photography* made us more aware and appreciative of light and colors.

Public experiments can be used to showcase what is being worked on but also as a way to collect feedback. Using a simple web interface reachable with a QR-code made it easy for people to connect without us being present. These experiments do not necessarily result in qualitative or quantitative data but provide value in conveying the progress and show innovative objects that can start a discussion. Some of our experiments resulted in exciting conversations with people that saw them, but we did not receive any feedback through our chat. Therefore, public experiments might be a better tool to show people what the researchers are doing than collecting feedback.

Showcasing the result or even a process snapshot in an *exhibition* can be a valuable tool to start conversations. From all our ways of engaging with a public audience, this was the most effective. An exhibition allows people with no prior knowledge of the project to become aware of it. By communicating through the exhibition, the project parts to be shown can be selected and staged so that the knowledge reaches a public viewer outside of the domain. Parts that are unfinished, too complicated, or distracting can be omitted.

It showed to be valuable to leave the knowledge and devices in the exhibition *open to interpretation* while still giving enough hints to direct the thought process of the viewers. The ambiguity can help to spark different kinds of discussion that the researchers would normally not assume. The uncertainty also leaves viewers wondering and thinking about the exhibition longer than a formal showcase would, and they hopefully bring this thought home.

Posters are a great tool to communicate knowledge ambiguously. They can contain abstract images that make the viewer wonder. Title and description can be used to direct the viewer in a particular direction.

Having a functional *interactive piece* in the exhibition is a great way of engaging visitors. It helps to transfer an idea by showing an example of how something could work. By not having a clear real-world use-case, the artifact stays open to discussion, and viewers can project their own ideas, commercial or hedonistic, onto it.

We also found that not openly utilizing digital materials, or even contextualizing the exhibited artifacts in a world without virtuality, can help to direct the focus on the idea itself and away from the look and function of the interface. Creating a highly polished artifact and using materials that are not commonly connected to digital processes, such as wood, helps to guide viewers further away from thinking about the technical parts to the direction of the idea itself.

Different *intermediate artifacts* that are created to support an exhibition can help to clarify to the researchers what their work is actually about and in what ways one could think about it. These artifacts can include posters and presentations but also more utilitarian things like press releases. Different channels of communicating with a public audience resulted in different engagements. While the website with the chat did create some interest, most were sparked through social media.

In this thesis, we have described how to work with light as design material while at the same time sharing knowledge through a transparent process. We have shown different supporting artifacts that served the exploration of the design space, and finally, a public exhibition as a place to converse. We succeeded in opening up a design space and sparking inspiration and conversation about the future of artificial lighting. This thesis may serve as a pillar carrying this design space so that it can be expanded upon by other researchers. We hope to inspire them to extend on our work. The future is bright.

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A

Appendix

A.1 Proposal Kolission

Ambient Atmospheres

COLLABORATION PROPOSAL

Frederik Max Göbel
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frederikgoebel.de

Mattias Hallin
mattais@student.chalmers.se
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Ambient Atmosphere Sampling and Reproduction

This project aims to use the advancement in smart lights and phones to reproduce encountered atmospheres inside the users home.

Each generation of smartphones brings increasing quality of visual and auditory recording. For now these recordings are made accessible through photos and videos. While these do great jobs by acting as memory-bridges to remember scenes from the past it seems they are only mirroring their analog equivalents. The digital medium allows non linear playbacks but also the near instant analysis of a recording. Furthermore are smartphones able to capture even more information during recordings like orientation, movement and time. Therefore it would be interesting to explore new ways of using the visual, auditory and extra data in combined ways to sample abstract atmospheres.

Smart lights have gained traction in the last couple of years but most interactions with such lights are still limited to the change of hue or automatic on/off switching. Furthermore has there been very little advancement in the lamp shapes themselves to reflect the digitalization of light. With only the bulb itself changing, static physical lamps and disregarded environments unnatural compositions emerge. But if instead all these materials are used as a compound they might be able to reproduce sampled atmospheres.

Combining the sampling and reproduction a unique way of remembering and reliving atmospheres could be achieved.

Exhibition

To spark a conversation about how the rapid technological changes of smart lights, ambiguous computing and recording possibilities will transform the way we can use light in the future we aim to create a speculative, but functional, exhibition piece.

We expect this artifact to be high-fidelity prototype that is able to recreate sampled light environments. In addition we aim to create a mid- to high-fidelity prototype of an ambient light sampling device or software.

At this stage we envision the light recreation artifact to be a large scale, room like, installation that visitors can step into to experience their sampled atmospheres. Even though we haven't decided how exactly the exhibition will look like we played with the thought to build an abstracted bed-room as the exhibition space to provide a context for the viewer.

We are thinking of using multiple light sources to recreate the sampled ambiances. Each light source can be controlled individually to change common attributes like hue, saturation and brightness. But it will also be possible to change the composition and relation of lights to change where light is coming from (direct/ indirect) and what textures are created by the lights. We think that by also altering the rate of change of these attributes real light ambiances can be reproduced.

All these variables should be controlled by the input from the sampled atmosphere. Therefore we will need to establish a mapping between measurement, atmosphere and light variables.

Sample

- Light color and direction
- Light movement
- Change of light over time
- Shadows
- Time

Ground

- Omnidirectional light bulbs
- Single colored lights
- Static lights

Re-created Atmosphere

- Re-created shadow and light pattern
- Moving light patches
- Mapping based on environment and textures

Mattias & Frederik

To make our vision in that scale reality we would need a **space for the exhibition**.

We would also need a **space to build** the final prototype.

