BIOPHILIC LIGHT TEXTURE

Applying biophilic design principles to lighting design

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PREFACE

Science and intuition are seemingly opposites, but both are different approaches to the same end: making sense of the infinitely complex reality we perceive. I believe that as a designer, especially in the field of lighting, one should embrace intuition. This is not to say that science should not be involved, on the contrary; however, one should understand the limitations of the scientific approach. At the basis of any scientific approach lies a simplified model of reality. Actual reality never follows the rules of that simplified model exactly, so nor should a designer follow any scientific approach by the letter. Where science ends, intuition should come into play.

One's intuition is a powerful tool. Our mind can intuitively comprehend infinitely complex experiences in a matter of a moment. What we understand with our intuitive (subconscious) mind is far richer and more profound than what we could possibly grasp with our rational (conscious) mind. Rational comprehension is not always a necessity for design; we can express what we intuitively experience in an artistic manner; which is often far richer than any scientific model could ever convey. While a scientific model can (and often should) be the basis for design, it should never be the end result.

I start my thesis with this note on the roles of science and intuition, because I feel that in the Delft Design method as taught at the TU Delft faculty of Industrial Design Engineering, the role of intuition is sometimes undervalued. It is not denied, but there is no significant attention to it either. I feel it is an invaluable quality that should be nurtured in any aspiring designer; design education should at the least provoke students to explore their intuitive sensibilities on their own and during the design project (PO) courses.

Secondly, I bring this up because I feel that in the current state of sustainable design, the emotional/human aspect is severely lacking. Scientific data on the environmental impact of a design is essential, but if a user does not relate to a design on an emotional level it will never be sustainable. Design we don't relate to will sooner or later be discarded; design that appeals to our emotional and intuitive sensibilities will be cherished and preserved. Thus if science based sustainable design is to be effective, the human aspect of it should be included as well - which is often best expressed intuitively.

This thesis for me has been an opportunity to develop my intuitive design qualities, and an exploration on how to incorporate these values into my personal approach to design.

SUMMARY

This thesis explores the topic of dynamic light textures, which is one of the lighting effects defined by the “Light Content” program of Signify (formerly Philips Lighting). A design approach is developed and showcased in a design project for Beersnielsen Lighting designers.

The proposed design approach is based on two main subjects as discussed in the introduction: light content and biophilic design. Light content is about the design of digital content for modern LED lighting products – in which the human experience of the lighting effect is taken as the main design objective. Biophilic Design (Kellert et al. 2008) is an architectural design framework that takes the hypothesis of biophilia (Wilson 1986; Wilson & Kellert 1995) as a basis for design. Biophilia is the inherent human inclination to affiliate with natural features, like views of nature, bodies of water, wild-life, etc. Biophilic Design aims to re-integrate the inherent human connection to nature into the design of the built environment.

The way people experience lighting is discussed in chapter 1. The main influence of lighting on the human experience of a space is creating atmosphere. This is mainly accomplished through focal glow and ambient luminescence – the first two elemental kinds of light defined by Richard Kelly (1952). A second way in which lighting can influence the experience of a space is by contributing to its character. The character of a space relates to its atmosphere, in the same way a person's personality relates to their mood. Light can contribute to this character mainly through play of brilliants – the third elemental kind of lighting described in Richard Kelly's framework for architectural lighting (1952).

In chapter 2 light texture is defined as a visual pattern created through lighting, projected onto any material surface. First the visual qualities of which a light texture is comprised are discussed: Style, Structure, Contrast and Dynamics. Secondly the differentiating qualities of light textures in nature are discussed. Natural variation, natural causality and natural dynamics are determined to be the most fundamental qualities of natural light textures.

Chapter 3 connects light texture (chapter 2) and light experience as outlined in chapter 1, to arrive at a design approach, from the perspective

of the biophilic design framework. The basis of this design approach is the following design principle:

*The minimum condition for creating a **biophilic design is** to create an **integrated design**. Any light texture should be an integral part of the architecture AND of its social, cultural and geographical context; this integration can be achieved by aligning the atmosphere and character that the light texture conveys, with the atmosphere and character of the architecture and its environment.*

From this principle follow the following design guidelines, according to the visual qualities of light texture defined in chapter 2:

- *Style creates character*
- *Structure is used to integrate*
- *Contrast defines atmospheric quality*
- *Dynamics introduce biophilic qualities*

Chapter 4 shows the explorations and experiments with dynamic light textures, that eventually lead to the theory outlined in chapter 3; and formed the basis of the design principle of the design project discussed in chapter 5.

Chapter 5 discusses a design project for Beersnielsen Lighting Designers, that applies this design approach to the design of a chandelier that creates shadow projections on an arched ceiling. The chandelier will be part of the interior of a visitor center of a nature reserve park.

The style and structure of the texture is designed to resemble the natural environment of the park. It is a stylized image of a forest canopy, with wildlife like birds and squirrels – projected onto the arched ceiling of the interior.

There is a dynamic element, that changes the brightness contrast of the texture over time, according to the dynamics of nature. Videos of natural dynamics – like a water surface or trees waving in the wind – are used as input for the dynamics of the light texture. This could even be real time video content, in order to establish a direct link between the interior and the exterior natural environment.

A prototype of this chandelier was created and showcases a proof of concept for the intended lighting effect. The shadow projection is created by a light source projecting light through a sheet of multiplex that has the desired pattern laser cut into it. The surface is curved to match the curve of the arched ceiling. The dynamic effect is created by using an LED-matrix as a light source, that is programmed to display edited video content of natural dynamics.

The prototype and design are evaluated on a technical level and an experiential level in accordance with the design approach defined in chapter 3.

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INTRODUCTION

There are two key subjects this master thesis is based on: Light Content and Biophilic Design. First both subjects are introduced separately, then their relation within this project is explained.

Light content

Light has played an important role in human life, for as long as mankind has been around. Natural light - the sun, moon and stars, fire - has been the only source of light for the major part of human existence. Hence, mankind has physically and psychologically adapted to natural light. When people started living and working inside buildings, the need for artificial lighting emerged. In the past two centuries, all kinds of electrical light sources appeared to serve this purpose. Nevertheless, since humans are so adapted to sunlight, artificial lighting has always been less than optimal in comparison, due to the limitations of conventional light sources***1**.

The introduction of LEDs however, created a degree of freedom in designing lighting products that was unimaginable just 10 years ago, when using conventional light sources. Today, LED technology has matured to a point that virtually any light effect and color can be created. This opens up new possibilities to improve the light quality of artificial lighting, by trying to approach natural light qualities, but also by creating entirely new lighting effects that are beneficial for people in a given context.

These new possibilities demand a new approach in the design of lighting products. Instead of taking a light source as a starting point, human experience should now be the starting point. The approach should no longer be optimizing the fixture design for a given light source, in order to get the best possible light quality with that light source. Instead it should be approached by optimizing the design of a lighting effect in order to achieve the best possible human experience in a given context. From there a product that can produce that lighting effect can be designed.

Signify's Light Content department addresses this issue, by researching how people are affected by different lighting effects, what their added value is and how to design for these lighting effects. These effects comprise of various lighting characteristics - for example intensity, color, texture - and dynamic changes in those characteristics. Light content is the design recipe composed of various lighting characteristics that

***1** A conventional light source is any electrical light source preceding LED technology, like incandescent bulbs, halogen bulbs, fluorescent tubes, etc.*

create a specific lighting effect and experience. In concrete terms, Light Content is about the creation of digital content for LED light sources.

Biophilic design

Biophilic design (Kellert et al. 2008) is the design framework that is at the basis of this master thesis. It finds its merits in the concept of Biophilia, as defined by Wilson (1986) and further developed by Kellert and Wilson (1995). Before going into depth about this concept, it should be noted that the scientific argumentation for the theory of Biophilia is debatable, as is critically pointed out by Joye and De Block (2011). This does not mean the effect of Biophilia is not real, but the cause for these effects might not be as single handed as Kellert and Wilson propose. This does not render it useless, but has consequences for the way with which one should assess Biophilia and the Biophilic Design framework.

First a summary of Biophilia and Biophilic Design is given, as Kellert proposes it in his book Biophilic Design (Kellert et al. 2008). Then an assessment is made on how Biophilic Design can still be a valuable approach to design, accounting for the existing critique on its underlying theory.

Biophilia

"Biophilia is the inherent human inclination to affiliate with natural systems and processes, especially life and life-like features of the nonhuman environment." (Kellert et al. 2008, p.3) In concrete terms: people have an inherent preference to reside in the presence of natural features like water, plants/trees, wildlife, daylight, etc. A mundane example is the preference to sit in a seat next to the window in a train. The hypothesis of biophilia explains this preference as a tendency that became biologically encoded in human nature over the course of evolution. Mankind has evolved in a largely natural environment for the majority of evolutionary time and was dependent on this environment for its survival. Specific natural features of this environment could be beneficial and others would have posed threats to human life. Automatic positive or adverse biologically encoded responses to these beneficial or threatening natural features, would increase the chances of survival for the human race throughout evolution. Examples of such beneficial features can be: open water(to drink, clean, fish, etc.), trees (shelter), wildlife/plant-life (food), viewpoints like hill tops (view to spot danger/prospect from a distance), etc.

While in modern society's man-made environment the recognizing of these beneficial natural features no longer plays an instrumental role in our survival, the biologically encoded need to affiliate with these features is still present. Take a look at the examples named above again and note that these are still places we like to reside at, while they do not serve any significant practical purpose anymore.

This biological need does not only present itself as a preference, but has a multitude of direct physical and psychological effects on people's well being as well. For example, views of nature can have a significant effect on restoration from stressful situations. "Studies in both laboratories and real environments have consistently found that viewing nature produces significant physiological restoration [from stress] within three to five minutes at most, as evidenced, for example, in brain electrical activity, blood pressure, heart activity, and muscle tension" (Kellert 2008, p91). Kellert (2008, p.85 - p.224) elaborately discusses a wide range of research in different fields of expertise showing various effects to support the hypothesis of biophilia as a biologically encoded treat in human nature.

In conclusion, biophilia is a biologically encoded inclination to affiliate with natural features that have had a benefit to humankind throughout evolution; which while seizing to have any instrumental role in modern society, still has a significant effect on people's physical and psychological well being.

Biophilic design

Biophilic design takes the effects of biophilia and translates its implications for human well being into design principles for architectural design. Kellert observes that modern architecture is getting increasingly detached from the merits of human nature, and is failing to address the human need for connecting with nature. Biophilic design aims at restoring this connection, for the benefit of human well being.

Another premise for biophilic design is environmental sustainability. This is an issue being increasingly well recognized in architectural design, which is of course a good development. However, the current approach to sustainable design is incomprehensive. Environmental sustainability is addressed from a purely scientific viewpoint, reducing energy consumption, using durable materials, reducing carbon emissions etc., by relying on hard data. The psychological and emotional - or human - element in ecological responsibility is currently under addressed. Biophilic design adds a human element to the current approach to sustainable design, aiming to evoke a heightened sense of responsibility in preserving the environment.

