The Spirit of Things

Biophilic Light in Urban Environments

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# INDEX

Abstract 4

1 Introduction 5
   1.1 The Spirit of Things 5
   1.2 Purpose and Aim 5
   1.3 Terminology 7

2 Methodology 7

3 Literature Review 9
   3.1 Definition of Biophilia 10
   3.2 Benefits of Biophilia, Brief Overview 10
   3.3 Areas of Exploration 12

4 Observations in Nature 15
   4.1 Soft Fascination Samples 16
   4.2 Gradual Variability Samples 17
   4.3 Dappled Light 18

5 Biophilic Lighting Design 20
   5.1 Definition of Biophilic Lighting Design 21
   5.2 Project Examples 22
   5.3 Parameters 23

6 Summary 24

7 Site Analysis 27

8 Model Testing 32

9 Lighting Design Concept 35
   9.1 Concept Outline 36
   9.2 Perspectives 38
   9.3 Evaluation 43

10 Discussion & Conclusion 46

References 48

List of Figures 51

Appendix 52
Abstract

This thesis looks to human biophilic response to natural environments, seeking to uncover methods to aid human health and well-being in urban environments. Light is explored as a source of soft fascination and as a tool to support cognition based on attention restoration theory and mind-wandering. Its biophilic potential is primarily linked to the direct visual experience of light itself but also to the ability of light to influence spatial perception. This forms the theoretical basis for a lighting design concept for an underground subway station in Stockholm. The concept draws inspiration directly from dappled light pattern found in nature which is translated for the urban environment. To contextualize the concept and its underlying theory it is related to a selection of project examples. Evaluation and analysis of the examples is used to define and point out an existing tradition of biophilic lighting design.

This thesis exemplifies how light can be used to trigger biophilic response, encourages doing so in urban environments and argues for further investigation into an arguably underexplored, complex and blurry area of research.

Keywords: Biophilia, nature, light, underground, soft fascination, attention restoration theory, mind-wandering, cognition, dappling, pattern, enclosure.
I. Introduction

1.1 The Spirit of Things

Human-centric lighting pose the question of how light can be used for the benefit of human health and well-being (Houser et al., 2021). Biophilia seeks to understand the relationship between humans and the natural world and so adds a valuable perspective. While all aspects of nature can’t be replaced with light, I believe that biophilic lighting design creates opportunity to reap some of its benefits. Looking to human response to nature can provide insight into how urban environments can be made more human-centric.

On a personal level two things led me to an interest in biophilia. The first thing was a year spent in a heavily urbanized environment (Melbourne, Australia). The absence of nature triggered “nature-cravings”, which had to be satisfied by frequent visits to national parks, and the benefits of nature became more tangible than ever. The second thing was a year of studying lighting design and noticing how often discussions related to and answers were found in nature and daylight.

The process of writing this thesis I have convinced me that there are many more stones to turn when it comes to light and biophilia. It provided me with a glimpse of how theory and practice can be bridged. Light brings life into the environment, biophilia explores life in the environment. They both dabble in the spirit of things.

1.2 Purpose and Aim

In a broad sense the purpose and aim of this thesis is to explore potentials and methods of biophilic lighting design in an urban context. This is narrowed down to a more specific central research question of:

“Can a biophilic lighting design concept for an underground Stockholm subway station be developed to support cognition by recreating and implementing elements of “soft fascination” found in nature?”
1.3 Terminology

Here various terms are collected and defined for understanding in the context of this thesis. If no external source is referenced the term has been defined by the author.

**Biophilia**

“The innate tendency to focus on life and lifelike processes.” (Wilson, 1984, p. 1)

**Biophilic Response**

Mind and body reactions developed in response to natural environments. Most commonly belonging to the categories of cognition, affect and/or stress.

**Biophilic Lighting Design**

Any lighting design project or installation inducing biophilic response.

**Biophilic Medium**

Anything physical (such as light) which can be perceived by the human body and/or mind and be used as a tool to induce biophilic response.

**Soft Fascination**

Visual “processes or objects” commonly found in nature which “readily hold attention, but in an undramatic fashion” and “provides opportunity for reflection” (Kaplan, 1995)

**Gradual Variability**

Gradual shifts in the intensity, color temperature, distribution, and other variables of light which are only perceived over a longer duration of time and therefore do not hold attention.

**Attention Restoration Theory / ART**

The theory of how directed attention is replenished through visual exposure to soft fascination (Kaplan 1989, 1995)

**Mind-wandering**

“A shift in the contents of thought away from an ongoing task and/or from events in the external environment to self-generated thoughts and feelings” (Smallwood & Schooler, 2015)
2. Methodology

Research
Research is conducted to understand how we benefit from nature through biophilic response, and how this is connected to the medium of light. Information is collected by reading diverse literature from various relevant fields - psychology, environmental psychology, ecology, neuroscience, light and lighting design, architecture. The information is connected and reflected upon.

Research is also conducted by studying existing lighting design projects and installations which trigger biophilic response. The projects are categorized based on the way in and degree of which they relate to/interact with natural environments. Evaluation and analysis of the projects are conducted to identify biophilic design parameters and methods. The knowledge gathered from the analysis forms a scientific base to inform the design.

Observation in Nature
Observation in nature is carried out to evaluate the behaviour of natural light as a source of soft fascination. But also to evaluate how light creates gradual variability in the environment. Methods of observation include direct observation, note-taking, sketching, photography and video. The observations are collected, summarized and illustrated in a sample bank.
Dappled lighting is studied more in depth, as it is chosen as source of inspiration for design elements of soft fascination in the subsequent design concept. It is photographed against a square piece of white paper (38x38 cm) brought along during observations at different times of day in order to separate the natural light effect and its behaviour from the vegetation. Its intensity, color temperature, distribution, level of contrast, scale and movement is studied.

Site Analysis
A site analysis is made of an underground subway station lacking daylight and natural elements, in order to understand the potentials and limitations of applying biophilic lighting design in the chosen context. Analysis is made from an architectural perspective, considering aspects such as spatial perception and movement. The space is also evaluated from a biophilic perspective, considering aspects such as depth of view / prospect and presence of natural elements which influence spatial preference. An analysis of the lighting is made to understand the current use of light in the space.

Scale Model Tests
By conducting tests in a simple scale model, an understanding is built of how contrast between brightness and darkness can be used to alter the spatial perception through its impact on sense of enclosure. This is connected to the identified issue of sense of enclosure discovered during the site analysis. It can also be used to gain an increased understanding of the impact of dappled pattern on spatial perception, particularly by altering the scale of the pattern. This is connected to the choice of dappled light as a design element of soft fascination.

Design Concept
The gathered material is combined in a design process and used to inform a proposed lighting design concept for a subway station. The final concept is presented and communicated in a collection of illustrated perspectives.

Survey
As a last step the illustrated perspectives of the design concept are evaluated in an online survey. They are compared to illustrated perspectives of the current design solution. Points of evaluation cover indicators of soft fascination, sense of enclosure as well as induced association to nature.

Limitations
The research on biophilia is somewhat limited, with a lot still to be researched. The best way of confirming the effects which constitute the aim of the design would be to create a large scale installation and do testing with methods such as “forward and backward digit span test”, “experience sampling” (ES), mobile eye tracking, etc - but this is beyond the time-frame, current personal level of knowledge and methods available.