In addition it would be great to **exchange knowledge**. Especially about how to design with light, different light sources and technology.

It would help us a lot if we could borrow **light fixtures** for the duration of this master thesis. At this point in time we do not know what light sources exactly we will need and would therefore like to receive input about the choice of different lights as well.

Kollision

As we are not creating a commercial product there is no monetary incentive for you to help us. Instead we can **offer the knowledge** we will gain during the thesis about light usage for ambient atmospheres.

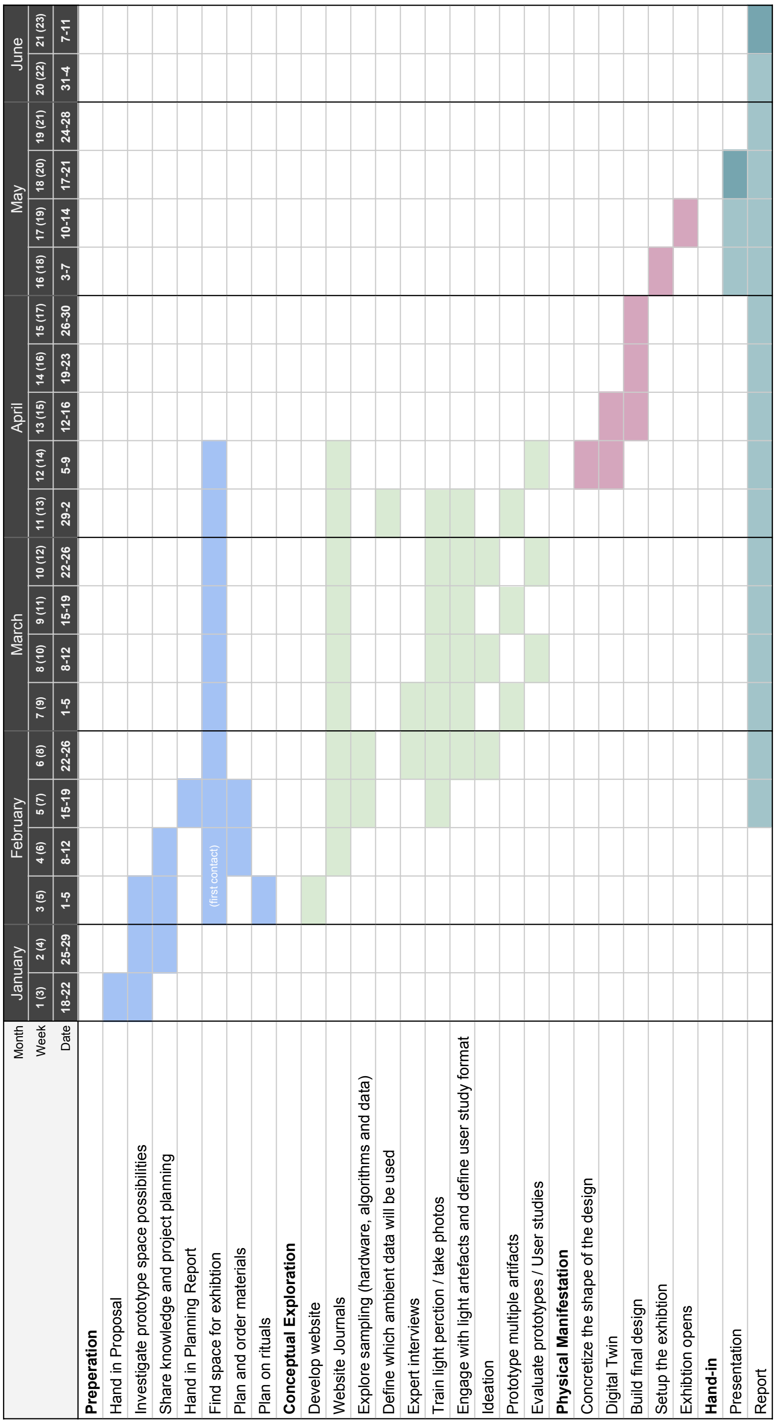
The exhibition could be seen as a **collaborative project** and therefore become part of **Kollision's portfolio**. At the same time it can serve as an **advertisement** for the company.

The collaboration would also be mentioned as an important part of the process in the **published thesis**.

Thank you!

We look forward hearing from you.