Biophilic design looks at the evolutionary roots of biophilia to conclude what type of design elements would be effective to restore the connection with nature and which would not. In the same way there are natural features that have been beneficial to human evolution, there are also natural features that would have posed danger - which in turn also cause negative physical responses like stress. Hence it is important to make the distinction between beneficial and stressful natural features - not just anything natural can be assumed to have a beneficial effect on people's well being. With this in mind, Kellert arrives at two basic characteristics*[1] of biophilic design:

1. *Organic/naturalistic:* This characteristic is defined as "shapes and forms in the built environment that directly, indirectly, or symbolically reflect the inherent human affinity for nature." (Kellert et al. 2008, p.5) Meaning returning a connection with nature in the built environment, by placing natural features, like daylight or a view outside of an actual natural environment (direct); cultivated nature like potted plants or aquariums (indirect); or representations of nature like images, photos, metaphors (symbolic)
2. *Place-based:* defined as "buildings and landscapes that connect to the culture and ecology of a locality or geographic area." (Kellert et al. 2008, p.6) In other words, creating a meaningful relation between a building and the people residing in it; by relating to the local natural environment and culture, the building becomes an integral part of people's individual and collective identity.

This sense of identity is instrumental for creating a sense of responsibility for the environment. "People are rarely sufficiently motivated to act as responsible stewards of the built environment unless they have a strong attachment to the culture and ecology of place." (Kellert et al. 2008, p.6) These two characteristics can be related to 6 design elements, which in turn can be divided into 70 design attributes designers can work with. Below these elements are briefly explained and backed up with some (not all) of their attributes. Some attributes speak for themselves, while others might require some explanation. However, these attributes are mentioned here only to give a general idea of the Biophilic Design framework as presented by Kellert (Kellert et al. 2008), but for a complete understanding on how to use these attributes in design, the book itself should be consulted.

1. *Environmental features:* this is the most obvious element, which is best described with its attributes - water, air, sunlight, materials, plants, animals - in their literal sense (no abstractions or symbolism). The use of any of these attributes directly creates a connec-

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**[1] Kellert uses the term "dimensions" here. However, he does not seem to describe a field of biophilic design, bound by two dimensions; rather he describes two required characteristics that make a design a biophilic design. Hence I find the term characteristics more accurate.*

tion with nature.

2. *Natural shapes and forms:* this element includes representations and simulations of the natural world. Some attributes in this element are: botanic/animal motifs, egg/oval/tubular forms, arches/domes, organic shapes, bio-mimicry etc.
3. *Natural patterns and processes:* this element incorporates properties found in nature into the built environment. Examples are: Sensory variability, age/change/patina, growth, fractals, hierarchy/ratios (like golden ratio), etc.
4. *Light and space:* this element focuses on light and spatial relationships. Attributes are: natural light, reflected light, light as shape & form (light texture), space as shape & form, spatial harmony, in-/outside spaces.
5. *Place based relationships:* this element refers to the successful marriage of culture with ecology in a geographical context. Locational familiarity - the yearning for home - remains a deeply held need for most people. Attributes: Geographical/ historic/ ecological/ cultural connection to place, indigenous materials, landscape features defining building form, spirit of place, avoiding placelessness.
6. *Evolved human-nature relationships:* while all other elements are also derived from their roots in human evolution, this element is about the more fundamental aspects of human affinities with nature. Attributes in this element are: Prospect and refuge, curiosity and enticement, change and metamorphosis, security and protection, affection and attachment, information and cognition, fear and awe.

Criticism on the biophilic hypothesis

As noted, there is some critique on the premise of the biophilia hypothesis, which reasons that the phenomenon is an inherent biologically encoded trait of our human nature. In other words, it is reasoned that biophilic effects exclusively have their roots in our genetic evolution (where nurture merely serves to awake this inherent human nature).

While it is not disputed that biophilia exists as a phenomenon, its argumentation for its exclusive roots in genetic evolution are debatable. Joye and De Block (2011) show a series of points for why this argumentation is at least unlikely, which is too extensive to elaborate on here in depth. The main point to be considered is the fact that what actually comprises a biophilic effect is rather unspecific in its definition by Wilson (1986). Within his loose definition an enormous range of effects that relate to our preference of nature can be attributed to biophilia. Genetically encoded roots might exist for some of these effects, as is demonstrated by a reasonable body of research cited by Kellert (Kellert et al. 2008, p.85 – 224). However, this research only covers specific biophilic effects; it cannot be assumed that this research can be interpolated to explain all effects that fit the loose definition of biophilia.

Accounting for this critique we can arrive at a redefinition of biophilia. Biophilia should be reconsidered as an effect that can also be highly influenced by nurture where social, cultural and geographical factors come into play as well. It might be more accurate to include cultural evolution, next to genetic evolution as a root for the observed biophilic effects.

Biophilia could be described as a collection of effects in which people are biased to favor natural over man-made features. This bias towards nature can be caused by our evolved human nature; or by nurture, consisting of experiences determined by social, cultural and geographical factors; or most likely a combination of these - depending on the effect.

Kellert presents Biophilic Design as a necessity, based on his premise that biophilia is a genetically determined, and thus directly affecting our physical well being. Combined with the holistic way in which Kellert defines biophilia, this leads to a very comprehensive and rigid framework for design. The new description of biophilia outlined above diminishes this premise for biophilic design to the extent that it is no longer as rigid as it is proposed by Kellert. It does not mean that the framework of biophilic design is no longer valid, but it does call for a more flexible interpretation of the theory – recognizing also the limitations of our scientific understanding of the underlying causes for the effects.

The other premise of Biophilic Design - the emotional aspect of environmental sustainability in design - still remains valid. How can one expect to succeed in environmental sustainability, if the people who should make it happen cannot relate to it on an emotional level? Biophilic design addresses the emotional relation between people, the built environment and the natural environment.

One could approach biophilic design by reversing its relation with biophilia; if biophilic effects are partly nurtured by cultural factors, then one could use biophilic design for nurturing people's biophilic tendencies, which would be a healthy development from an ecological perspective. If people would grow up in a man-made environment that was designed to incorporate and value the natural environment, these people would have grown a richer experience of nature throughout their lives, and likely will value the natural world more greatly as a result.

On a more concrete level, the biophilic design framework itself needs to be reassessed as well. Some design rules proposed in the framework are rather narrow and compulsive in their definition. Though when defining biophilia as something that is not as rigid and universal as originally proposed, it doesn't make sense to adhere to these design rules in such a strict manner. As a whole biophilic design might be more effectively approached as a framework of guidelines rather than strict rules - adaptive to the cultural and environmental context it is used in. Some exceptions to this could be made to the effects that actually have been proven to have a very defined and universally applicable effect, inherent to human biology - like blue light in relation to the circadian rhythm (biological clock); or the immediate positive health effects of a view of nature in hospitals.

Biophilic light content

There is an obvious overlap between biophilia and the striving to approach natural light qualities in artificial lighting. Consequently it makes sense to use Kellert's biophilic design framework as a basis in designing light content. Additionally, the current public concern about environmental sustainability, provides good reason to emotionally reconnect people to their local natural environment. Emotional attachment to one's natural environment can stimulate to actively engage in preserving it. Equally, emotional attachment to the building (or product) itself, creates incentive to preserve that building rather than to replace it with something new every few decades (or merely 2 years when talking about most modern products).

The biophilic design framework outlines some general design principles and a set of concrete design attributes designers can work with. This master thesis aims at applying these principles to the field of light content and specifically to light texture (definition in chapter 2), in the end arriving at a concrete design approach. While the scope of this thesis is limited to light texture, biophilic design is applicable to the other elements in light content as well. Thus it is also encouraged to further explore it as a basis for designing light content in general.

1 _ THE EXPERIENCE OF LIGHT

As outlined in the introduction, designing light content is aimed in the first place at designing for human experience. When trying to design a light experience, first we need to get a better feeling for how people do experience light. The word “feeling” is used here, rather than “understanding”, because light is something that is experienced much more intuitively rather than cognitively. This intuitive experience of light is not as straightforward as one might think. Light is a rather intangible phenomenon, that is often experienced on a subconscious level.

Light is a medium through which people perceive their surroundings. Every object around us is perceived only because of the light that is reflected off its surface. Light is mostly perceived indirectly in combination with its surroundings. As a result, people often are not consciously aware of the light in a space, rather they only consciously perceive the physical space itself. This does however not mean that people do not experience light, on a subconscious level it certainly affects our experience.

1.1 _ Atmosphere

The most impactful way in which lighting can influence the perception of a space is by setting an atmosphere. To illustrate this in a simple way, let me take you to an imaginary space:

Imagine looking for a new house to move into. You are visiting a property you are interested in, and you enter a room. The room is empty. It has a wooden floor, white walls and white ceiling. There are no windows and it is about 4x5 meters in size. The lighting is off.

Once you have this room clearly in your mind, imagine some different lighting scenarios:

1. First imagine in the ceiling are fluorescent light tubes, uniformly lighting the room in cold white light.
2. Now imagine the room without the light in the ceiling, but with a single standing lamp in one of the corners, illuminating the walls and the ceiling around it, in a soft warm white light.
3. Lastly, imagine the room without lighting again, but with a glass ceiling viewing the sky on a sunny summer afternoon.

(See figure 1.1a-c)

The moment you enter that space, you immediately attribute a feeling towards it, without consciously thinking about it. This feeling depends on our own mood and expectations, but also is

Figure 1.1a _ Fluorescent lighting

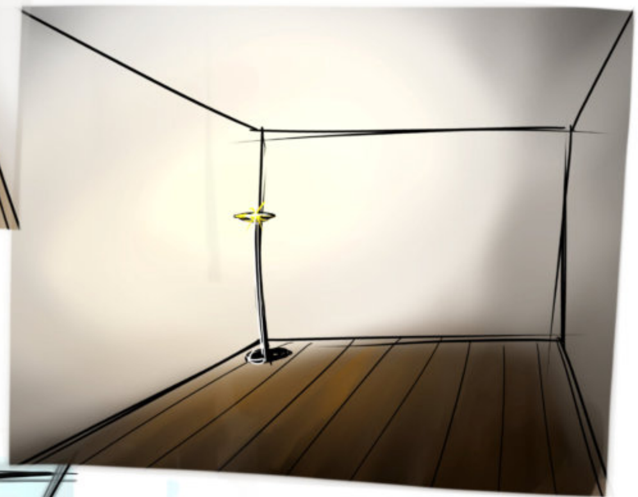


Figure 1.1b _ Single standing lamp in corner

Figure 1.1c _ Skylight

influenced by the atmosphere in the space. The room is exactly the same, but the different lighting creates a very different atmosphere in each scenario, which likely influences the way you feel about that space significantly.

These three scenarios show the impact lighting can have on the atmosphere in a space, even if its white and empty. The materials used, the type of furniture, the colors, etc. can of course all influence the atmosphere in a space as well; but lighting determines how these elements are perceived. If you would imagine that room as a bedroom, with its interior fitting accordingly, it is unlikely you would prefer the first scenario with fluorescent lighting. However, if it would be an office space, that same scenario might be quite acceptable. Light can both contribute to the atmosphere, or ruin it completely.

The role of atmosphere

It is clear lighting can have a great impact on atmosphere, but what is atmosphere? Ingrid Vogels (2008) describes atmosphere as follows:

"Atmosphere differs from emotion and mood in the sense that it is not an affective state, but it is the experience of the surrounding in relation to ourselves. The atmosphere of an environment is a subjective experience through the perception of external elements and internal sensations, but it does not necessarily give rise to a particular feeling. An environment only has the potency of changing people's mood in accordance with its atmosphere. If I am thinking of all the work I have to do, I would still feel pretty stressed in a relaxed environment. However, in a stressful environment I will never feel relaxed. Hence, the effect of environmental variables on mood will depend, among other things, on the initial affective state of the observer. On the other hand, the effect on perceived atmosphere is expected to be independent of people's mood."