The results of the survey are not to be considered as fully reliable or accurate conclusions, but rather as preliminary indicators. Evaluating three-dimensional environments with images in this way alters the experience. The level of realism is not as high as it could have been which further compromises the method.
3. Literature Review

This chapter outlines general background information about biophilia and biophilic response by providing a brief overview of literature. It then relates the research to light, narrowing down the theory to a more specific focus. This forms the theoretical foundation which the remainder of the thesis revolves around.
3.1 Definition of Biophilia

In 1984 Edward O. Wilson defined Biophilia as “the innate tendency to focus on life and lifelike processes” (Wilson, 1984, p. 1). The theory behind the concept holds that biophilia is embedded in our genes and that response mechanisms to natural stimuli have evolved through evolutionary process and advantage (Ulrich, 1993; Wilson 1984; 1993).

Rather than just a single instinct, Biophilia is suggested to consist of a cluster of individual learning rules. The cluster, though there is no agreed upon definition of it, evokes a range of emotional responses to interaction with nature and the living world (Wilson, 1993).

3.2 Benefits of Biophilia, Brief Overview

Studies of the effects and benefits of exposure to nature has focused on 3 main areas: affect, stress and cognition. Though often studied separately, it is worth pointing out that they are connected and influence each other in various ways as part of a larger mind-body system. There is also a growing body of research on the biophilic benefits of natural light. This section is intended to provide a brief overview.

**Affect**
Natural landscapes evoke emotional response and positive mood shift (Hartig, et al., 2003; Berman et al., 2012; McMahan & Estes, 2015; Neill, Gerard & Arbuthnott, 2019). This is evident in aesthetic preference for and stronger positive response to natural landscapes in comparison to urban landscapes (Valtchanov & Ellard, 2015; 2010; Hartig et al. 2003). The biophilia hypothesis holds that these emotional responses developed through evolutionary advantage, creating aesthetic preference for certain types of landscape elements which are perceived as beneficial (Ulrich, 1993). Theories such as the refuge-prospect theory (Appleton, 1975) developed from this understanding. Although other, non-evolutionary factors such as cultural background also impact landscape preference (Ren, 2019), evidence support the notion that certain landscape characteristics are in general preferred above others (Grahn, 2010). In The Biophilia Hypothesis (1993), based on research existing at the time, authors discussed closed spaces, heights and darkness as eliciting negative response and water, vegetation and openness as eliciting positive response (Ulrich, 1993; Heerwagen & Orians, 1993; Wilson, 1993). Positive emotional response to natural environments is not dependent on long exposure; responses have been shown to occur rapidly and within minutes, even from brief exposure (Barton & Pretty, 2010; Neill, Gerard & Arbuthnott, 2019).
Stress
Nature has a restorative effect on stress, impacting various physiological indicators such as muscle tension, pulse and blood pressure, but the effect is also evident in the shift from negative emotions such as fear and anger to positive emotions - known as an indicator of stress relief (Ulrich et al., 1991; Hartig et al., 2003). Research indicate that the natural environments have to be perceived as unthreatening for restoration to occur and presence of natural elements and option to retreat to a secluded and safe space, or refuge, have been identified as important spatial qualities for achieving the effect (Grahn, 2010; Ulrich et al., 1991). Exposure to natural environments can reduce stress even if short-term, restorative effects are known to occur within minutes, and more frequent or longer durations of exposure contribute to overall well-being (Ulrich, 1993; Ulrich et al., 1991).

Cognition
Research suggest that exposure to natural environments nurture cognitive functioning and performance. For example, its effect have been shown to aid creative thinking process (Williams et al., 2018), to improve attentional control (Tennessee and Cimprich, 1995) and to have a positive impact on concentration and impulse inhibition (Faber et al., 2002). An important cognitive benefit of exposure to natural environments consists of the recovery from mental fatigue. This effect is derived from nature’s ability to replenish directed attention through so called “soft fascination” - a theory known as “Attention Restoration Theory” (Kaplan, 1995; Berman et al, 2008).

Natural Light
Light is a foundational component of nature and biophilia. Research on natural light maps visual and physiological effects, as well as conscious and subliminal processing. It is a young and novel field of research in the process of expanding.

Similar to natural environments, daylight has been shown to induce positive emotional response, improve mood and to have a therapeutic effect on depression (Figueiro, et al., 2017; Benedetti et al., 2001). Studies conducted in hospital environments have produced findings that daylight can promote healing, shorten hospital-stay and reduce pain (Walch, et al., 2005; Choi, et al. 2012).
In recent years, a prominent and quickly advancing area of research is the effects of daylight on circadian rhythm and the sleep-wake cycle (Figueiro, et al., 2017; Blume et al., 2019). This is an expansion on earlier known physiological effects, such as the early discovery that sunshine triggers production of vitamin D in the skin (Holick et al., 1980). Studies have also indicated that daylight might increase cognitive performance (Münch et al., 2012), although there is uncertainty due to the difficulty of separating daylight from other environmental factors. For example, high illuminance levels (characteristic of but not limited to daylight) can increase cognitive performance (Smolders, et al., 2012), as well as views of nature (Li & Sullivan, 2016).

Beyond this, natural light has spiritual and cultural values, provides temporal cues about time of day and season - connecting humans to natural systems. This is true for natural light beyond daylight, such as the nocturnal light from the moon and stars.

3.3 Areas of Exploration

The topic of soft fascination intrigued me as I understand it as intertwined with and largely communicated via light. This section explores research and potentials of soft fascination, seeking an understanding and discussing its relation to light.

**Soft Fascination**

According to Kaplan (1995), nature contain high levels of elements called “soft fascinations” - visual stimuli which capture attention and are inherently fascinating to the human mind. These stimuli are often characterized by mesmerizing and tranquil movements, such as swaying branches and drifting clouds. (Kaplan, 1995; Kaplan & Kaplan, 1989).

While no exact definition of soft fascination have been formulated, they have been described by Kaplan (1995) as “processes or objects” which “readily hold attention, but in an undramatic fashion” and “provides opportunity for reflection”. Fascinations are proposed to exist on a sliding scale between hard and soft, capturing attention in either a gentle (soft) or forceful (hard) manner (Kaplan; 1995).

![Soft Fascination illustration](image)
Attention Restoration Theory
Attention Restoration Theory (ART), formulated by Kaplan (1995), considers attention as consisting of two components - "directed attention" (demanding effort) and "involuntary attention" (effortless). Directed attention is considered a limited mental resource, meaning it can be used up, and ART argues that its depletion causes mental fatigue. Mental fatigue makes it difficult to perform or focus on any task requiring directed attention, such as problem-solving or reading. However no effort is required to focus on soft fascinations. The basic underlying theory is that directed attention is allowed to rest and replenish while the mind absorbs and engages with soft stimuli. This is what constitutes the assumption that natural environments are restorative and can remedy mental fatigue (Kaplan 1995; 1989).

Later research has provided support and evidence for the theory (Berman et al, 2008; Berto, 2005; Valtchanov & Ellard, 2015), though it is worth mentioning that attention restoration is most evident in adults and that the effect of exposure to natural environments on cognition, including attention restoration, seem to differ depending on factors such as age and gender (Stevenson et al, 2019; Faber et al, 2002).