A.2 Time Plan


Month
Week
Date
January
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April
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June
1 (3)
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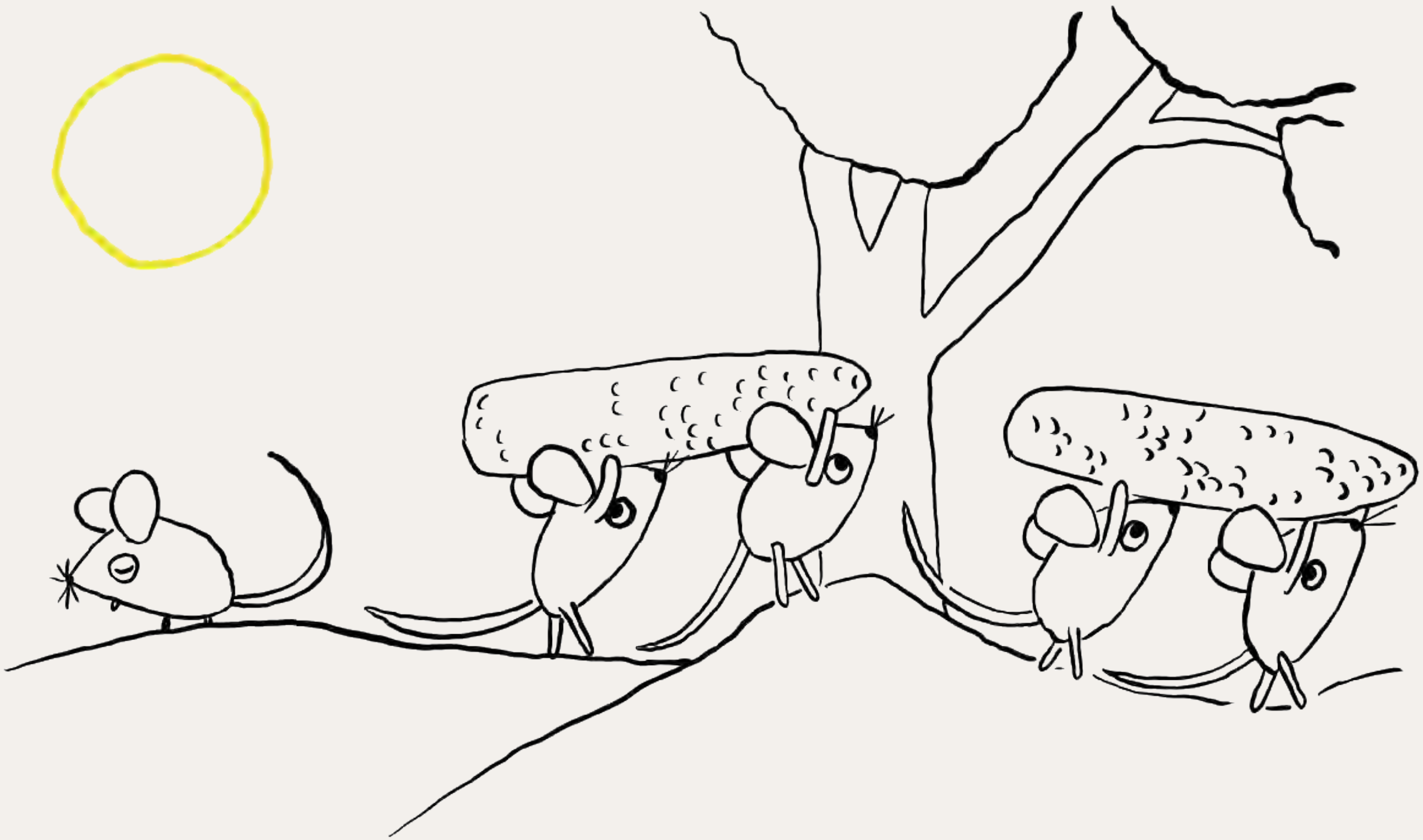
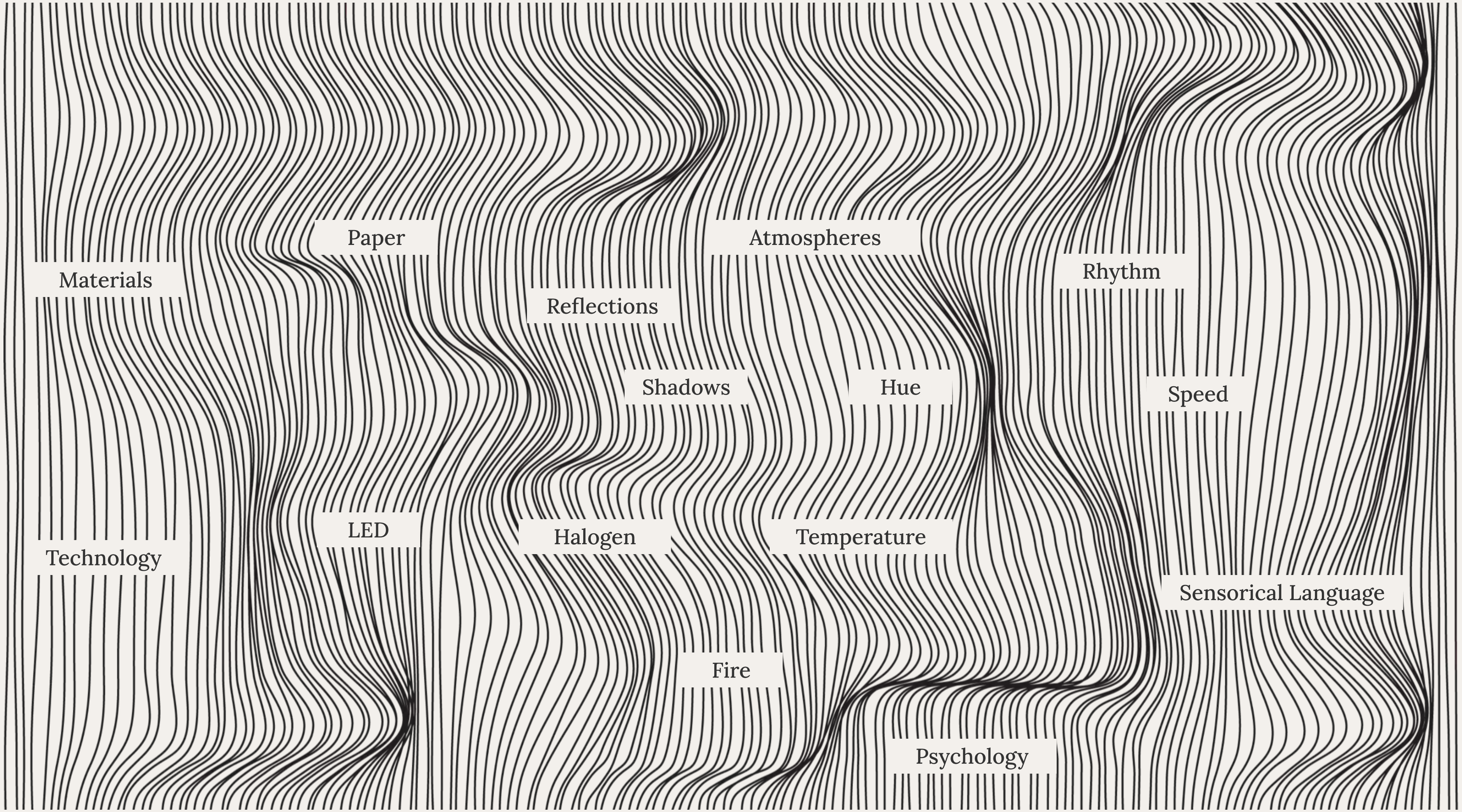
8-12
15-19
22-26
29-2
5-9
12-16
19-23
26-30
3-7
10-14
17-21
24-28
31-4
7-11
Preperation
Hand in Proposal
Investigate prototype space possibilities
Share knowledge and project planning
Hand in Planning Report
Find space for exhibition
(first contact)
Plan and order materials
Plan on rituals
Conceptual Exploration
Develop website
Website Journals
Explore sampling (hardware, algorithms and data)
Define which ambient data will be used
Expert interviews
Train light perction / take photos
Engage with light artefacts and define user study format
Ideation
Prototype multiple artifacts
Evaluate prototypes / User studies
Physical Manifestation
Concretize the shape of the design
Digital Twin
Build final design
Setup the exhibition
Exhibtion opens
Hand-in
Presentation
Report