Relating back to our imaginary space: the atmosphere in each of the three imagined scenarios is subjective, but remains the same regardless of mood. However, our feeling towards each scenario changes when regarding it from a "bedroom mood" or an "office mood", because of how each atmosphere fits with that particular mood.

The role of atmosphere is to align our human emotional experience with our surroundings. Which means that it is important to consider the context of a space, when designing its atmosphere – or when designing a lighting experience. This context involves the function of a space, but equally important is also the social, cultural and environmental context, approaching it from a biophilic design perspective.

1.2 _ Character

So far the influence of light on atmosphere has been discussed. However, there is more to the human experience of a space than atmosphere. Lighting also plays a role in the character of a space.

The character of a space is to its atmosphere as a person's personality is to their mood. They are not completely unrelated from one another, but are definitely two different things. Just like the atmosphere in a space, when first meeting a person, their mood is usually quickly perceived (be it conscious or not). Personality is more complicated, and is comprised of many small things that take time to get to know; like a quirky smile, a peculiar way of talking, a favorite type of food, etc. Some superficial or extravagant qualities might be quickly recognized, other more subtle

Figure 1.2a _ Classical character bed room[*1]

Figure 1.2b _ Office with creative character[*2]

Figure 1.2c _ Brick bedroom with very distinct character

*[*1] Figure 1.2a - Interior deisgn: JC Associates*
*[*2] Figure 1.2b - Interior deisgn: asd|Sky*

details take effort to discover. The adding up of all these little details and the relation between them, is what comprises a personality.
This is the same for the character of a space. Lighting in this case certainly does not comprise the whole character of a space, it is but one of the little things within the whole collection of characteristics that make the character of a space. Things like the materials used, the design language of the furniture, the way in which things are arranged, patterns and decorations, paintings on the wall, etc. are all expressions of character. Figures 1.2a-c show how these kind of design elements can create very different characters in a space.

The best way to illustrate how lighting can contribute to this, is the architectural lighting framework as outlined by Richard Kelly (1952). He defines three elemental kinds of light:

1. Focal glow or highlight.
2. Ambient luminescence or graded washes.
3. Play of brilliants or sharp detail.
   (figure 1.3)

The first two kinds of lighting are strongly related to atmosphere as discussed in 1.2. In the example of the imaginary room, scenario 1 (fluorescent lighting) could be regarded as an example of ambient luminescence; scenario 2 (single standing lamp) is a good example of focal glow.

Focal glow or highlight
Focal glow is about directed light. A spotlight on a painting, a reading light, the headlight of a car. It is about creating contrast, areas of light and dark, directing attention to particular focal areas in the space. It can create a dramatic atmosphere, mystery, coziness.

Ambient luminescence or graded washes
Ambient luminescence is the opposite. It is the lack of contrast, smooth gradients, an overcast sky as opposed to direct sunlight. It can create a more calming, rustic atmosphere in combination with focal glow. Or a very impersonal, detached atmosphere when focal glow is lacking completely.

Play of brilliants or sharp detail
The third elemental kind of light is about character. Kelly defines play of brilliants as the sparkling of crystal chandeliers, the flickering flames of candles, the shimmering of water, etc. With the possibilities of modern lighting technology, one could add the shape of light to this description (sharp detail). This could involve shadow projections, or the shape of a light source itself (neon tubes, exterior LED lights in cars, etc.)

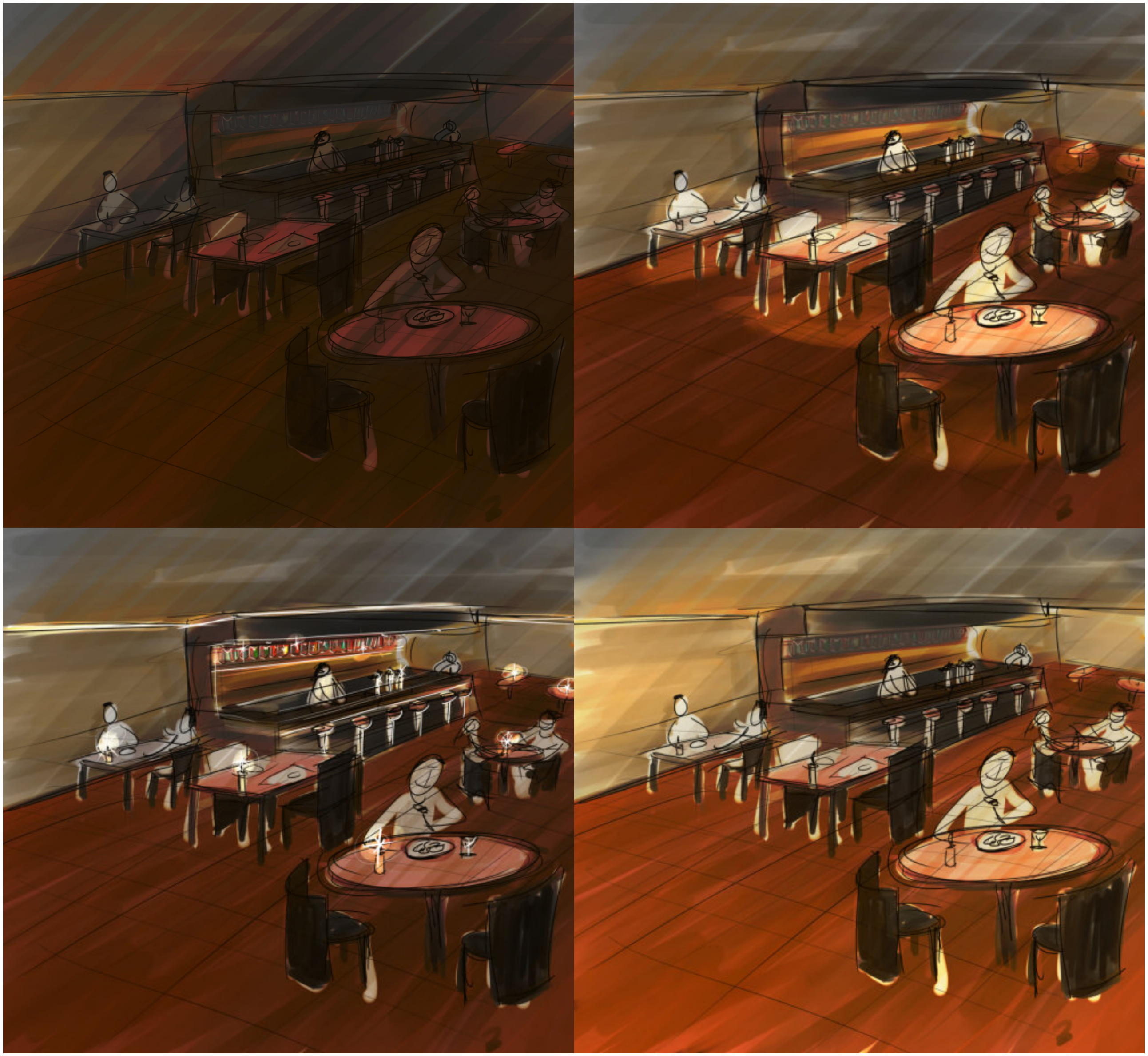


Figure 1.3 _ Richard Kelly's elemental kinds of light, clockwise starting top left: no lighting; focal glow; ambient luminiscence; play of brilliants

Play of brilliants can entertain, or create a sense of discovery. It adds visual interest. It can be subtle, but also overwhelming (Kellly names Times Square as an example, an extravagant personality in our metaphor). It adds a layer of richness, intricacy, depth and meaning to an otherwise bland space.

Play of brilliants is not required to establish a character in an architectural design, the physical design itself might be able to establish that by itself already. However, it is a way that light can contribute to that character. In the same way atmosphere should fit with the context of the space, so should the character of the light fit with the character of the space. In case of atmosphere this is a bit abstract, and involves people's moods in accordance with the context. Character is often more aesthetic of nature, and involves graphical details, colors, shape and dynamics, that should fit with the context of the space and the design of the space itself.

1.3 _ Experience of natural light

Until now, the experience of light has been discussed in a rather simplified analytical way. It helps to understand the basic principles, but it does little justice to the richness of our actual experience.

This is even more so the case when looking at

Figure 1.4 _ Brilliants can be flickering candles, stars, but also the shape of light in for example car lights or neon tubes

our experiences of nature. Nature is an infinitely complex system, in which everything is connected to everything. Our analysis of our experience of light so far, applies to nature as well, but it does not begin to cover even the essence of that natural experience.
Biophilic design aims to bring back some of that richness of our natural experiences to the built environment, but it would be futile to analyze what this richness may be. So rather let me conclude with an anecdote of one of my own experiences of nature, which will illustrate the richness of our experience in a more intuitive way, without losing its essence (though admittedly still not nearly justifying the actual experience itself):

November walk in the fields
It is lunch time and I head out, walking through the fields just outside town, as I do every day. It is a cold day in November. Cold in a way that is only experienced the first cold days of the season, with the warm summer sun still fresh in memory. Last night was the first night of freezing this season, the grass is white with ripe, a film of ice covers the puddles, the mud is softly crunching under the pressure of my feet. The paths are covered in a sheet of brown and orange leafs, stacking thicker as autumn progresses. I scuff through it - it is a subtle expression of the fun and rashness of childhood, busting through the leafs as I did ages ago - smiling at the memory.
The sun rises low above the horizon, hardly higher than the trees. The trees are like sundials along the path, casting long shadows forward. Bright contrasting textures of light and shadow are on the autumn fields – brown leafs, frozen muddy tracks, grass that's been mowed for the last time this year, plowed land ready for the next farmer's season. The yellow sunlight is casting a comforting glow, like a warm blanket over this cold landscape.
A cool breeze finds its way up my ankles, where my pants and socks meet - I steady my pace to circulate my blood, yet inhaling a large breath of cold winter air. My face benumbs in that same cold breeze, but I enjoy every ray of sunlight feeling like a soft caress over my cheeks.
My thoughts dwindle, back to memories of countless of these walks. Walks with family during Christmas, with my dad spotting birds, with my friends collecting chestnuts - the memories warm me up from within.

Every season I tell myself: "this is the best season of year". But every new season, I need to correct myself again. It is the contrast with the previous season, that is still fresh in memory, highlighting the beauty of the next. It is the first days of each season, that are the most beautiful days of year. Today is only late November, but it was the first day of winter.

Figure 1.5 _ Frozen fields in November, near Eindhoven, the Netherlands

2 _ LIGHT TEXTURE

When talking about texture in the tactile sense, we are talking about what we feel when we stroke a surface with our finger tips. In other words: the tactile qualities of a surface. This is more than just describing a smooth or rough surface, a texture could also refer to the shape of objects (sharp or rounded edges) or the consistency of a material (soft, hard, solid, liquid and anything in between). Everything perceived with the finger tips is a tactile quality, that when put together describe a texture. For example, temperature is a tactile quality, which is an important characteristic of a metal surface texture (cold to the touch).

When translating those tactile qualities to visual light qualities, we get light textures. Basically any kind of light projected onto a surface has a light texture (just like any physical surface has a tactile texture). A simple spotlight on a wall might be equivalent to for example a polished metal surface that is brushed in one spot.

However, it does not make a lot of sense to talk about light texture, when talking about a spotlight or a wall washer. It starts making sense when talking about shapes of light, about visual light patterns. This is when the texture of the light becomes its defining quality.

2.1 _ Visual qualities of light texture

Light texture can be defined as the visual shape and structure of any lighting effect on a surface and/or in 3D space. For this project, the scope will be narrowed to the situations where the light texture is the *defining* quality of the lighting effect.