Mind-wandering
A similar but different process is known as mind wandering, a form of conscious internal reflection. It is defined as a "a shift in the contents of thought away from an ongoing task and/or from events in the external environment to self-generated thoughts and feelings" (Smallwood & Schooler, 2015). Similarly to ART, it is thought to be induced or "triggered" by exposure to soft stimuli in nature (Atchley, et al., 2012). Williams et al. (2018) suggest that mind-wandering plays an important role in the different forms of cognition, such as spontaneous associations between ideas, which are related to creativity. It is theorized that the pathways of mind wandering and directed attention are separate, but that both processes occur intermittently during exposure to natural environments; that the mind swings or shifts between internal mind wandering and focusing on soft stimuli in an irregular pattern (Williams, et. al, 2018).
Urban Environment
Attention Restoration Theory points out that soft fascinations are characteristic of natural environments and not as prevalent in urban environments, meaning that urban environments are not as restorative and does not offer the same level of opportunity for replenishing of directed attention or mind-wandering (Kaplan, 1989; 1995). The notion that urban environments deplete cognitive resources such as directed attention has been supported by findings that blink-rates increase during observation of urban scenes, indicating higher cognitive load (Valtchanov & Ellard, 2015).

"It is only in the modern world that the split between the important and the interesting has become extreme. All too often the modern human must exert effort to do the important while resisting distraction from the interesting." (Kaplan, 1995, p. 170)

Variability
Undeniably, natural light is an important compositional layer in the visual perception of nature. One of the most essential qualities which distinguishes natural daylight from artificial lighting is its variability. It changes direction, it moves, it combines diffuse and direct light and so on. The impact of this quality is made clear when daylight enters a room - the atmosphere becomes less static and more spirited, a sense of presence is achieved. Variability of light is one of the lifelike processes in nature which induce biophilic response.

Variability of light is essential to soft fascinations. Soft fascinations draw attention through shifts which are perceivable within short timeframes - often only seconds or less. However, variability is also perceived on a long-term temporal scale. This involves daily and annual gradual shifts of intensity, color temperature, distribution, and so on. These gradual shifts do not hold attention like soft fascinations do, but are likewise important.

Natural light is a composition of soft fascinations and gradual variability. It appears that gradual variability forms the backdrop for the soft fascinations. It is what lends light in nature its depth and credibility on a subliminal level. Combined they are a contributing factor to immersion in nature.

In the context of this thesis I will differentiate and refer to these two types of variability as "soft fascinations" and "gradual variability". They are distinguished by occurring on different temporal scales and being perceived in different ways; while soft fascination grabs and holds attention, gradual variability does not.

Fig. 3.5 Soft Fascination and Gradual Variability diagram • By Author
4. Observations in Nature

As biophilic response developed in response to the natural environment, understanding how we function in nature can provide insight and inspiration for built environments. This chapter attempts to understand how soft fascination and gradual variability occur in nature. This is useful for later translation into a design concept.

*The method was partly inspired by the thesis by Anna Torvaldsson (2019).*
4.1 Soft Fascination Samples

<table>
<thead>
<tr>
<th>Light-Play on Clouds</th>
<th>Cloud Passing Sun</th>
<th>Dappled Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light from the sun and the sky interacting with clouds and generating slow shifts of light and shadow. During sunset and sunrise the play often involves bright colors.</td>
<td>When a small cloud passes the sun on a mostly clear day, a shadow can be seen sweeping across the landscape - mirroring how the sun first covers and then uncovers the sun.</td>
<td>Characteristic of forests, an abstract pattern of light is created on the ground as sunlight is filtered through the leaves and branches of trees and plants.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Foliage Glow</th>
<th>Figurative Shadows</th>
<th>Landscape Silhouettes</th>
</tr>
</thead>
<tbody>
<tr>
<td>When direct sunlight is transmitted through leaves and foliage, a warm and vibrant glow occurs. It can appear almost neon.</td>
<td>Shadows trace and recreate a reduced and flipped version of the shapes found in nature - such as trees, rocks, hills. Movement is also translated into shadow, adding interest.</td>
<td>Landscape elements such as mountains and treetops and other occur as black silhouettes when backlit during low light (sunset/sunrise), resulting in a familiar but atypical appearance.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Sparkles</th>
<th>Water Reflections</th>
<th>Water Mirroring</th>
</tr>
</thead>
<tbody>
<tr>
<td>When sunlight hits a water surface tiny reflections create a sparkling and shimmering effect. The effect moves with the movement of the water and the position of the observer.</td>
<td>Light being reflected on the surface of water creates a pattern on nearby surfaces. The pattern moves and shifts along with the movement of the water, recreating its ripples and waves.</td>
<td>Sky and landscape elements near are mirrored on the surface of water, creating a symmetrical composition. It alters with change of perspective and water movements.</td>
</tr>
</tbody>
</table>
### 4.2 Gradual Variability Samples

<table>
<thead>
<tr>
<th>Direction of Shadow</th>
<th>Length of Shadow</th>
<th>Color Temperature Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>As the sun moves across the sky the direction of shadows change accordingly.</td>
<td>As the sun rise higher and fall lower, shadows grow longer and shorter accordingly.</td>
<td>Color temperature of daylight changes - it is warmer during mornings evenings and colder during the day.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light Level</th>
<th>Softness of Shadow</th>
<th>Haze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light levels rise and fall depending on the position of the sun and weather.</td>
<td>Depending on cloud coverage, shadows can appear soft and diffuse or sharp and defined.</td>
<td>Particles in the air (such as water or pollution) can decrease clarity and potentially discolor the atmosphere.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Darkness of Night</th>
<th>Length of Day</th>
<th>Seasonal Hues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depending on the lunar cycle, the moon reflects more or less light during nighttime. This alters the darkness of night.</td>
<td>Due to the tilt of earth, days vary in length and are consistently getting either shorter or longer.</td>
<td>As the seasons change colors and materials in nature change, causing a slight shift in color of reflected light outdoors.</td>
</tr>
</tbody>
</table>
4.3 Dappled Light

A composition and pattern
Dappled light is a composition of light and shadow. It is an abstract pattern of organic shapes of sunlight situated in a negative space of shadow. It is different from figurative shadows, which are recognized as traced shapes situated in a negative space of light.

Origins
Dappling is created by filtering of light and overlapping of multiple shadows, typically cast by trees and foliage. This overlapping renders the shadows no longer figurative, instead forming the abstract pattern of light patches. It can also be created by the diffusion of shadow as edges are obscured and softened. The scale of the pattern varies and is dependent on the object/s creating it.

Movement
As the sun moves the dappled light changes its direction. The change of angle between sun and the object/s casting shadow/s also comes with altered shapes of light - new overlapping occurs and the patches of light are stretched or contracted. Movement is also generated by the movement of the object/s. This is more immediately recognizable, often resulting in a soft swaying and/or flickering motion.
### CCT and Illuminance of Dappled Light

#### Average values:

**CCT**
- **Light:** 3950 K
- **Shadow:** 6800 K
- **Difference:** 2850 K

**Illuminance**
- **Light:** 7690 lx
- **Shadow:** 1610 lx
- **Difference:** 6080 lx

#### Summary

Light patches have noticeably warm CCT during mornings and evenings, and more neutral CCT during daytime. The CCT of shadow stays within a more narrow range and is more consistent throughout the day although appear to be somewhat colder during mornings and evenings. The contrast of CCT between shadow and light patches peak during morning and evenings and is lower during daytime. Both light patches and shadow peak in illuminance during daytime. The contrast in illuminance is also highest during daytime. In conclusion - the overall visual contrast between light patches and shadow is more reliant on CCT levels in mornings and evenings, and on illuminance levels during daytime.

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**Fig 4.6** Dapple, CCT and Illumination table - By Author
This chapter aims to explain and define biophilic lighting design. Project examples are presented and analyzed as a way of demonstrating an already existing biophilic context within lighting. By observing how projects are constructed from a technical viewpoint patterns of tools and methods are discovered.
5.1 Definition

Light itself is a senseuous experience. But it is also a medium which alters how space is perceived and experienced. Biophilic lighting design is from this viewpoint not only about mimicking daylight, it is also about altering environments aesthetically.