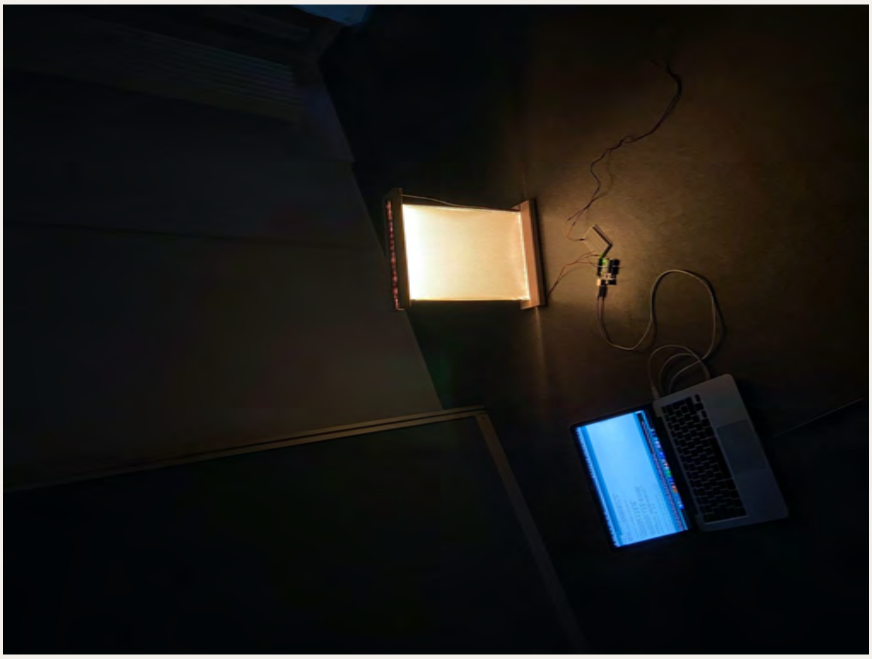
A.3 Guest Lecture

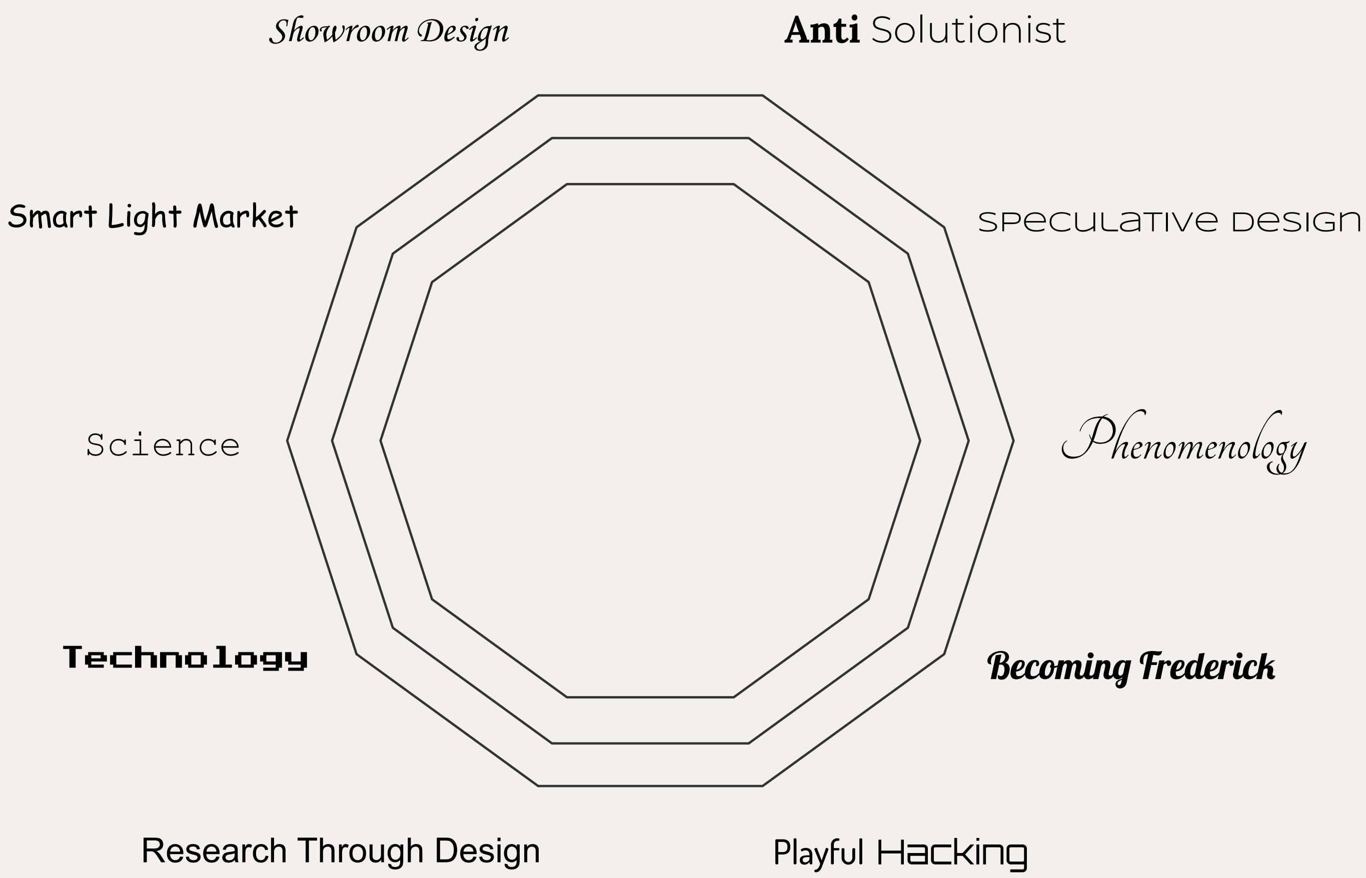


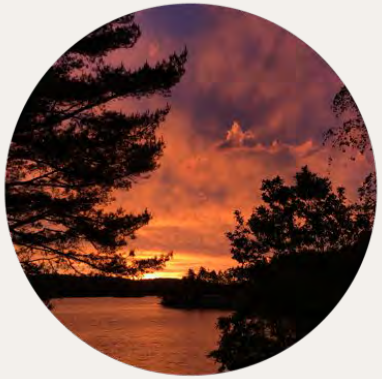
Res **Design*** earch

* Research Through Design


Paper
Atmospheres
Materials
Rhythm
Reflections
Shadows
Hue
Speed
LED
Halogen
Temperature
Technology
Sensorical Language
Fire
Psychology




Showroom Design
Anti Solutionist
Smart Light Market
Speculative Design
Science
Phenomenology
Technology
Becoming Frederick
Research Through Design
Playful Hacking



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Sample

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Ground

- Omnidirectional light bulbs
- Single colored lights
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Re-created Atmosphere