In practice this means we are mainly talking about *visual patterns* created through lighting, either by direct light (being the light source itself: neon tubes, the stars, etc.), or by indirect reflections or projections of light and shadow on any material (rigid surfaces, water, fog, hot air etc.).

A visual pattern can be broken down into the following visual qualities:

1. *Style:* geometric - organic
2. *Structure:* Grid (square, triangular, circular, linear), fractal, random
3. *Contrast:*
    - Brightness (shadow – light)
    - Focus (crisp – blurry)
    - Color (for example, red - cyan)
4. *Dynamics:* A change over time in any of the above qualities.

Style

A pattern is composed of a number of shapes or elements, organized in a certain structure. Style in this case refers to the style of the individual elements within the pattern. For example a set of triangles could be considered a geometrical pattern and a set of flower shapes an organic pattern. All geometry could be mapped on a scale from geometric to organic (figure 2.1). Though, describing a shape only as geometric or organic might not fully cover its style. Below a few styles are listed, but basically an infinite number of styles could be invented - moiré, baroque, art-deco, etc. (figure 2.2a,b,c,)

Figure 2.1 _ Organic*[1] and geometric*[2] light textures

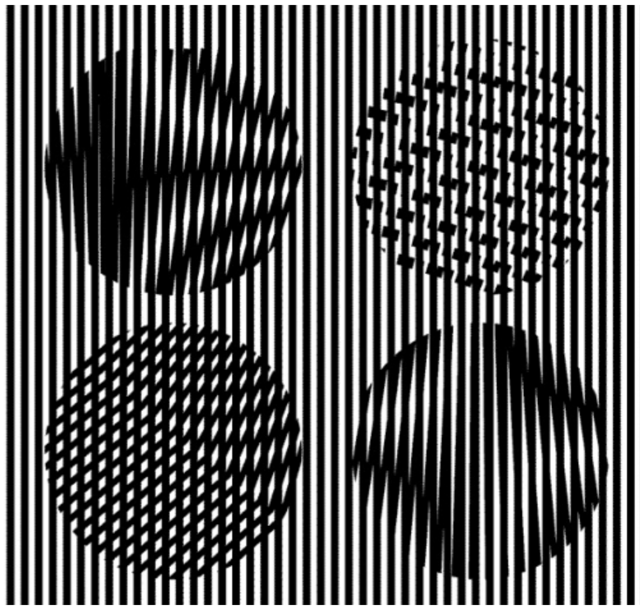


Figure 2.2a _ Moiré patterns

*[1] Top image - Andromeda, by Ross Lovegrove for Yamagiwa

*[2] Bottom image - Gallery of Blairgowrie Back Beach, by Wolveridge Architects

Figure 2.2b _ Baroque style wallpaper

Figure 2.2c _ Art-deco style wallpaper

Structure

Structure is the way in which the collection of shapes that make up the pattern are organized. The individual elements do not necessarily need to be identical, but usually are of the same style. These elements can be structured in different ways. The most basic way is a grid structure, where different types of grids are possible: rec-

Figure 2.3 _ Pattern with square and circular grid structrue*[1]

*[1] Figure 2.3 - Kaust Investment Management Company, Arlington, by Studios Architecture

tangular, triangular, linear, radial etc; or a combination of these grids (figure 2.3). A grid can also be deformed, for example mapped along a curve or a surface; a change of density at different positions within the grid; or varying the orientation of the shapes within the grid. The grid can be deformed in such a way it creates a direction in the pattern or even in a repetitive way to create an additional pattern on a macro level.

Fractals are another pattern structure, which use a recursive algorithm to structure the elements. Such an algorithm typically takes the previous position of an element as a parameter for the position and orientation of the next one. The resultant pattern is usually a recursive series of identical shapes, that are placed in a series and oriented/scaled/distorted according to the the parameters of the previous shape. Figure 2.4 shows an example to give a better understanding. Fractals often also occur as growth patterns in nature, think of a cauliflower or the shell of a snail. (figure 2.5)

A set of shapes does not have to be strictly organized to be a pattern. A random structure will work as well, as long as the individual elements are visually related – having a similar style, or being placed in close proximity. (figure 2.6)
The occurrence of a single shape of light will here

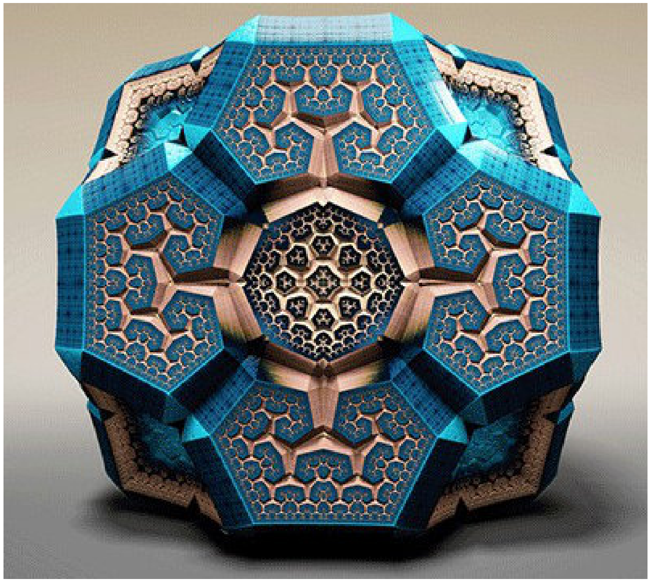


Figure 2.4 _ Fractal patterns

Figure 2.5 _ Fractal structure of a Romanesco cauliflower

Figure 2.6 _ Random pattern structure*¹

also be included as a light texture, while strictly it has no structure and cannot be regarded as a visual pattern. Take figure 2.7 as an example. It is

Figure 2.7 _ Single sunlight patch*², no pattern structure

a clearly defined shape with crisp edges, which can be regarded as a texture quality. In this case that specific shape is the defining quality of the light effect, leading to including it within this visual description of light texture.

Contrast

Contrast is inherently necessary to distinguish the elements of a pattern from their background. There are three different types of contrast that can accomplish this in light textures: Brightness, Focus and Color.

Brightness: contrast in brightness is the most obvious form of contrast. It is nothing else than the difference between shadow and light. The larger the difference in brightness, the higher the contrast and the easier the pattern is to observe. Contrast in brightness is the bottleneck for any

[1] Figure 2.6 - The Louvre Abu Dhabi Museum, by Ateliers Jean Nouvel
[2] Figure 2.7 - Recreation of Daylight, by Daniel Rybakken

lighting effect. The brightness of the surroundings matter. In a dark room, you need significantly less brightness to make a lighting effect visible. In a room where daylight can enter, the lighting effect needs to compete with sunlight, which might be nearly impossible on a bright summery day. A simple example that anyone will have experienced is the brightness of a smartphone screen – it can be challenging to see anything on a phone screen in direct sunlight.

Focus: Focus is about the border between two contrasting areas – between a light and shadow area. This border can range from crisp (high contrast) to very blurry (low contrast) – until a point where light and dark are blurred completely into one gray area (no contrast). Figure 2.8 illustrates that range. Figure 2.10 (next page) shows some examples of different focal contrast.

Color: Color contrast comes from the way our eyes perceive color. Our eyes are sensitive to red, green and blue light wavelengths. Our brain mixes these primary colors together into the wide color spectrum of visible light we can perceive. Two different colors can be distinguished, even if they have the same brightness (no brightness contrast) – this difference in color is color contrast.

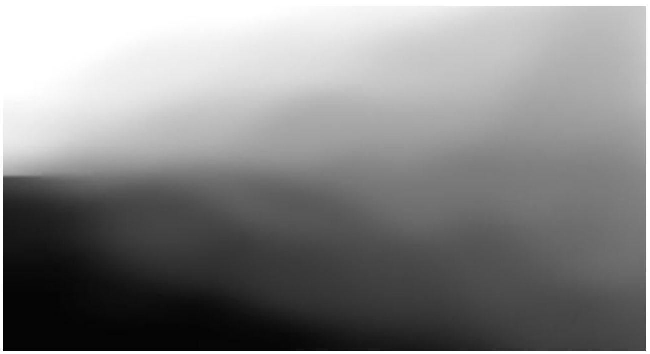


Figure 2.8 _ Crisp to blurry contrast

Dynamics

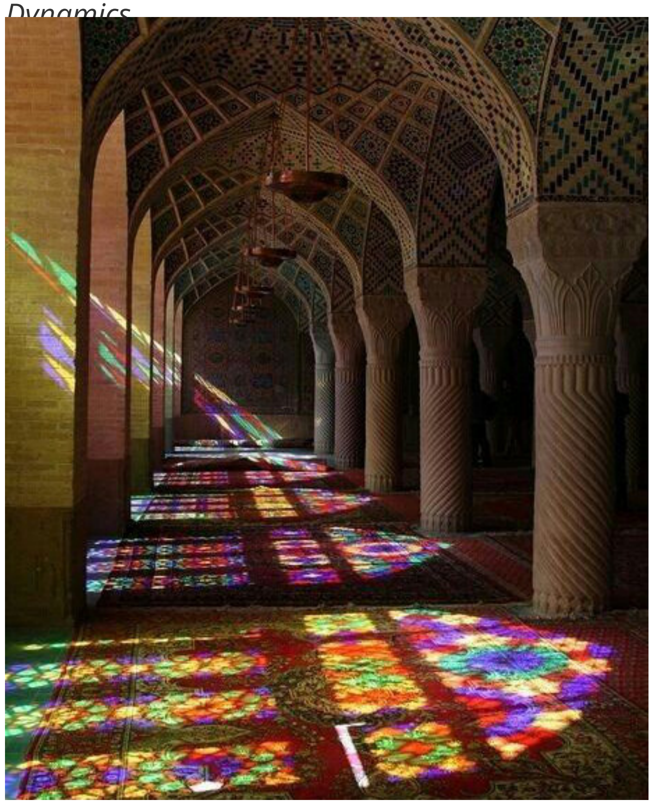


Figure 2.9 _ Color contrast of stained glass windows[*1]

[*1] *Figure 2.9 - Alhambra, Granada, Spain*

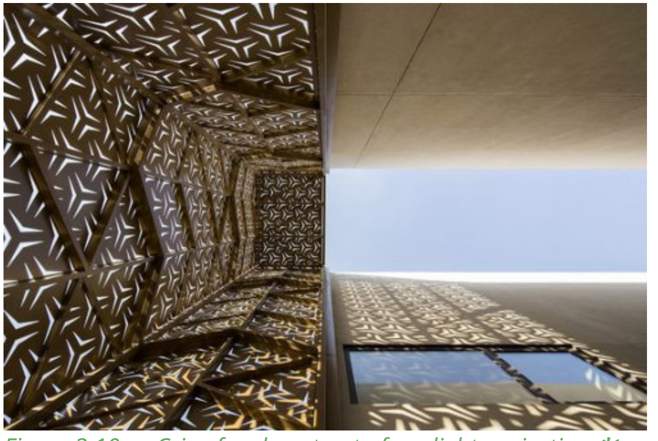


Figure 2.10a _ Crisp focal contrast of sunlight projections*[1]

Figure 2.10b _ Less crisp, but still defined projections*[2]