"We all know how different the same landscape can look under different weather conditions as a result of differences in the behavior of light." (Appleton, 1975, p. 78)

As no clear and agreed upon definition of ‘Biophilic Lighting Design’ exists, I will use the following definition:

Any lighting design project or installation inducing biophilic response.

The response/s may or may not have been phrased as “biophilic”. An understanding of what this means in a practical sense can be derived from evaluating projects which correlate with the above definition. While more categories could surely result from analysis of a wider selection, the given examples are divided into 3 groups:

1. Abstracting Nature
   Lighting design artificially reformulating nature or aspects of nature.

2. Interacting with Nature
   Lighting design merging and reacting with nature.

3. Mediating Nature
   Lighting design channeling or enabling direct contact with unaltered nature.

In addition, biophilic lighting design can also be understood as existing on a sliding scale between abstracted and representational (based on the understanding of the terms as when used in reference to visual art):

<table>
<thead>
<tr>
<th>Casino</th>
<th>Reduced Landscapes</th>
<th>The Weather Project</th>
<th>Salvation Army Chapel</th>
<th>Gates of Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACTED</td>
<td></td>
<td></td>
<td></td>
<td>REPRESENTATIONAL</td>
</tr>
</tbody>
</table>

Artificial or altered experience of nature, not necessarily understood as nature

Natural or unaltered experience of nature, understood as nature
5.2 Project Examples

**Light Abstracting Nature**

Description: Lighting design artificially reformulating nature or aspects of nature.

1. **Casino, 2017 by LichtKunstLicht**
   Circadian lighting project by Lumen Architecture in an underground hospitality canteen. The lighting supports circadian rhythm and emulates daily and annual shifts of daylight. (LichtKunstLicht, 2017)

2. **Reduced Landscapes, Submerged, 2020 by Maja Petric**
   A series of light sculptures reconstructing the experience of depth and parallax found in natural landscapes, as well as the dynamic quality of daylight. (Maja Petric, 2020)

3. **The Weather Project, 2003 by Olafur Eliasson**
   Lighting installation which recreating the natural atmosphere of sunlight, allowing for imaginary interaction and play with the light and a sense of connection to the natural world. (Olafur Eliasson, 2003)

**Light Interacting with Nature**

Description: Lighting design merging and reacting with nature.

4. **Skyspace by James Turrell (Ongoing series)**
   Enclosed space inducing an immersive experience with the natural sky and light, altered and enhanced through artificial light. (James Turrell, 2021)

5. **Salvation Army Chapel, 2004 by Carpenter Lowings**
   Window design for minimizing urban and maximizing natural landscape. The visual presence of the sky is amplified through reflection, resulting in the blocking out of buildings from the view, with the intention of creating a space for contemplation (Carpenter Lowings, 2004).

6. **Spectrum Chamber, 2018 by Charles Ross**
   Explorative and immersive experience of sunshine through conscious play with its physics, allowing for observation of its daily and annual shifts (Charles Ross, 2021).

**Light Mediating Nature**

Description: Lighting design channeling or enabling direct contact with unaltered nature.

7. **Gates of Light, 2017 by Studio Rosegaarde**
   Illumination through interaction between car headlights and a reflective prism-material mounted on building facades. Supports interaction with natural night-sky by diminishing light pollution (Studio Rosegaarde, 2017)

8. **Louvre Abu Dhabi, 2017 by Jean Nouvel**
   Natural daylight enters the building through a perforated dome, allowing for a dappling effect during direct sun hours. (Louvre Abu Dhabi, 2017)
Unintended or Accidental Examples
Biophilic response to light can in many situations be triggered without intention or by accident, and in situations which are small-scale and subtle. This demonstrates that biophilic lighting design doesn't have to be grandiose or complex, and actually occur on an everyday basis. Because of this, these situations can be said to play a more important role in everyday life than elaborate design projects in exclusive environments. They are also a reminder of the value of incorporating biophilic lighting design in the type environments that most people spend most of their time in.

Everyday situations can be categorized in the same way as the project examples. Light Abstracting Nature can occur when light strikes aluminum foil and makes it resemble a shimmering sea or when buttons glowing in a dark room create a miniature nightsky. Light Interacting with Nature can occur when sunrays create indoor rainbows as they are refracted by a window, when daylight transmitt through colored plastic objects and picks up artificial sunset hues, or when light hit dirty dishes in the sink and create a moving reflection of water in the ceiling. Light Mediating Nature can occur when the dappling of a tree outside enters through a window and covers the floor like a carpet, or when a low sun gives a warm glow to the back wall of a room.

5.3 Technical Parameters
The project examples were analyzed to understand the technical design parameters enabling biophilic response in each situation. Five parameters were found to frequently occur and play a role in a majority of the projects. Rather than offering a full analysis each project, these parameters are described below to identify and understand common methods of biophilic lighting design. The importance of each parameter vary between projects. Sometimes different parameters are connected, sometimes not.

![Fig 5.3 Technical parameter illustrations](https://example.com/figure53.png)

1. Spectrum
Description: The spectrum of light.
Function: The spectrum of light in a space can serve various biophilic purposes. A common physiological purpose is the artificial imitation of daylight to support circadian rhythm (for example Casino). In environments lacking daylight this also provides sense of connection to the outside and information about time of day. Another purpose may be to isolate wavelenghts in order to evoke association with specific situations and/or settings in nature. For example the spectrum of light used in The Weather Project is limited to emphasizes color associated with sunlight, while Reduced Landscapes limits spectrum to color associated with water. Spectrum can also be used to experiment with and alter visual perception and experience of nature - In Skyspace it is used create contrast with and enhance the experience of the sky. In Spectrum Chamber the projected color spectrums allow for novel experience of daylight. In Salvation Army Chapel and Louvre Abu Dhabi the full natural spectrum of daylight provides direct connection to nature/weather/time of day and instill life in the space through gradual shifts throughout the day.
2. Scale
Description: The size of the light field or pattern.
Function: Light can be scaled up to be perceived as an environment which the observer steps into. Scale of light can be used to encapsulate the observer in light (for example The Weather Project), allowing them to physically step into the environment. But scale can also be used to create the image of an expansive environment in front of the observer (for example Reduced Landscapes). This doesn’t enable the observer to physically step into the environment, but a similar effect can be achieved through by dominating the visual field. Large scale can generate the experience of one’s own body as small in relation to the light, making an experience powerful. Smaller scale on the other hand can be used to allow the observer to hold and isolate the light, allowing for immersion through closer visual observation and investigation (for example Spectrum Chamber).

3. Material
Description: The interaction of light and material.
Function: Material can be used to enhance the experience of light. The most common method found in the project examples is the use of white surfaces. White surfaces enable the visual isolation of light and efficient display of its color, distribution and movement (for example Spectrum Chamber). Details of light become easy to visually distinguish, and the reflected light is not discolored by surface color. This can be used to give light a more dominant role in the visual impression of the space (for example Skyspace). Therefore white surfaces can enable light to more fully fill and merge with the space.

4. Variability
Description: Variation of the light.
Function: In the project examples real or artificial variation of light is essential to the experience: change in color, CCT, brightness and/or intensity, as well as movement. The change follows a pattern that can’t be precisely predicted (for example Skyspace). Variability has the ability to instill a lifelike quality, as if the light is or is generated by something living and is therefore connected to the natural world. This creates interest and captures attention. Variability of light can also be used to communicate time of day or the passing of time - creating a sense of connection to natural systems (for example Louvre Abu Dhabi). It can also be related to circadian stimulus (for example Casino).