- Re-created shadow and light pattern
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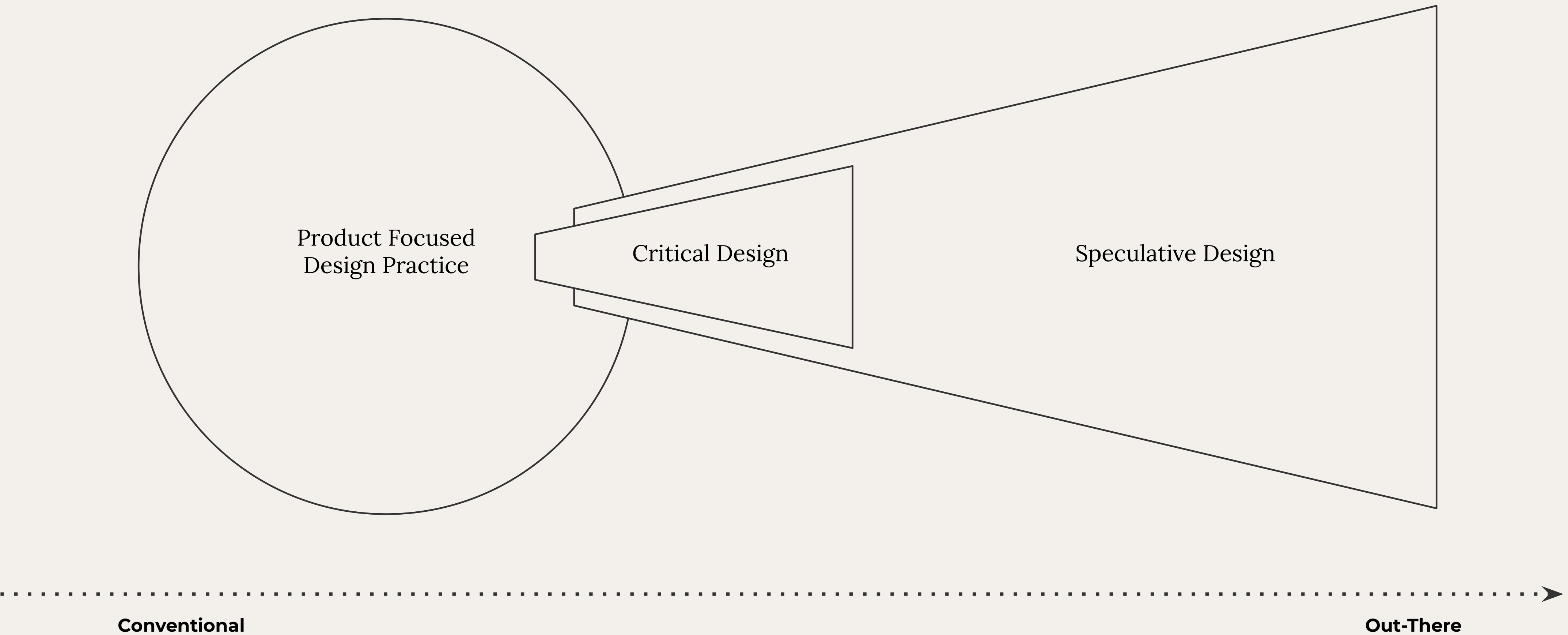
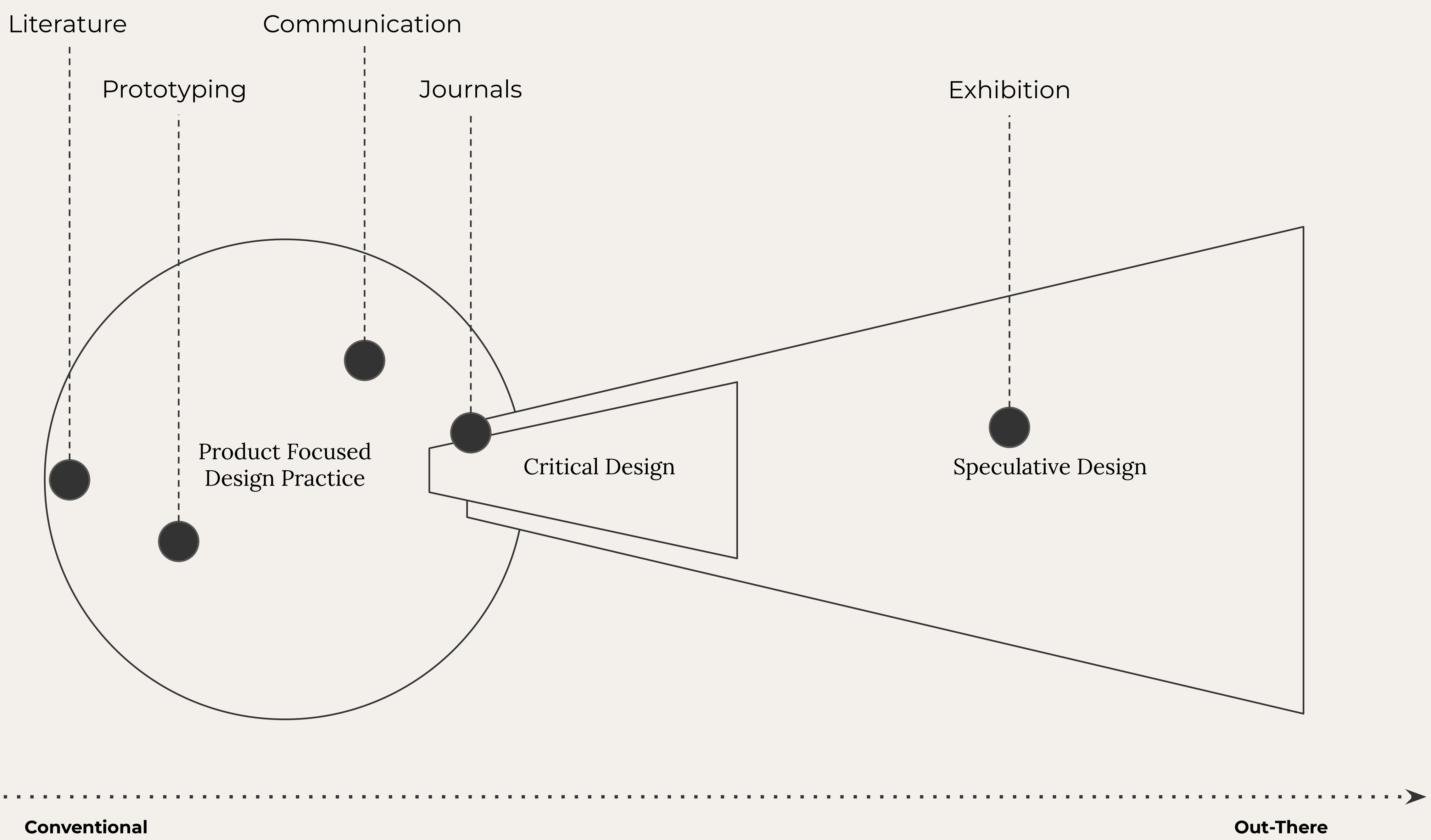
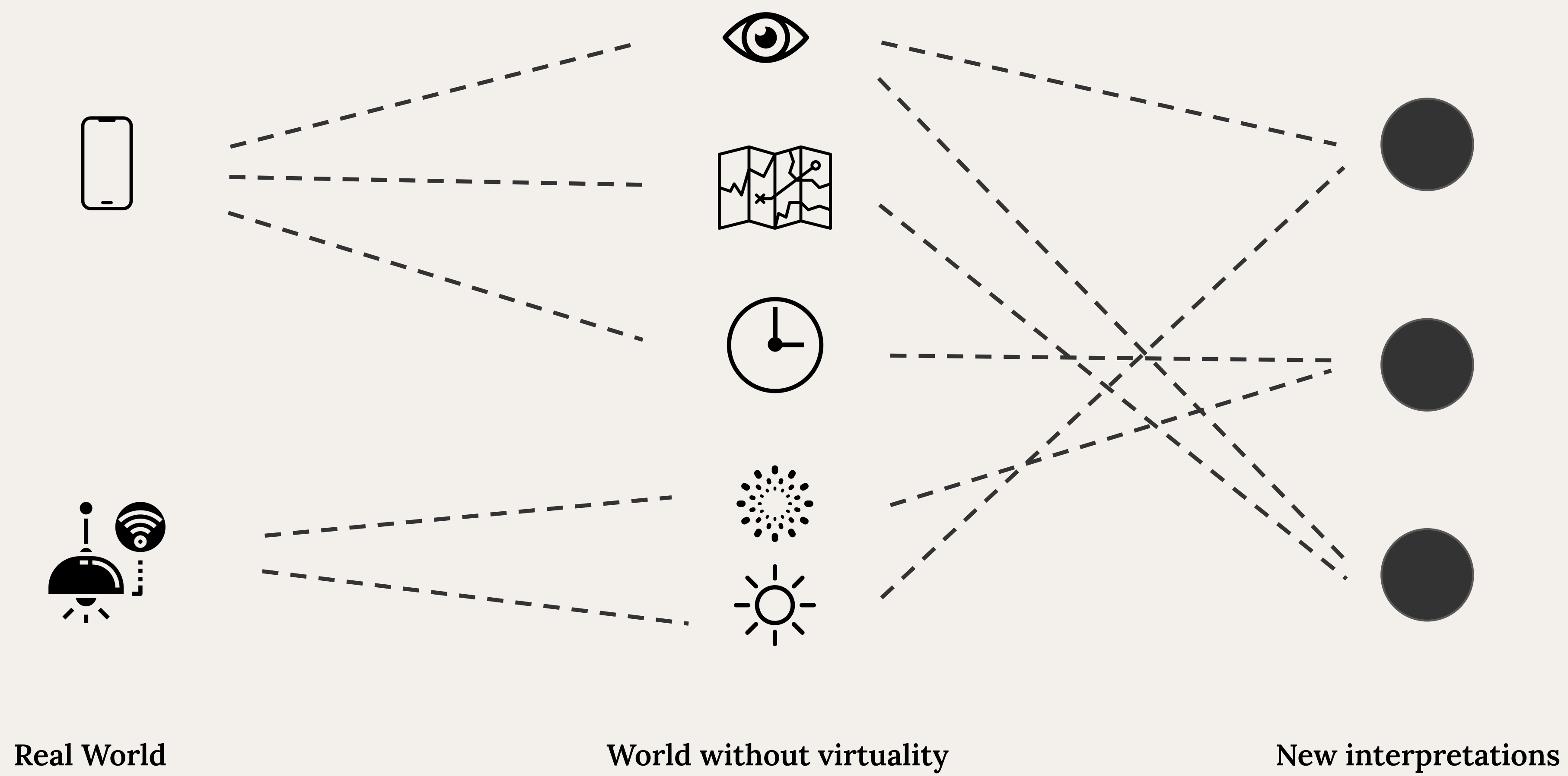