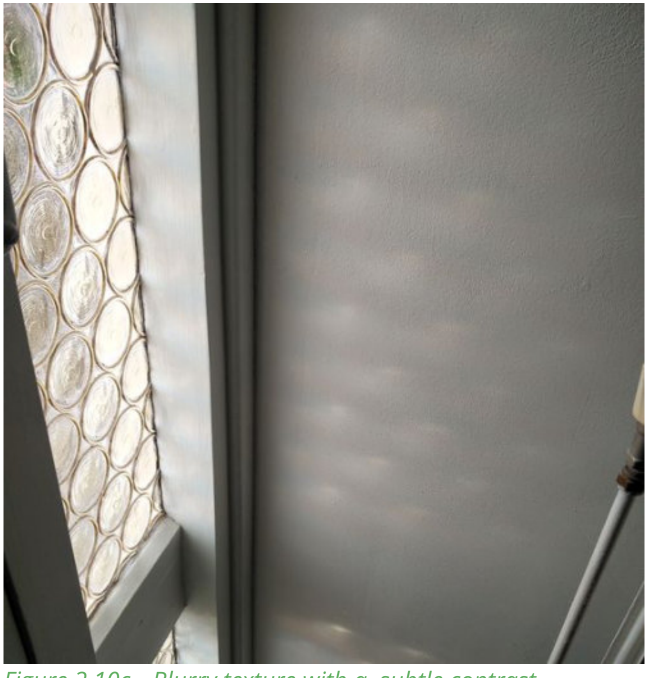


Figure 2.10c _ Blurry texture with a subtle contrast

Figure 2.10d _ Very blurry texture of an overcast sky

*[1] Figure 2.10a - Design: Ali Mohammed T. Al-Ghanim Clinic, by AGi architects

*[2] Figure 2.10b - Design: Banvard Gallery, Knowlton School of Architecture, Ohio State University

Dynamic changes can occur in any of the previously mentioned visual qualities. For example a pattern could change in color and focus over time, the structure could deform, the shapes could morph from geometric to organic etc.
Dynamics can also occur as a pattern by itself in the form of rhythm. Rhythm is a repetitive change in dynamics over time, and can be considered as a temporal pattern.
Dynamics in light texture are a complex subject in itself that will not be elaborated on here. Within the scope of this thesis, it is focused on dynamics in natural light – which will be further discussed in chapter 2.2

2.2 _ Natural light qualities

Light textures also occur in nature quite abundantly. In fact, the type of textureless lighting (fluorescent office lights, spotlights, etc.) that is so prevalent in the built environment, is actually hardly found in nature. Most often shadow projections are created by the sun in combination with trees and plants. The shimmering of water surfaces by themselves can be regarded as light textures, as well as the reflections that are projected on anything surrounding that water surface. Even on an overcast day, the sky as a light source has a texture in the gray clouds.

Figure 2.11 _ Light textures in nature

Natural variation

There is one quality that characterizes anything created by nature: natural variation. Nothing in nature copies itself in the exact way that for example mass produced man-made objects can be. Nothing in nature is repeated a second time in exactly the same way. A tree grows hundreds of leaves. They are all clearly similar, but none of them is an exact copy of another.

When looking at dynamics, reed waving in the wind is a good example. (Video 2.12) The movement could be characterized as natural variation. It has no rhythmic pattern, not an exactly repeating sine wave that could be described by a single mathematical formula. Yet it is also not random. The variation in its movement is dependent on a vast number of factors from its environment, most notably the wind. The direction and speed of the wind in one specific point in space is impossible to predict, but it is also not a random parameter – it is in turn dependent on an infinite amount of parameters. Yet, when looking at the waving reed, any human being will intuitively be able to distinguish between movement by the wind, and movement by a person waving that reed randomly.

Video 2.12 _ Natural variation in the movement of reed waving in the wind.

When looking at the visual qualities described in chapter 2.1, natural variation could be introduced to any of those qualities, in order to make it appear more natural. One could argue for example that the pattern structure shown in figure 2.6 (p. 27) is actually not random, but a naturally varied structure (and style). While on the other hand the baroque pattern in figure 2.2b (p. 25), is clearly man-made due to its precise structure and style, despite it's inspiration in nature.

Natural causality

Light textures in nature do not occur out of nowhere, they are the result of cause and effect. This might seem like stating the obvious, but the fact is that light is often merely experienced indirectly and subconsciously, hence it is important to consciously consider this causality. Additionally, with the large number of cause and effect relations in any natural effect, this causality can become rather blurry.

A light texture will never appear natural, if there

2.12 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/uaecby0vbhd6iuu/Video2.12.MTS?dl=0 is nothing to make its appearance likely. A projection of sunlight through a window does not appear natural if there is no window present, or if it isn't at least likely there is a window somewhere out of sight. Figure 2.7 (p. 27) for example shows such a patch of light, which in reality is not an actual projection of sunlight, but an artificial light emitting panel. This only works successfully in combination with the general lighting in the space. Had the wall above it not been illuminated more brightly to suggest the presence of a window in that direction, it would not have seemed natural.

This example of a patch of sunlight is quite straightforward. However, in nature cause and effect are often not quite as obvious. In principle there can be sunlight plus a tree as a cause, and shadow projections as a result. However, there is a lot more going on than just that – there is wind, there is clouds, there might be a lot of layers of leaves. All this influences the resulting projection. Take a look at figure 2.13a and 2.13b. One is the shadow projection of one branch, the other of a forest. A single branch with leaves creates a quite recognizable projection. In a forest there are so many layers that the graphical shape of the leaves is not distinguishable anymore in the resulting shadow projection. This is where cause and effect relation becomes more blurry; but the

Figure 2.13a _ Clear graphic shadow projection of a branch

Figure 2.13b _ Shadow projection of a canopy, not graphically defined, but still instantly recognizable

causality still exists, and is still intuitively quite clear that they are shadows of leaves.

In principle it can be stated that this increasingly complicated natural causality is at the origin of natural variation; in some instances where the causality is becoming very complex, it might be more effective to talk about natural variation.

Natural dynamics

The static nature of the built environment is perhaps the most elemental difference between the built and the natural environment. Nothing in nature is static, not even rock, which often facilitates life and erodes under influence of weather and life.

Dynamics in nature are characterized, quite evidently, by natural variation and causality. Where no object in nature occurs exactly the same twice, the same goes for any movements. While there might be exceptions in this regard (day and night is quite a steady rhythm, or when scaling down to vibrations/sound/energy) in the scale that is relevant for light textures this generally applies. The example of waving reed that was discussed under natural variation quite covers natural dynamics as well.

Another good example is shown in video 2.14, which shows the shadow projection of trees, waving in the wind, and fading and reappearing because of clouds moving in front of the sun.

Video 2.14 _ Tree shadows fading and reappearing

This is a good illustration of how natural variation and causality characterize natural dynamics.

Other natural light qualities

There are many other characteristics of natural light textures and nature in general that might be interesting for the creation of light textures, too many to list here. For inspiration, it is best to simply observe nature. However, natural variation, causality and dynamics are the most fundamental qualities that differentiate nature from purely man-made creations.

2.14 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/qwm3fryefa9khtf/Video2.14.mp4?dl=0

3 _ DESIGN APPROACH

Having a basic grasp of how light is experienced and a basic definition of light texture, a design approach for light texture as a part of light content can be conceived. While specifically tailored to light texture, the basic principle of this approach could be applied to any type of light content in architectural design.
It is important to note that, since the experience of lighting is to a large extent rather subjective, this will not be a framework of hard rules with which anyone could design light textures – the designer's own subjective experience and intuition are a crucial element in this design approach.

3.1 _ Design principle

As discussed in the introduction, the design of light content is in the first place about designing for human experience. Hence the experience of light as outlined in chapter 1 will form the backbone of this design approach. Light texture has the potential to contribute to both the atmosphere and character experienced in a space.
The premise from which the basic principle of this design approach follows, is the way in which light textures occur in nature as an integral part of their environment. This premise is continued into architectural design, arriving at the following design principle:

*The minimum condition for creating a **biophilic design is** to create an **integrated design**. Any light texture should be an integral part of the architecture AND of its social, cultural and geographical context; this integration can be achieved by aligning the atmosphere and character that the light texture conveys, with the atmosphere and character of the architecture and its environment.*

3.2 _ Design guidelines

To translate this design principle into clear guidelines, the visual qualities of light texture as outlined in chapter 2.1 are related to character, atmosphere and biophilic design, arriving at four basic guidelines:

1. *Style creates character*
2. *Structure is used to integrate*
3. *Contrast defines atmospheric quality*
4. *Dynamics introduce biophilic qualities*

This division between the visual qualities of light texture is of course no hard division, there will be some overlap in practice; to some extent character also contributes to atmosphere and vice versa; style and contrast also contribute to integrated design in their own way; and dynamics inherently influences the other qualities. Designing for each guideline requires to account for the other three guidelines.

Style creates character

How style can contribute to create a character should be obvious, and is probably best explained through examples. Figure 3.1 shows examples of how light textures can contribute to character. Besides lighting, other design elements like materials, physical textures, furniture, etc. also help create different characters of spaces. The style of all these design elements is the most basic descriptor of character in architectural design. *The style of a light texture should first and foremost fit with the style of the architectural design.* The character of the cultural and natural environment comes as a second priority – if the character of the light texture does not fit the architecture, its integration fails despite fitting with the cultural and natural context. Ideally the style of the architectural design itself aligns with the cultural and natural environmental context.

Structure is used to integrate

In chapter 2.2, causality is described as an important factor to create a convincing effect. This is also the main way in which structure is

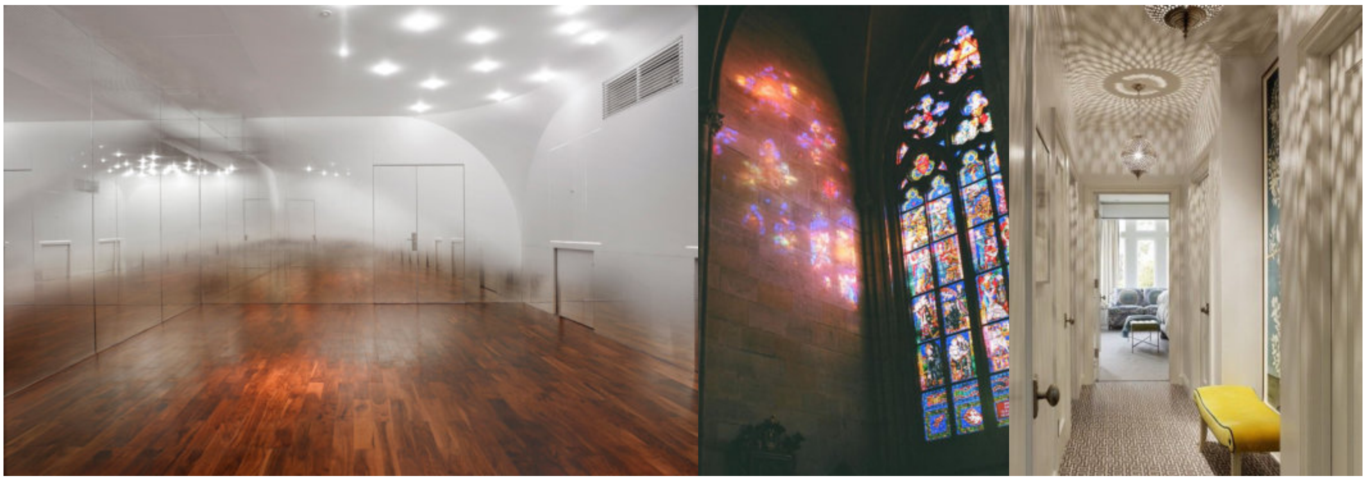


Figure 3.1 _ Light textures can contribute in widely different ways to the character of an interior design.[1, 2, 3]

[1] Figure 3.1, LEFT - ANZAS Dance studio, by Tsutsumi and Associates
[2] Figure 3.1, MIDDLE - St. Vitus Cathedral, Prague, Czech Republic
[3] Figure 3.1, RIGHT - Home interior in San Fransisco, by Palmer Weiss interior design

used to integrate with the architecture. There are four parameters to consider, in relation to the causality of the effect:

- Structure type
- Scale (of structure and of total texture)
- Position in space
- Orientation in space

The structure type is what has been described in chapter 2.1 as a visual quality. The way in which this aligns with the causality of the effect is evident – simply put, if the cause of the effect is a tree branch, then the structure is that of a tree branch.