5. Time
Description: The duration of exposure to the light.
Function: For many projects a longer exposure to the light is part of or adds to the experience. It may be to perceive slowly occurring shifts which are not immediately detectable, or to allow the eyes to adjust to the color of light (for example Skyspace) or light levels (for example Gates of Light). For projects involving soft fascination (for example Salvation Army Chapel) longer duration of exposure allows for attention restoration and mind-wandering. It can also be related to physiological response, as is the case with circadian lighting (for example Casino).
Chapter 3-5 are synthesized in conclusions and a discussion about questions that are raised by their content.
Conclusions
Soft fascinations in natural environments are often consisting of or communicated by light. This opens up for potential methods of supporting cognitive functions through lighting design in urban environments.

As pointed out in the literature, preferred environments are more likely to be restorative (Kaplan & Kaplan, 1989). This expands the understanding of biophilic lighting design and makes use of light’s potential to alter spatial perception. Therefore, it will also be important to consider how to increase spatial preference in general as part of the design concept.

As demonstrated by the project examples, biophilic lighting design can but doesn’t have to look like real nature (be representational). A degree of abstraction, carefully constructed, can be applied without losing intended biophilic response. This opens up for the possibility of “filtering” the natural soft fascination of dappled light during the design process, preserving properties of the light effect which are necessary for the biophilic purpose while also translating well into the new context.

Query
A central question worth discussing is whether soft fascinations and their effects, occurring in nature, can be replicated in other contexts. I believe that it would be possible, at least to a degree. Several of the project examples rely on elements of soft fascination for biophilic response, even purely artificial ones such as in The Weather Project and Reduced Landscapes. (As mentioned in the limitations, testing this hypothesis with scientific methods is beyond the time-frame, current personal level of knowledge and methods available.)

The experience of soft fascination is an immersive experience. I believe immersion is aided by “authenticity”, meaning that the immersive experience is in line with expectations on the behaviour of reality/the physical world. When these expectations are not met, people react - it creates a sense of unnaturalness or even unease/alert. This risks “breaking the spell” of immersion. I believe visual richness and complexity are important factors of generating “authenticity” when designing with artificial light. Immersion should therefore be more likely to occur if soft fascination is coupled with gradual variability, as it is in nature. It adds another layer in terms of visual expression and temporal experience, in line with expectations.

Immersion is known to not only occur with exposure to nature but also to artificial light and in artificial environments. Experiments conducted on VR (e.g. Valtchanov & Ellard, 2010) have proven biophilic responses to occur even when the observer is highly aware that the environment is artificial. Another interesting example showing how biophilic response extends beyond the natural world is the empathy we feel for artificial intelligence (Schmetkamp, 2020). It appears that our mind can both know something and dismiss it at the same time. For something to be real it only has to be “real enough”. This resonates with the following quote:

"Another factor that can contribute to perceived extent is at a more conceptual level, encompassing the imagined as well as the seen. It promises a continuation of the world beyond what is immediately perceived. […] One can experience extent at an even more abstract level. There can be a sense of connectedness between what one is experiencing and what one knows about the world as a whole. This higher-level sense of connectedness is what gives the “other world” a sense of reality.” (Kaplan & Kaplan, 1989, p. 190)
This chapter summarizes the most important parts of the conducted site analysis of Zinkensdamm subway station. Insights from the analysis are used to identify issues and inform subsequent design decisions.

Method of analysis was partly inspired by the thesis by Linnea Henstam (2018).
Zinkensdamm Subway Station
The Zinkensdamm subway station was chosen for analysis and implementation of design concept. It was chosen because of its position in a highly urbanized environment in central Stockholm (Södermalm) and due to the fact that is of a very typical character - meaning it is almost fully underground, has not been modernized and lack daylight and other natural elements.

The station was sectioned into 7 zones which were individually analysed. Analysis was divided in 4 parts: light, biophilic, physical and behaviour (see appendix A).
<table>
<thead>
<tr>
<th>Luminaires</th>
<th>Description</th>
<th>Image</th>
<th>Location</th>
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</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Ceiling mounted fluorescent, downlight</td>
<td>![Image](Z1, Z2, Z3, Z4, Z5, Z7)</td>
<td>Z1, Z2, Z3, Z4, Z5, Z7</td>
</tr>
<tr>
<td>Type B</td>
<td>Ceiling mounted fluorescent, downlight</td>
<td>![Image](Z4, Z6)</td>
<td>Z4, Z6</td>
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<tr>
<td>Type C</td>
<td>Wall mounted fluorescent, downlight</td>
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<td>Ceiling</td>
<td>Concrete painted white</td>
<td>![Image](Z1, Z2)</td>
<td>Z1, Z2</td>
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<tr>
<td>Walls</td>
<td>Tiles</td>
<td>![Image](Light: Z3, Z4, Z5, Z6, Z7 Green: Z3, Z4 Brown: Z7)</td>
<td>Z1, Z2</td>
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<td><img src="Green" alt="Image" /></td>
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<td>Light: Z3, Z4, Z5, Z6, Z7 Green: Z3, Z4 Brown: Z7</td>
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<td>Details</td>
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### Qualitative Evaluation

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### Biophilic

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<table>
<thead>
<tr>
<th>Soft Fascination</th>
<th>Low - High</th>
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<tbody>
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<thead>
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<th>Gradual Variability</th>
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**Fig 7.5 Qualitative Analysis table • By Author**
Summary

For the aspects considered in the analysis Z3-Z7 are overall identified as less qualitative while Z1 and Z2, which have access to daylight and visual connection to the surrounding, as identified as more qualitative. The platforms (Z7) are of particular importance, as they have the highest frequency/duration of use. The absence of natural elements, sense of enclosure and lack of orientation in time and space throughout the station stand out as possible areas of improvement through lighting design. Ease of wayfinding was found to be good in all zones - mostly due to the straightforward layout and small scale of the space which provide easy overview.

Orientation in Time and Space
Inside the subway station sense of orientation in both time and space is lost. This is due to loss of daylight and lack of visual connection to the surrounding. The artificial light inside the station is static, staying the same throughout the day, and offers no time cues. Understanding one's relation to the structure of the city above is made difficult by one's own movement and change of direction when turning corners below ground. The result is a separation in time and space between the underground environment and the above ground environment. They become two disconnected and separate contexts.

However one's vertical movement is perceived with more ease. As one enters the station and goes deeper down, further away from the surface, there is a build-up of experienced distance. As one exits the station the reverse is true. The experienced distance between the underground and above ground contexts depend on vertical movement. This becomes the main way of understanding one's relation to the above environment.

Sense of Enclosure
The sense of enclosure is high for all parts of the station that is below ground level, but increases further down in the station. Access to daylight and option of route decrease sense of enclosure. Sense of enclosure increase in the more compressed areas with limited route options - such as in the escalator. It decreases somewhat on the platforms, due to the larger scale of the space (vertically and horizontally) but also due to airflow from and view into the tunnels.

Soft Fascination and Gradual Variability
In the parts of the station without daylight access the lighting is very static. The color temperature and level of light stays rather consistent throughout the different zones, which all have even distribution. In some zones times the light becomes somewhat warm or takes on a green tint (in areas with dark green tiles). The light stays the same throughout the day and contains no movements or shifts of any kind. In other words all zones, except for Z1 and Z2, which have access to daylight, lack both soft fascination elements and gradual variability.
Both dappled light and sense of enclosuse are impacted by and connected to contrast of brightness and darkness. Simple box model studies were carried out in order to better understand contrast as a lighting design tool related to each aspect.
Sense of Enclosure

Sense of enclosure is here used to describe a negative sensation of being trapped or compressed in a space. The opposite sensation of this is here referred to as “openness”. Factors which influence sense of enclosure/openness include route options, connection to the outside and spatial dimensions. Light and surface materials can be used as tools to alter the contrast in a space, influencing the spatial perception and above mentioned factors, resulting in an illusion of openness and decreased sense of enclosure without actually altering spatial configuration.