Product Focused
Design Practice
Critical Design
Speculative Design
Conventional
Out-There


Literature
Prototyping
Communication
Journals
Exhibition
Product Focused
Design Practice
Critical Design
Speculative Design
Conventional
Out-There


Real World
World without virtuality
New interpretations

Thank you!

Come to our exhibition!

fb.me/e/1DZgwyAC2

ambient-atmospheres.com
@ambient.atmospheres

Ambient
Atmospheres

A.4 Press Release

Bright Memories

Ambient Atmospheres
TOPOLOGY OF LIGHT

THE PROJECT

Ambient Atmospheres is a project aiming to spark a conversation about the future of artificial lighting. In our research we are exploring how atmospheres are created, how we interact with digital lights and in how far we can translate natural light settings into new contexts.

While our work is grounded in scientific research and continuous prototyping we take an artistic stance to communicate our ideas.

By working closely with physical and digital materials we are able to create our own ecosystem of lights. Our framework allows us to engage with the real representations of discrete calculations and bridge the gap between numbers and emotions.

Through our website we invite people to follow our process, play with light and join the conversation.

THE EXHIBITION

What if you could not only save a moment as a picture or video but you could save the feeling, the atmosphere of your surroundings?

And what if you could change your room to make it feel like that moment, to use light as a memory bridge in the same way you look at old pictures or play that one song to change your mood?

With modern sampling technology, complex algorithms, advancements in artificial lighting and modern knowledge of human psychology this idea might be within our reach.

In the exhibition ”Ambient Atmospheres - Bright Memories” we explore how far ambiances are translatable and how a possible implementation might look like. Our artifacts are contextualized in an alternative future in which no virtuality exists and all technical processes are overdrawn and symbolic. Visitors are invited to create their own interpretation of how exactly the exhibited devices work and how they translate to our world of technology.

Exhibition open May 15 – 19
At A Working Lab, Johanneberg Science Park
Sven Hultins Plats 5
Göteborg

fb.me/e/1DZgwyAC2
@ambient.atmospheres
ambient-atmospheres.com

ABOUT US

Mattias Hallin

Industrial design engineering student pursuing his master in interaction design and technologies. In his work he focuses on combining digital and physical design to create interesting and innovative interactions.

mattiashallin.com

Frederik Max Göbel

Interaction design student with a background in computer science and communication design. His work focuses on tangible interactions beyond the screen.

frederikgoebel.de

A.5 Exhibition advertisement poster

A.6 Toilet experiment poster

A.7 Bright Memories Brochure

Bright Memories

What if you could not only save a moment as a picture or video but save the feeling, the atmosphere of your surroundings?