The example of the patch of sunlight (figure 2.7, p. 27) as discussed in chapter 2.2 (p. 31), explains quite well how the relation between causality and the spatial parameters (scale of total texture, position and orientation) works. The causality in the example (suggestion of a window out of sight) determines the logical scale, position and orientation of the sunlight panel.

The example in figure 3.2 shows a more symbolic causality. No one will be fooled here that the light texture occurred naturally. However, its realistic proportions align perfectly with an actual tree, making it a believable symbolic representation of nature.

Lastly, scale can refer to both the total size of the

*Figure 3.2 _ Light projection of a tree*1*

texture in relation to the space, and to the scale of the texture structure itself. The scale of the structure should be proportionate to the total size of the texture and to the size of the space. What exactly is proportionate is in first instance related to the aesthetic of the architecture. If a specific natural atmosphere is symbolically or directly related to (say a forest), then the scale of the texture and structure should relate to that intended atmosphere as well. This is something

*1 *Figure 3.2 - Design: "Tree", by Simon Heijdens*

for which no general rules can be invented, but is determined intuitively by the designer.
The scale of the structure and texture as a whole also have an influence on the atmospheric quality of the light texture, which is discussed in the following guideline.

Contrast defines atmospheric quality
Contrast, in all three of its aspects (brightness, focus and color), is the main way in which focal glow and ambient luminescence (Kelly, 1952) occur within a light texture. For example a very crisp and high brightness contrast light/shadow projection (figure 3.3a), could be described as adding focal glow to the space; a light texture that is more blurry and less contrasting (figure 3.3b) also adds an ambient element to the space. This is what defines the atmospheric quality of the light texture - the way in which it contributes to the atmosphere in the space.
The scale of the structure within the texture also has an influence on this. A coarse structure (large elements of light and shadow) will contribute more to the focal glow in the space, whereas a fine structure will add an ambient element (figure 3.3c).
The scale of the light texture as a whole relative to the space has an influence on the strength of its atmospheric quality. The larger the light texture, the stronger the atmospheric quality, and the greater the influence on the atmosphere in the space. Figures 3.3a,b,c are good examples of large scale light textures. The other way around, when the light texture has a very small scale relative to the space (for example like the experiments shown in chapter 4.1), the influence on focal glow/ambient luminescence in the space is negligible, and rather only the brilliant element remains.

*Figure 3.3a _ Crisp and high brightness contrast light texture**[1]

**[1] *Figure 3.3a - Casa Encuentro, Tabernas, Sapin, by Carlos Arroyo Arquitectos*

The general lighting design of the architectural design should be carefully aligned with the design, scale and position of the light texture and vice versa; specifically when the scale of the light texture is such that it has a significant atmospheric quality.

The amount of light in the space – especially daylight – should also be accounted for. The brightness contrast in the texture should be adapted to these general lighting conditions of the architecture. If not, a light texture could disappear in overpowering daylight; or might itself overpower the general lighting design in the space and become the central element rather than an integrated design element.

Figure 3.3b _ Less contrasting light texture[1,2]*

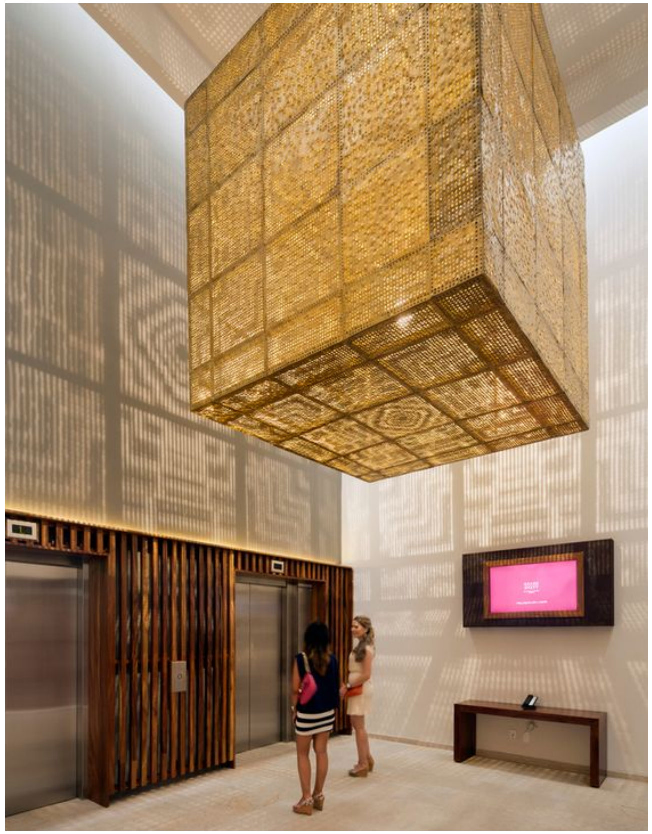


Figure 3.3c _ A light texture with a very fine structure[2]*

*[1] *Figure 3.3b - Interior design: Pacific heights pied-à-terre, by Angela Free interior design*

*[2] *Figrue 3.3b - Fixture design: Confetti Cube Pendant, by Currey and Co.*

*[2] *Figure 3.3c - Hotel Grand Hyatt Playa del Carmen, Quintana Roo, Mexico, by Sordo Madaleno Arquitectos*

Dynamics introduce biophilic qualities
While the other visual qualities of light texture by themselves have the ability to convey elements of nature, dynamics holds by far the largest potential to introduce a biophilic element in architecture. As discussed in chapter 2.2, the static character of most of the built environment is perhaps the most elemental way in which the natural environment and the built environment differ from each other.
Light texture, and lighting in general, offer a great opportunity for bringing back some natural dynamics into the built environment, without disrupting its function.

Dynamics as a visual quality of light texture, is in fact an element of each of the other three visual qualities, as defined in chapter 2.1. Hence introducing dynamics to any of the three qualities requires to consider the effect it has on its role in integrating the design with the architecture and its environment. In no way should this role be compromised to an extent the light texture is no longer an integral part of the architecture.
For example, if dynamics were to be introduced into the contrast of the light texture, this would have a great influence on the atmosphere it conveys. This creates a potential to change the atmosphere according to the use of the space, but also creates the danger of mismatching that atmosphere.

There is a myriad of ways to accomplish natural dynamics in light textures. However, that is a rather complicated subject by itself. It will not be discussed here in depth, however chapters 4 and 5 discuss one way to accomplish this, through a design project that applies the design approach outlined here.

3.3 _ Biophilic expression

How to integrate biophilic qualities in a design will depend largely on the context. There are some basic practical principles however, to express biophilic qualities regardless of the context. In principle this is the intuitive application of natural variation, causality and dynamics (chapter 2.2) in design.

Natural variation through artistic expression
In order to approach natural light textures, one could either directly use nature to create these textures (using actual plants to create projections, or using sunlight). But one could also introduce natural variation to a light texture through the visual qualities described in chapter 2.2.
Intuition is the key in creating this natural variation. What is perceived as natural and what isn't,

is difficult to exactly define in objective parameters due to its complexity – but it is quite easy to distinguish intuitively. Intuition is often difficult to express accurately in words and parameters, rather it is best expressed artistically.
As an example, one could “design” a series of three horizontal lines. With modern graphic software at our disposal, one could easily create three exact copies. Or one could draw them by hand, without any tools like rulers, and arrive at three slightly different lines. (figure 3.4) In the most basic level, this is already introducing natural variation; in fact, the less skilled one is, the better the result.
Taking it a step further, emotion can be added to those lines: a confident one, an insecure one and

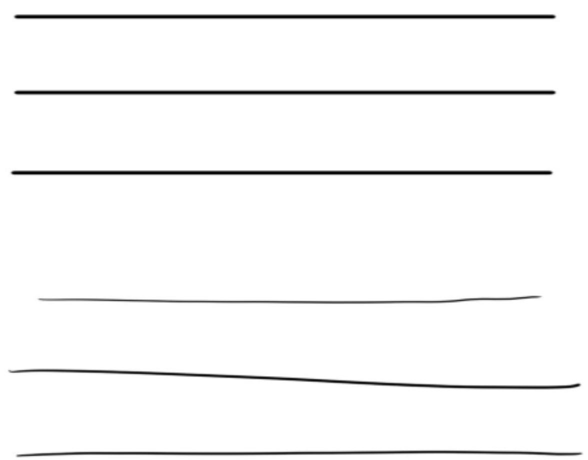


Figure 3.4 _ Hand drawn lines create natural variation

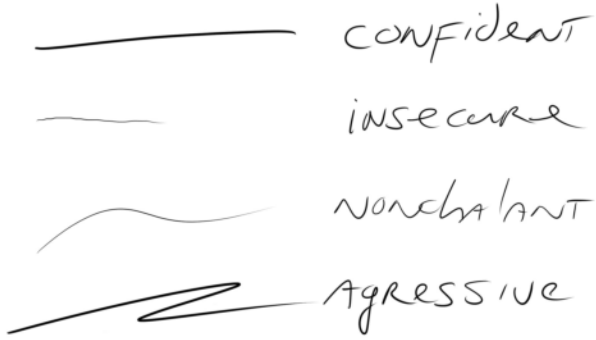


Figure 3.5 _ Emotion expressed in hand drawn lines

an aggressive one for example. Emotion is the link between our body and our mind – and thus it is very easy to translate this emotion to something drawn by hand. On a computer screen, this translation is only visual – it will take some tweaking, and assessing multiple times to arrive at a satisfying result; whereas one could express the same emotion in a single stroke by hand. (figure 3.5)
Someone with reasonable artistic sensitivity will be able to express much more complicated emotions and experiences, by in the basis using the same principle.
This does not mean that software tools should be abandoned completely in favor of drawing by hand (obviously not everyone has the drawing skills required), but it is an effective way of introducing natural variation to a design – even if after it is further developed digitally.

Specifically when designing the style and structure of a light texture, some hand drawing as a start can be quite effective.

Different means of artistic expression than drawing can also be used, depending on what suits the specific design. The basic principle here to keep in mind is the emotional link between the intuitive mind and the human body. Direct physical input is the most effective.

Natural variation through natural input

Another way to create natural variation is to directly use nature as an input. This is especially effective when getting to more complicated design elements, where artistic expression (or one's skills in that regard) might not be sufficiently adequate to convey the complexity of nature.

A distinction needs to be made between using nature as an input in design, and using nature as a literal element in design. Both should be used with care, keeping in mind the objective of integrated design.