Continuation / Closure

![Continuation / Closure](image1)

Brightness can be used to create a sense of the space continuing (feel less enclosed), and darkness can be used to create a sense of the space closing (feel more enclosed). Observing a bright area creates a similar experience of openness as that of an opening, while a dark area appears more solid.

Compression / Expansion

![Compression / Expansion](image2)

Darkness can be used to compress a space (feel more enclosed). Brightness can be used to expand a space (feel less enclosed). While the dark surfaces create a sense of heaviness, the bright surfaces create a sense of lightness.
Dappled Pattern

When patterns are applied to surfaces of a space the spatial perception is altered in different ways. An organic and rounded pattern, such as dappling, can be used to influence the perceived shape of space and to understanding of spatial depth. Furthermore the pattern creates a system of focus points which the eyes are triggered to move between, which in turn generates an illusion of movement.

Shape of Space

A dappled pattern can make the shape of the space appear "softer" and less orthogonal by making straight lines less visually dominant and definitive of the space. It increases roundness and decreases linearity.

Scale of Pattern

A larger pattern can divide and separates the space into sections, while a smaller pattern blends in and becomes an integrated part of the space more easily.

Dappled pattern can aid understanding of spatial depth as the pattern shrinks with increased distance. The variation of size between individual focus points created by this perspective becomes a visual measurement tool. This shrinking is more visually apparent in a large scale pattern than in a small scale pattern.
Allowing theory and abstract ideas to take physical form makes them clearer and easier to understand. Previous chapters are synthesized in a design concept, further clarifying their practical purpose and potential.

The design concept is contextualized and related to the project examples mentioned in chapter 5. It is also evaluated with an online survey.
9.1 Concept Outline

Vision
To support cognitive functioning through soft fascination and to improve preference of space by decreasing sense of enclosure, while maintaining function of space.

Concept
Drawing inspiration from the experience of going down a valley: dappled lighting is applied to provide soft fascination. Brightness generated is used to decrease sense of enclosure. Gradual variability is used to induce association to lifelike processes and natural systems.

Technical Parameters

Spectrum
Neutral and warm color temperature is used to create visual contrast between ambient light fields and dappled light pattern. It also is used to communicate time of day via reference to shifts occurring in daylight. Supporting circadian rhythm is not the aim or taken into consideration.

Scale
The light is applied throughout and so is merged with the space, enveloping the visitors at a large scale. As individual patches or areas of dappled light are observed and focused on by visitors, a secondary smaller scale is created.

Material
Tiles are removed to reveal the rock or concrete behind, which is painted white. This allows for the behaviour and appearance of light to be visually enhanced. It is also used a method to decrease sense of enclosure through bright surfaces.

Variability
Shifts in color temperature, intensity and distribution are used to provide variability. This increases visual interest and ability of light to capture attention - therefore supporting the dappled pattern as soft fascination. It gives the space living quality, creating association with lifelike processes and natural systems. It also allows for experiencing the passing of time by witnessing changes in the light - the light looks different depending on time of day, but also between days.

Time
The cognitive benefits of soft fascination - attentional restoration and mind-wandering - build over time. A longer visit allows for higher degree of response and regular visits allow for benefits to accumulate over time.
## Layers of Light

### Soft Fascination

The absence of natural elements and daylight results in a deficit of soft fascination in the subway station. Introducing soft fascination through artificial light supports cognition by enabling attention restoration and mind-wandering.

- Provide soft fascination
- Create association with nature
- Communicate time of day
- Immersiveness

- Dappled light pattern falling on floor and walls surfaces.
- Light is filtered through a mesh to generate the dappling.
- Intensity is higher on and near walls. Lower on floor areas with high level of foot traffic.
- Multiple dappled light layers overlap, through combination of multiple light sources.
- Light sources programmed to individually perform random soft shifts in intensity: creating a sense of motion / lifelike quality. Soft and vibrant pace.
- CCT kept within a warm range during mornings/evenings and within a neutral range daytime.
- Different configuration of intensity on different days, generating unique compositions.
- Surrounding the observer with dappling to create immersion.

Spotlights, LED, dynamic white. Concealed and/or recessed in cavities in ceiling or walls. Filtered through a mesh.

The cavities in the ceiling create the impression of an opening, similar to a skylight.

### Ambient

Light is applied to ensure the practical function of the space, work together with the soft fascination layer and decrease sense of enclosure.

- Provide general lighting and visibility in the space
- Communicate time of day
- Decrease sense of enclosure

- Uniform, soft lighting on wall and ceiling surfaces.
- Higher intensity on ceiling to increase reflected light in the space and general light levels.
- Lower intensity on walls to visually enhance dappling through contrast.
- CCT always within a neutral range. Slightly colder during mornings and evenings to contrast with dappling.
- Randomly programmed slow and subtle shifts in intensity, perceived over a moderate duration of time.
- Illuminate the tunnels visible from platforms.

Wallwashers, LED, dynamic white. Light fixtures hidden/concealed.

### Guiding

As the soft fascination layer might make visual overview of the space less immediate, a layer of light is added to guide the eye for more efficient understanding of space.

- Aid wayfinding in the space by subtle highlighting of important spatial elements and functions

- Only added where needed.
- Added light to entrance passage to balance against daylight levels.
- Added light to stairs, escalators, platform edge and other important areas / elements to aid their function as well as to improve navigation in the space.
- Light levels higher than surrounding without causing glare.
- Neutral CCT, perceived as consistent. Only minimal shifts occurring very gradually without being noticed, to balance against daylight (at entrance) and other layers.

LED-strips, diffuse, dynamic white.

Wallwashers, LED, dynamic white. Light fixtures hidden/concealed.

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Fig 9.2 Layers of Light table • By Author
9.2 Perspectives

Perspective 1: Entrance
Perspective 2: Transition
Perspective 3: Escalator
Perspective 4: Platform

Fig 9.3 Perspective Locations • By Author
Soft Fascination
A dappled lighting pattern from inside the station is visible at the bottom of the stairs, creating visual interest and inviting commuters.

Ambient
The ambient lighting on walls and ceiling reflects into the space and decreases the sense of enclosure. Its intensity is adjusted to balance with daylight levels.

Guiding
Additional light on stairs and increase visibility during hours of low/no natural light. Light added in the passage area at the bottom of the stairs for a smooth visual transition between outdoor and indoor, when needed.
Soft Fascination

Light from fixtures concealed in cavities above is filtered through a mesh, generating dappling on floor and wall surfaces. Overall intensity is higher on/near walls, lower in high flow areas. Intensity shifts bring a lifelike quality to the dappled pattern. CCT is kept within neutral range daytime, and warm range during mornings/evenings.

Guiding

Additional light on wall and floor surfaces are concentrated around important functions and areas in the space, pointing them out to commuters.
Soft Fascination

Light from fixtures concealed in cavities above is filtered through a mesh, generating dappling on wall surfaces. Intensity shifts bring a lifelike quality to the dappled pattern. CCT is kept within neutral range daytime, and warm range during mornings/evenings.

Ambient

The ambient lighting on walls and ceiling reflects into the space and decrease the sense of enclosure. Intensity somewhat lower on walls in order to enhance dappling.