What if you could change your room to make it feel like that moment, to use light as a memory bridge in the same way you look at old pictures or play that one song to change your mood?

With modern sampling technology, complex algorithms, advancements in artificial lighting and modern knowledge of human psychology this idea might be within our reach.

In the exhibition *Bright Memories* the two interaction designers Mattias Hallin and Frederik Göbel explore how far ambiances are translatable and how a possible implementation might look like. The shown artifacts are contextualized in an alternative future in which no virtuality exists and all technical processes are overdrawn and symbolic. Visitors are invited to create their own interpretation of how exactly the exhibited devices work and how they translate to our world of technology.

ambient-atmospheres.com
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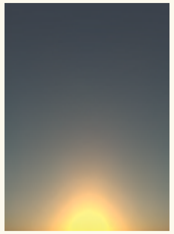
Bright Memories

Ambient Atmospheres
TOPOLOGY OF LIGHT

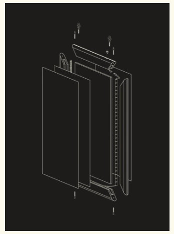


Taken With a MacBook Pro

Sunset and sunrise can be simulated through different computational models. The look of the simulation is influenced by attributes like time, location, ground color and particles in the air.

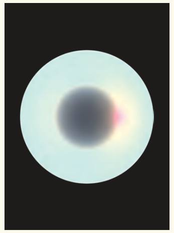
The Sunset Never Sets

Interpreting the sun's position in non-linear time allows to step out of previously known experiences.



Framing the Light

With relatively simple technology it is possible to create diffuse light sources that can be used to represent atmospheres.



Overcoming Reality

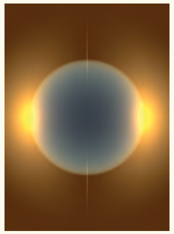
Once we are able to simulate a sunset we can not only recreate seen scenes but start to imagine. What does a sunset on Venus feel like?

Creased Light

Shadows on folded paper or a dynamic lamp shade?

Illumination Vectors

We are taught that light travels in a straight line but it is helpful to think about light as different forces that interfere and redirect each other.

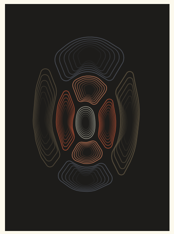


Help! I Screwed Up the Math

Translated lights might fail by simple mathematical mistakes. But these errors might also lead to new experiences, unseen lights and poetic simulations.

Shapes Shape Shadow

Shadows carry information about lights illuminating objects. Computers can interpret these patterns to estimate the position and radiance of the light source.



Colored Space

Different colors and saturations of light can help to direct the focus in a space. Brighter colors pull the viewers attention while darker, dull colors help in framing a scene.

A.8 Exhibition introduction poster text

Bright Memories

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In the exhibition Bright Memories the two interaction designers Mattias Hallin and Frederik Göbel explore how far ambiances are translatable and how a possible implementation might look like. The shown artifacts are contextualized in an alternative future in which no virtuality exists and all technical processes are overdrawn and symbolic. Visitors are invited to create their own interpretation of how exactly the exhibited devices work and how they translate to our world of technology.

Ambient Atmospheres

Bright Memories is a part of the Ambient Atmospheres research project aiming to spark a conversation about the future of artificial lighting. The project explores how atmospheres are created, how we interact with digital lights and in how far natural light settings are translatable to new contexts.

The two researchers stay grounded in scientific research and continuous prototyping but take an artistic stance to communicate their ideas. By working closely with physical and digital materials they were able to develop their own ecosystem of lights. Their framework enables them to engage with the real representations of discrete calculations and bridge the gap between numbers and emotions.

Parts of their research focused on quantitative measurements of natural light settings through modern technology and algorithms.

They explored how different light phenomena can be reproduced through computerized lights and how simulations can extend out of the virtual space into the physicality of reality.

By making parts of the process public through their website, Instagram and this exhibition they hope to spark interest in and discussion about the future of artificial lighting.

ambient-atmospheres.com
@ambient.atmospheres

Mattias Hallin

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mattiashallin.com

Frederik Max Göbel

Interaction design student with a background in computer science and communication design. Through his work he investigates the tangible interplay of human and digital artifact.

frederikgoebel.de

A.9 Evaluation Script

1. *Introduction*
   Hello and welcome to this evaluation session of the interactive exhibition Bright Memories. We have conducted research on artificial lighting for 5 months and this installation is showing selected pieces of our process. For the first part of the evaluation we would like you to enter the exhibition space and walk through it on your own. Feel free to read and play around. We will wait outside and after 10 minutes we will join you for a walk through.

   As you might notice the posters are lying the floor, that is unfortunately not a feature. We have sadly enough not yet received the hangers.

   During the walk through we will ask you questions and to reflect on different parts of the installation. Is it okay if we record you during the walk through?

   Please use hand sanitizer before you enter the space.

2. *Alone walking in the space for roughly 5 minutes*

3. *Walk through space with them again*
   Hi, here we are again! So first you can just leave out any thoughts / opinions that you had. Everything is good.

   (a) *Walk to the left poster set*
   What does this set of posters convey to you? What associations do you have?

   (b) *Walk to right poster set*
   What ideas do these posters create in your head? Do you have thoughts about how the shown artifacts could be used in artificial lighting?

(c) *Walk to player*
Take an memory that you find interesting and play it. Why do you think it is interesting? What did it make you feel

(d) *Walk to light installation*
What light atmospheres do you think could be represented by this installation?

4. Room for talk