Literal use of nature

Using nature in the literal sense, is for example using actual plants to create shadow projections. This is probably the easiest way to create a realistic representation of an actual natural light texture. However, taking nature out of its natural context is not always realistic. A plant in nature does never exist on its own, there is an environment that belongs to it. If the architecture in some way relates to that environment (even if just in a symbolic way), the use of a real plant can be very effective – if not, it may look as an independent element in space, rather than an inte-

Figure 3.6 _ Plant-life incorporated in interiors. Out of place in the top interior[1], fitting in the bottom interior.*[2]

*[1] *Figure 3.6, TOP - Republic Newspaper, Columbus, US, by Skidmore, Owings & Merrill*

*[2] *Figure 3.6, BOTTOM - Every day is the day office, Tokyo, by General Design Co.*

gral part of it. Figure 3.6 shows two different interiors in which plants are placed. In the first image the plant-life is much more out of place than in the second. The second interior uses more natural materials (wood) and raw finishes (bare concrete), and a less strict and less repetitive structure/hierarchy - these all contribute to a more natural atmosphere, where actual plants seem less out of place, even though it is still a clearly man-made space.

Nature as an indirect input

Using nature as an input for design can be done in a lot of ways. One example is to use photographic material of nature, as an underlay for the design of a pattern. That way the natural variation in that picture can be copied into the design. One could think of a myriad of other ways to use nature as a direct or indirect input. Another example is shown in chapter 4 and 5, where videos of nature are used as an input to create natural dynamics.

Especially in a situation where it is not possible to make the architecture itself more natural in its appearance (for example in projects involving already existing architecture), this approach allows for more flexibility in fitting the texture design with the architecture.

4 _ Exploring dynamic light textures

During formulating the design approach and theory of the previous chapters, a lot of experimentation was done to explore the field of dynamic light textures. These explorations eventually lead to the theory outlined in the previous chapters, and formed the basic principle for the design project outlined in chapter 5.

4.1 _ First series of experiments

There are many ways to create dynamic light textures. For the experiments in this project, the setup as shown in figure 4.1 is used. This particular setup is used, because it enables a high degree of (digital) control over the dynamic effect, while keeping the physical setup relatively simple.

The basic principle is the use of a light source and a patterned material to project light/shadow patterns on a surface. The light source used is a digitally controlled 8x8 LED matrix. By displaying dynamic content on this LED matrix, the resulting light/shadow projection also becomes dynamic. The LED matrix is controlled through programming software - MAX 7*¹ - from a computer, and an Arduino micro controller. Video 4.2 shows this setup in practice.

A series of experiments with this setup is shown in video 4.3. In these experiments, two key parameters were explored: the patterned materi-

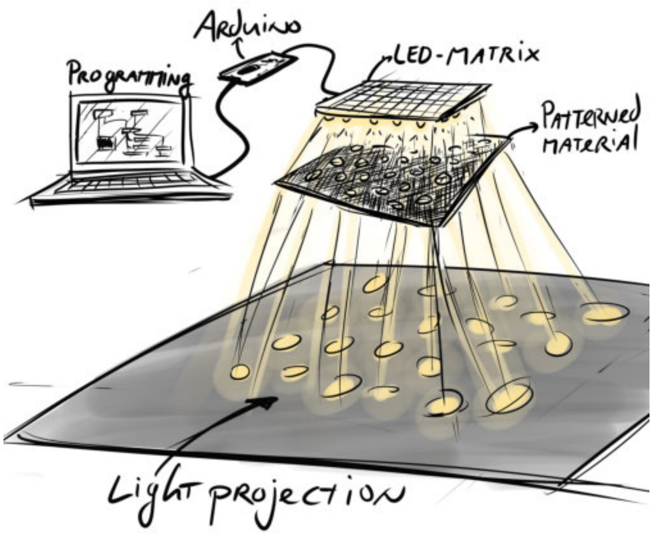
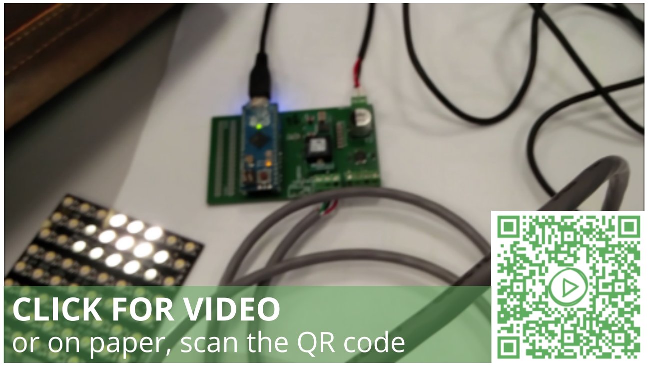


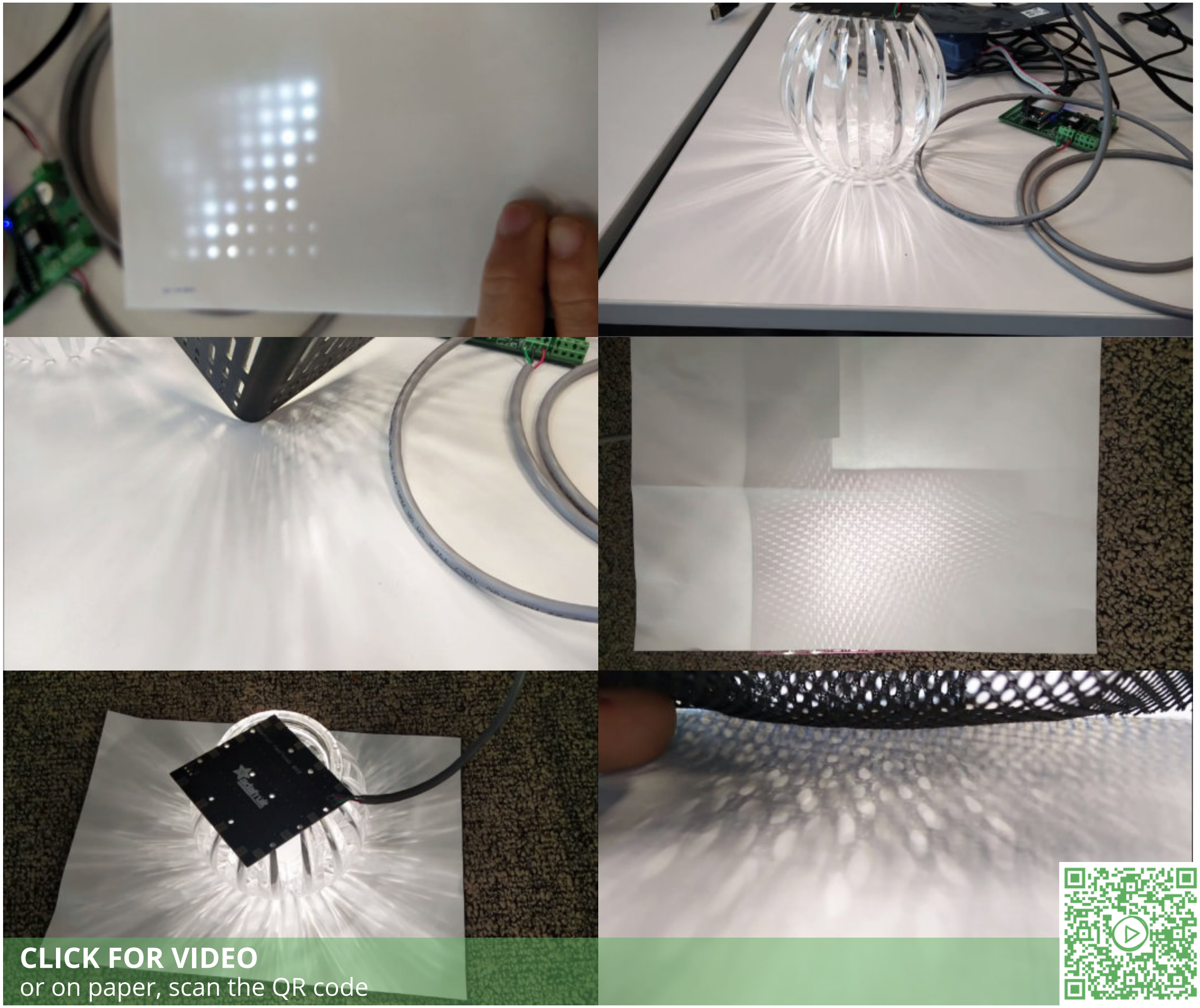
Figure 4.1 _ Schematic of setup of first series of experiments



Video 4.2 _ Setup of first series of experiments

*¹ *MAX 7 is a visual programming interface for creating interactive sound- and graphics effects: https://cycling74.com/products/max/*

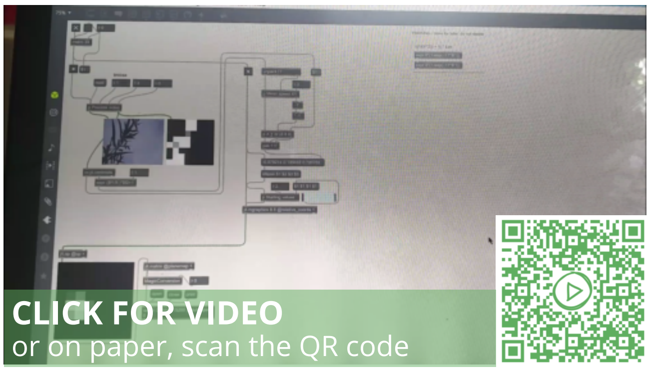
4.2 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/3h7u4bxoutn0szv/Video4.2.mp4?dl=0



Video 4.3 _ Selection of the first series of experiments

4.3 - *If the QR-code does not work, navigate to: https://www.dropbox.com/s/sj5w3r0257sno4m/Video4.3.mp4?dl=0*

als, and the programming of the dynamic effect.
The exploration of materials rather speaks for itself, and can be observed in the videos. The programming of the dynamic effect is less straight forward. The dynamic effect was generated by an algorithm that controls the movement of a dot displayed on the LED matrix. The movement of this dot could for example resemble the movement of a waving leaf. In this first instance, it was attempted to generate this movement by mathematical expressions; later on, video content of nature was used as an input for the algorithm. Natural dynamics appeared to be too complex to convincingly generate by a simplified mathematical model.
Video 4.5 shows the screen of the MAX 7 programming; one can see the video input on the top left, and the resulting moving dot of light in the bottom window - this bottom window is what is displayed on the LED matrix.



Video 4.5 _ Max 7 programming of first experiments

4.2 Second series of experiments

As can be observed from video 4.3, the first setup works on a rather small scale - about 5cm from the table for a clear projection, and maximum 30cm until the projection becomes too faded to be visible. While this scale is useful as a proof of concept, it is too small to really experience the dynamic effects as part of a space. In a second series of experiments, a Fresnel lens was added to the setup. The Fresnel lens bundles the light, allowing it to be projected over a larger distance, making it possible to really experience the effect. Figure 4.6 shows a schematic of the setup

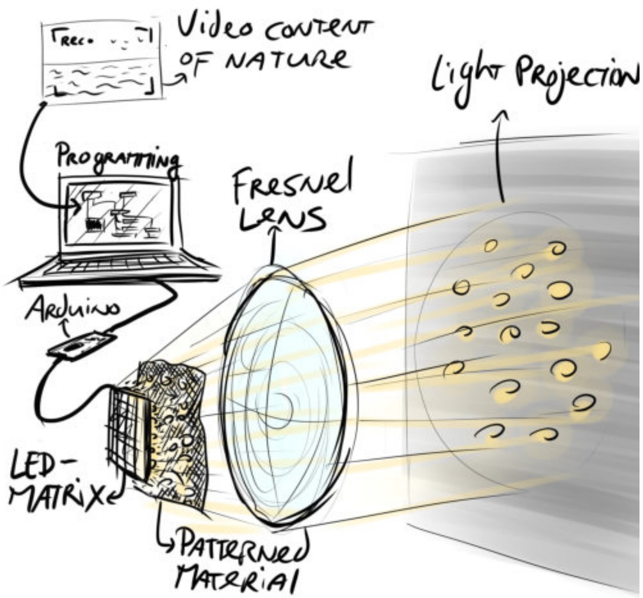


Figure 4.6 _ Schematic of setup for second experiments

4.5 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/2ahqf1llqai7qkr/Video4.5.mp4?dl=0

Video 4.7 _ Setup of second series of experiments

for the second series of experiments; video 4.7 shows the setup in practice. Video 4.8 shows a selection of the second series of experiments, with various different patterned materials, different video inputs and various types of video processing. The different types of dynamics were the main focus of this series of experiments.