Gradual variability:
• Slight and random gradual shifts in intensity.
• CCT subtly shifting but always within neutral range.

Guiding

Additional light on the escalator for increased visibility, making the space more welcoming and user-friendly.
Soft Fascination

Light from fixtures concealed in cavities above is filtered through a mesh, generating dappling on floor and wall surfaces. Overall intensity is higher on/near walls, lower in high flow areas. Intensity shifts bring a lifelike quality to the dappled pattern. CCT is kept within neutral range daytime, and warm range during mornings/evenings.

Ambient

The ambient lighting on walls and ceiling reflects into the space and decrease the sense of enclosure. Intensity somewhat lower on walls in order to enhance dappling.

Light applied at tunnel opening to further decrease sense of enclosure.

Gradual variability:
- Slight and random gradual shifts in intensity.
- CCT subtly shifting but always within neutral range.

Guiding

Additional light on white edge of the platform to make it more visible and increase safety in the space.
9.3 Evaluation

Survey

Description
A survey was conducted to evaluate to which degree the design concept fulfills its aims. Participants were asked to observe illustrated perspectives of the subway stations. Identical perspectives with different lighting design scenarios were presented side by side to enable comparison. The scenarios consisted of the current design and the design developed in this thesis. Multiple perspectives of different parts of the station were presented in order to discover trends rather than isolated cases of response. (For detailed results see appendix B)

The survey focused on two main aspects:
1. Does the dappled light function as a source of soft fascination?
2. Has the sense of enclosure been reduced by the developed design?

It also focused on two secondary aspects:
3. Is the entrance perceived as more inviting in the developed design?
4. Does the developed design create association with nature?

In total 25 participants took part in the survey.

Results

1. Participants were more likely to respond that the developed design was more prone to capturing attention and was more interesting to look at. These factors are indicators of soft fascination, suggesting that the dappling fulfills its intended purpose.

2. Participants were also more likely to respond that the sense of enclosure had been decreased by the developed design. Results suggest that the design strategy was slightly more successful in areas of a larger spatial dimension - such as platform and transitional areas - and slightly less in areas of smaller spatial dimension - such as the escalator.

Fig 9.8 Result Diagrams 1

* By Author
3. Results suggest that the entrance is perceived as more inviting as a result of the developed design concept.

4. Participants were much more likely (48%) to associate the developed design with nature compared with the existing design (4%). Most associations were in one way or another related to vegetation and sunlight, both factors directly connected to dappling in nature. However, there were also associations to water and to environments where visual patterns similar to dappling occur.

Interestingly the developed design seem to create associations with natural environments known to be biodiverse and hospitable to life, while the only association with natural environments generated by the existing design was to an environment known to be low in biodiversity and hostile to life.

Associations appeared to be more personal for the developed design. In some cases associations were related to memories or places which the participant have personal connection to. Associations seemed more specific, varied and original in general. Though this is just speculation and no conclusion can be drawn based on the collected data alone, it suggest possibilities such as that the developed design generated a more personal connection to the space or that it triggered a higher degree of mind-wandering in participants.

The existing design seemed to create higher levels of association with negative emotions and everyday life. However, there were also examples of positive association which were unique to the existing design. Replies also suggest that some find the developed design too distracting/busy.
Relation to Project Examples

**Category**
To place the project into a category the dappled lighting effect /soft fascination element is analyzed. While it draws inspiration from dappled light in forests, it does not take all aspects into consideration. Instead a limited number of visual characteristics have been selected in a filtering process. It imitates the shift of color temperature throughout the day (to a limited degree), the composition of overlapping patches, and shifts in intensity. However gradual shift of light angle and the swaying movement which is characteristic of dappled light in nature is not incorporated into the design. The result is a lighting effect is a stripped version of the natural source of inspiration, reformulated through artificial light. Therefore the project slots into the category of “Light Abstracting Nature”.

The project does not relate to any real natural elements, and is not aimed to reinforce contact with actual nature, meaning it is also excluded from the other two categories.

**Sliding Scale of Abstracted / Representational**
As supported by the findings of the survey the effect is largely associated with dappled light in nature but can't be placed with absolute certainty. The survey showed that associations were frequently made to the natural source of inspiration (dappled sunlight) and the type of environment where it is found (trees/forests). However other associations to nature were also made (stars/snowflakes/raindrops/etc). The light does not carry absolute resemblance to its original source of inspiration - it deviates from certain visual characteristics while still frequently being recognized as what it is imitating. It is not as easily recognized as the sun in *The Weather Project*, but at the same time is more representational than *Reduced Landscapes*, falling somewhere in between.
Final thoughts about the process and the content of the thesis are presented and discussed.
Discussion and Conclusion

Relating to project examples was an attempt to clarify and root biophilic lighting design as part of an existing context. Seeing the individual projects as part of a bigger picture made underlying ideas and practical application more easily understood.

Soft fascination can be produced by light in a variety of ways. Any of the soft fascination samples presented in chapter 5 could be used as a source of inspiration, but there are of course a lot more examples in nature. An understanding of the value of soft fascination can be used both to motivate artificial light solutions but also preservation of naturally occurring such, especially in urban environments.

This thesis has glimpsed at the possibilities of biophilic lighting design - mainly the potentials of artificial light as a source of soft fascination. I consider it as just an example and believe that there are many more methods of using light to trigger biophilic response. This could be to benefit cognitive functioning, but other interesting areas are the other mentioned main categories of response (stress reduction and affect).

As suggested by this thesis, two key design aspects to consider is perhaps our isolated experience of and response to light itself (psychological, physiological, etc) as well as the ability of light to influence spatial perception.

I believe that observing natural light and nature is necessary for achieving successful biophilic lighting design. It takes some decoding and time, but there are a lot of lessons to learn about how we respond to light and space from observing oneself and others in nature. These insights can then be applied in other contexts.

Lastly it is important to point out that this thesis is very conceptual. For this reason a lot of aspects were not considered in the design concept. This includes for example standards, regulations and technical solutions. It should therefore very much be understood as a concept/idea rather than a final solution. It was a method of communicating the underlying thoughts of the thesis and making practical application easier to perceive.
References

Books:


Articles & Papers:


Liljefors, A. (1999). The VIP Lighting Theory - Basic knowledge to lighting design. CIE.


Online sources:


Academic Work


List of Figures:

All pictures, illustrations and diagrams are produced by the author unless otherwise stated.

Cover Illustration. Illustration by Author.

Chapter Introduction Slides. Picture by Author.

Fig. 2.1 Methodology Diagram • By Author
Fig. 3.1 Biophilic Responses Diagram • By Author
Fig. 3.2 Positive and negative stimuli diagram • By Author

Fig. 3.3 Soft Fascination illustration • By Author
Fig. 3.4 Mind Swing diagram • By Author
Fig. 3.5 Soft Fascination and Gradual Variability diagram • By Author
Fig 4.1 Soft Fascination table • By Author
Fig 4.2 Gradual Variability table • By Author
Fig 4.3 Dapple Illustrations, composition • By Author
Fig 4.4 Dapple Illustrations, Origins • By Author
Fig 4.5 Dapple Movement • By Author
Fig 4.6 Dapple, CCT and Illumination table • By Author
Fig 5.1 Categories of biophilic lighting design illustrations • By Author
Fig 5.2 Abstracted / Representational scale diagram • By Author
Fig 5.3 Technical parameter illustrations • By Author
Fig 7.1 Location map • By Author
Fig 7.2 Subway Axonometry, Areas, zones and measurements • By Author
Fig 7.3 Duration and Speed of movement diagram • By Author
Fig 7.4 Luminaires and Materials table • By Author
Fig 7.5 Qualitative Analysis table • By Author
Fig 8.1 Model pictures, Continuation / Closure • By Author
Fig 8.2 Model pictures, Compression / Expansion • By Author
Fig 8.3 Model pictures, Shape of Space • By Author
Fig 8.4 Model pictures, Scale of Pattern • By Author
Fig 9.1 Parameter Symbols • By Author
Fig 9.2 Layers of Light table • By Author
Fig 9.3 Perspective Locations • By Author
Fig 9.4 Concept Perspective 1 • By Author
Fig 9.5 Concept Perspective 2 • By Author
Fig 9.6 Concept Perspective 3 • By Author
Fig 9.7 Concept Perspective 4 • By Author
Fig 9.8 Result Diagrams 1 • By Author
Fig 9.9 Result Diagrams 2 • By Author
Fig 9.10 Category Illustration • By Author
Fig 9.11 Abstracted / Representational scale diagram • By Author
## Appendix A - Subway Evaluation

### LIGHT

<table>
<thead>
<tr>
<th>Perceived</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of light</td>
<td>Even</td>
<td>Varied</td>
</tr>
<tr>
<td>Distribution</td>
<td>Sharp</td>
<td>Soft</td>
</tr>
<tr>
<td>Shadows</td>
<td>None</td>
<td>Many</td>
</tr>
<tr>
<td>Reflections</td>
<td>None</td>
<td>Disturbing</td>
</tr>
<tr>
<td>Glare</td>
<td>Intact</td>
<td>Distorted</td>
</tr>
<tr>
<td>Color temperature</td>
<td>Cold</td>
<td>Warm</td>
</tr>
<tr>
<td>Color</td>
<td>Intact</td>
<td>Distorted</td>
</tr>
<tr>
<td>Daylight</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>Balance</td>
<td>Natural</td>
<td>Artificial</td>
</tr>
<tr>
<td>Consistency</td>
<td>Varied</td>
<td>Fixed</td>
</tr>
</tbody>
</table>

### Measurements

- **Illuminance:**
- **CRI:**
- **CCT:**

**Luminaires:** (Document with pictures)
**BIOPHILIC**

**Perceived**

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th></th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Views of Nature</td>
<td>None</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Views of Surrounding</td>
<td>None</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Orientation in Space</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Orientation in Time</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Sense of Enclosure</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Path-finding</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Natural Elements</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Soft Fascination</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Gradual Variability</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
</tbody>
</table>

**Other:**
PHYSICAL

Materials: (Document with pictures)

Objects: (Document with pictures)

Dimensions and Layout: (Document with pictures)
  Width:
  Depth:
  Height:
  Shape of Space:

Other:
BEHAVIOUR

Transition Time:

Direction of Movement:

Speed   Still   -------------------------------------------   Fast

Visual direction and focus:  (Document with pictures)

Other:
Appendix B - Online Survey

General information:

The survey was shared online with students at the KTH Architecture School (Architecture Programme and Architectural Lighting Programme). In total 25 people participated in the study.

Participants were briefly informed about the purpose and context of the survey. They were also given the information that the perspectives depict an underground subway station, however not which one or where it is located.

Photos from the site were used to illustrate current light conditions in the B-category of perspectives. In the A category an estimate was made about the increased brightness level on wall and ceiling surfaces as a result of changed materials and lighting strategy. Dappling was also added. Brightness of floor surfaces and scale figures were kept the same for both A and B perspectives.
Results:

Question 1: “Which scenario do you find to appear more inviting?”

Options:
A) “A is more interesting to look at.”
B) “B is more interesting to look at.”
C) “No difference, A and B look equally inviting.”

Results:
Perspective 1: A: 96%  B: 4%  C: 0%

Question 2: “How do the two alternatives compare in terms of capturing your attention?”

Options:
A) “A captures my attention more.”
B) “B captures my attention more.”
C) “No difference, both A and B capture my attention to the same degree.”

Results:
Perspective 2: A: 92%  B: 0%  C: 8%
Perspective 3: A: 100%  B: 0%  C: 0%
Perspective 4: A: 96%  B: 0%  C: 4%

Question 3: “How do the two alternatives compare in terms of being interesting to look at?”

Options:
A) “A is more interesting to look at.”
B) “B is more interesting to look at.”
C) “No difference, A and B are equally interesting to look at.”

Results:
Perspective 2: A: 84%  B: 0%  C: 16%
Perspective 3: A: 96%  B: 0%  C: 4%
Perspective 4: A: 88%  B: 0%  C: 12%

Question 4: “Consider sense of enclosure versus sense of openness. How do you perceive each space?”

Options:
A) “A as more open and less enclosed”
B) “B as more open and less enclosed”
C) “No difference, I perceive A and B as equally open/enclosed.”

Results:
Perspective 2: A: 88%  B: 0%  C: 12%
Perspective 3: A: 72%  B: 8%  C: 20%
Perspective 4: A: 80%  B: 4%  C: 16%
Question 5: “Do these pictures create any sort of association for you? Do they make you feel or think of anything?”

* Participants were given the option to skip this question.

Results:

**Perspective A2-A4:**
- “The remind me a bit of the forest. The reflections look like sunlight popping through leaves.”
- “Grandmother’s house, sun shining through the branches of the walnut tree.”
- “Galaxer, lövverk och porer!”
- “It feels like being underwater”
- “Linked to the outside world that is changing through time, making the sensation of being underground reinforced, adding to the sense of place.”
- “Patches of sun light created through tree leaves”
- “The place is more bright and feels that it has more "things", "objects"”
- “The light and openings/windows in the ceiling gives a more open feeling which makes me feel safer (which is important in an enclosed environment)”, “Brighter public spaces feel more safe and inviting”
- “Clutter”
- “The lightning makes it look like a safer place and looks more thought through”
- “Rain dripping on a roof, being under water, sunlight filtered through clouds”
- “Snowflakes”
- “They feel airy (as opposed to heavy) and remind me a little bit of the spotted light in a forest”
- “The light setting in these images remind me of sun glitter i.e. the light that is created when sun reflects on waves of water”
- “They feel like a standard solution of how to design light sources in this kind of context.”
- “I wish it was like that!”
- “Airports, impersonal, Disco, futurist”
- “Maybe I associate them to the stars in the sky”
- “Nature, forest, water, flowers”

**Perspective B2-B4:**
- “boring. There is nothing to focus on in these images. It looks cold and grey.”
- “No”
- “Öppna ytor, öknar och institutioner?”
- “Feeling of connection to the daily routine”
- “I am wondering which textures and colours are used there. It could be very nice there too but would require some imagination to substitute black&white images with nice colours/textures/materials. Feels stable and concrete. Routine and focusing on what happens inside the space instead of the urban fabric itself.”
- “Feeling like nothing. An unnoticeable indoor space.”
- “Calm, private, minimal, anonymity.”
- “Feels darker and more empty”
- “Quite dull, like subway stations in Stockholm now. I don’t dislike these but they do feel darker and more closed.”
- “Classic underground settings”
- “Damp”
- “Tunnels or subway stations late at night, travelling far alone”
- “Not really”
- “They feel heavy, enclosed and more subterranean, but also more restful and less distracting”
- “I find these images dull. These spaces are dark and uninviting.”
- “They feel like renders or images that are not done yet.”
- “Picture A is darker/more closed than reality I think but B and C is more realistic and very much how it appears in Stockholm’s metro.”
- “Simple, hard, strict, austere.”
- “No”
- “Trapped, danger, dull”