The better experience of the light texture in this setup, allowed for better experimenting and evaluating of the dynamic effects. Various different types of input video material were explored, as well as different ways of processing and editing the video material to be sent to the LED matrix.

For every type of video content - a waving leaf, rippling water, birds swimming or flying, etc. - different ways of video processing were explored to see what works best.

As a result, a better understanding of requirements for the video material was gained as well. For example, the use of a tripod is necessary, to eliminate unwanted dynamics in the video, caused by the camera moving; only the intended dynamic should be present in the movie, since it is difficult to isolate two different dynamics (for example a leaf waving in the wind, with leaves falling in the background); the dynamic element in the movie should also be the most contrasting element, otherwise it is difficult to isolate from the background; the length of the video matters, not only to avoid observable repetition, but also to include a proper range of natural variation in the dynamic. These are useful insights to take into account when shooting video material, to make the processing of it less complicated.

4.3 Practical conclusions

The main conclusions of these experiments on an experiential level, are already outlined in the previous chapters. The experimenting with different patterns and dynamics, together with observations in nature, were the main drivers in arriving at the previously described design approach. There are however some more practical conclusions related to the specific setup used in these experiments, that are relevant for the development of the design project described in the following chapter.

4.7 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/2rtudfae6kzi59j/Video4.7.mp4?dl=0

Video 4.8 _ Selection of the second series of experiments

4.8 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/j1p73d49w7n4079/Video4.8.mp4?dl=0

Brightness of the light source

While an improvement over the first setup, the setup used in the second series of experiments still has its limitations. The most notable one is the brightness of the light source. This brightness is what limits the maximum scale of the projection. The last two shots in video 4.8 (also bottom two images on the left page) show more or less the maximum scale that is possible - and this is only possible in a room with dimmed lighting. Any larger and the brightness contrast would be too low to make the texture clearly visible, without darkening the room completely.

Resolution of the LED matrix

The 8x8 resolution of the LED matrix is a limiting factor in the type of dynamics that can be displayed. Dynamics in nature often have multiple layers of scale - for example imagine the the waving of a tree branch as the primary large scale dynamic. The shimmering of the leaves on that branch would then be a second layer of much smaller and faster dynamics.

From experimenting with this setup, it can be concluded that the 8x8 resolution is just a tad too small to accommodate both these scales of dynamics at the same time. An estimate is that at a resolution of at least 10x10 LEDs, it would be possible to convincingly display such a double layered dynamic. More subtleties and nuances of the natural effect can be displayed at this higher resolution. This does not mean however that bigger is better - at a too high resolution, one would be observing the actual input video footage, rather than a dynamic lighting effect.

Efficiency in programming

Video editing is in principle not very different from the editing of an image - the main difference is that 30 images per second are edited (frame rate of a video). This requires quite some processing power of a computer.

When I started this project, I did not have any previous experience in the programming language used, and hence I did not start out with the most efficient ways of programming. However, since video editing does require some considerable resources from a computer, this programming efficiency is extra important.

In the experiments done this caused some lagging in the dynamic effects, when increasing the complexity of the dynamic. (for example when creating a second layer of dynamics as described previously).

There are two bottlenecks in the programming here: CPU versus GPU processing, and the resolution of the source video. The latter is easily resolved; since the output is a low resolution 8x8 pixel video, the input video material of nature does not have to be of high resolution. Compressing the video to a lower resolution, before starting the editing process, helps reducing the resources required significantly.

CPU versus GPU processing requires some basic knowledge of how computers work. Computers have both a processor (CPU) and a graphics card (GPU). In principle any normal calculations and processes are performed by the CPU. More complex things like 3D video games and video processing are best done by the graphics card, which is much more efficient for those tasks than the CPU.

In the MAX 7 programming used, there are different objects for CPU and GPU. The latter are less intuitive to use, and require a steeper learning curve. Hence I started out using CPU objects, but then hit the limitations of the CPU rather quickly. Hence in future setups, first a leap in programming efficiency needs to be made, by doing as much as possible on the GPU.

5 _ DESIGN CASE - VISITOR CENTER DE HOGE VELUWE

The theory and the experiments in the previous chapters, eventually found their way into a practical application in a design project for Beersnielsen Lighting Designers.*[1] The company was asked to create a lighting design for a newly designed visitor center of nature reserve park "de Hoge Veluwe" in the Netherlands. The project is a joint effort of Beersnielsen lighting designers – my personal contribution mainly involved the design of the light texture pattern and the dynamic effect of the chandelier, which is what will be discussed in this chapter.

5.1 _ Design brief

The architects*[2,3] of the visitor center won the project on the basis of creating a space with a modern character, rather than dwelling in archetypes of the past. One major design element responsible for this modern character is the arched ceiling, which the architect intended as a canvas for telling the story of de Hoge Veluwe. Figure 5.1 shows a render of the proposed interior design and the arched ceiling in question. The client initially envisioned this storytelling as a video projection or screen on the arched ceiling.

In the view of the lighting designer, this story

Figure 5.1 _ Render of the design of the visitor center

could also be told in a more subtle way, other than a video projection, more fitting with the natural character of the park. A proposition was made to create light/shadow projections of natural elements on the arched ceiling, telling the story of the nature reserve park in a subtle way. Using the ceiling as an integrated element of the space, rather than an attraction demanding full attention of the visitors.

The reason for visiting the visitor center is not the attraction of the visitor center. Rather the reason for visiting is the nature reserve park itself. In that light it makes sense to design an indoor character and atmosphere, that is a continuation of that of the surrounding nature outdoors. Bringing the reason for visiting the park to the indoor space of the visitor center as well. In other words, following the biophilic design

*[1] *Lighting design of visitor center: Beersnielsen* www.beersnielsen.nl

*[2] *Architect of visitor center: Monadnock* http://monadnock.nl/

*[3] *Architect of visitor center: De Zwarte Hond* https://www.dezwartehond.nl

approach, creating a (lighting) design that is integrated with both the architecture AND its geographical environment.

5.2 _ Design proposal

The design proposed is a chandelier that works according to a similar principle as the experiments shown in chapter 4, but on a full architectural scale. Figure 5.2 shows the basic principle: there is a powerful LED matrix as a light source; a curved surface that is laser cut with a pattern; and a resulting dynamic light texture on the arched ceiling. The LED matrix is controlled in the same way as the experiments of chapter 4.2, using video material of nature as an input to create dynamic effects. The technical challenges involved are further discussed in chapter 5.3.

Character and integration

The design of the light texture is symbolically creating a connection between the architecture and the nature park around it. Imagine walking on a path in the forest; the canopy of the trees running along it together form an arched ceiling over the path (figure 5.3). The light texture created by the chandelier, projects the image of a forest canopy onto the arched ceiling of the visitor center, symbolically relating to the experience of a forest path.

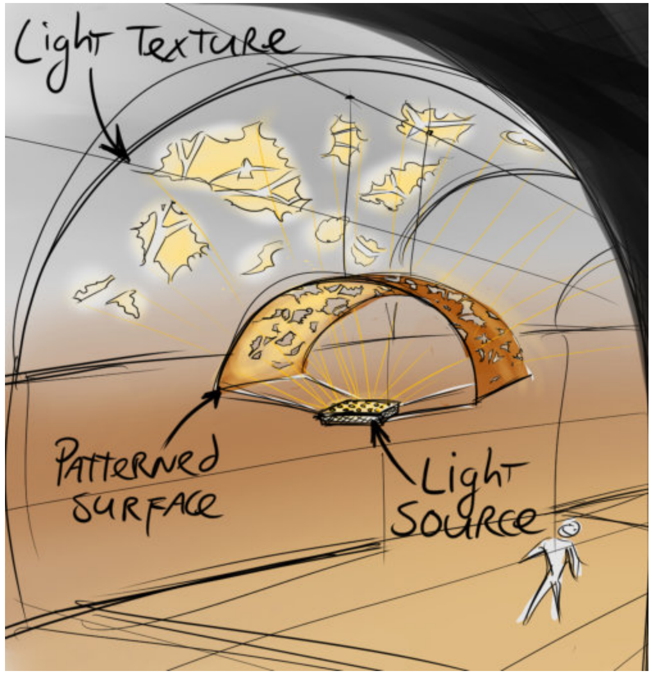


Figure 5.2 _ Chandelier design principle

Figure 5.3 _ The "arched ceiling" of a forest path

The pattern has a graphical style, that is more symbolic than realistic. Branches, leaves, and forest animals are clearly recognizable due to this symbolic representation, fitting in a space that is also clearly man-made. The graphical style of the projection conveys the character of the nature park, while also fitting with the man-made nature of the architecture.
Where a video projection would make the architecture 'vanish'; the chandelier creates a projection that works together with the architecture to tell the story.

The structure of the light texture is dictated by the natural theme. Natural variation is ensured by designing the texture by hand, not copying any shapes or elements that would cause a repetitive image.
The structure of the pattern is more closed to the sides and more open towards the top of the arch, just like how the canopies of trees meet in the middle above a path, leaving a more open view to the sky where they meet (figure 5.4). Aside from being congruent with the forest path metaphor, this structure also works to integrate with the architecture. The arched ceiling is a blank white canvas, where the light texture dictates what happens. The walls are not blank, but have defined textures and materials of their own. By making the pattern more closed towards the sides, the light texture transitions from dominant at the top of the arch, fading towards the walls where the material textures take over the aesthetic of the space.

Figure 5.4 _ Canopies meeting above a path

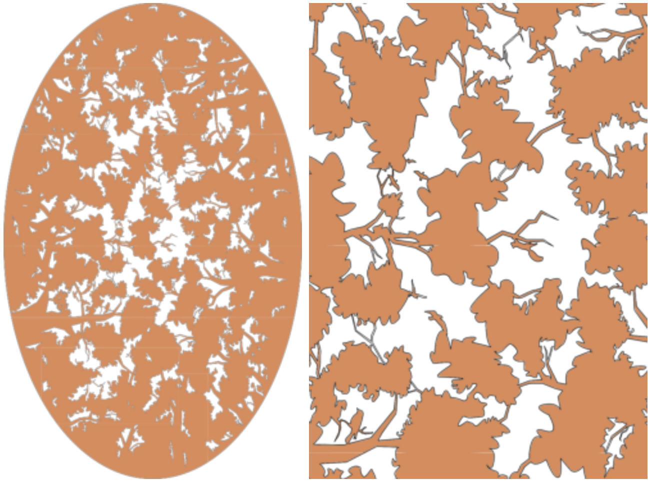


Figure 5.5 _ Pattern design, open in middle, closed towards sides. A closer look on the right, showing animal details.

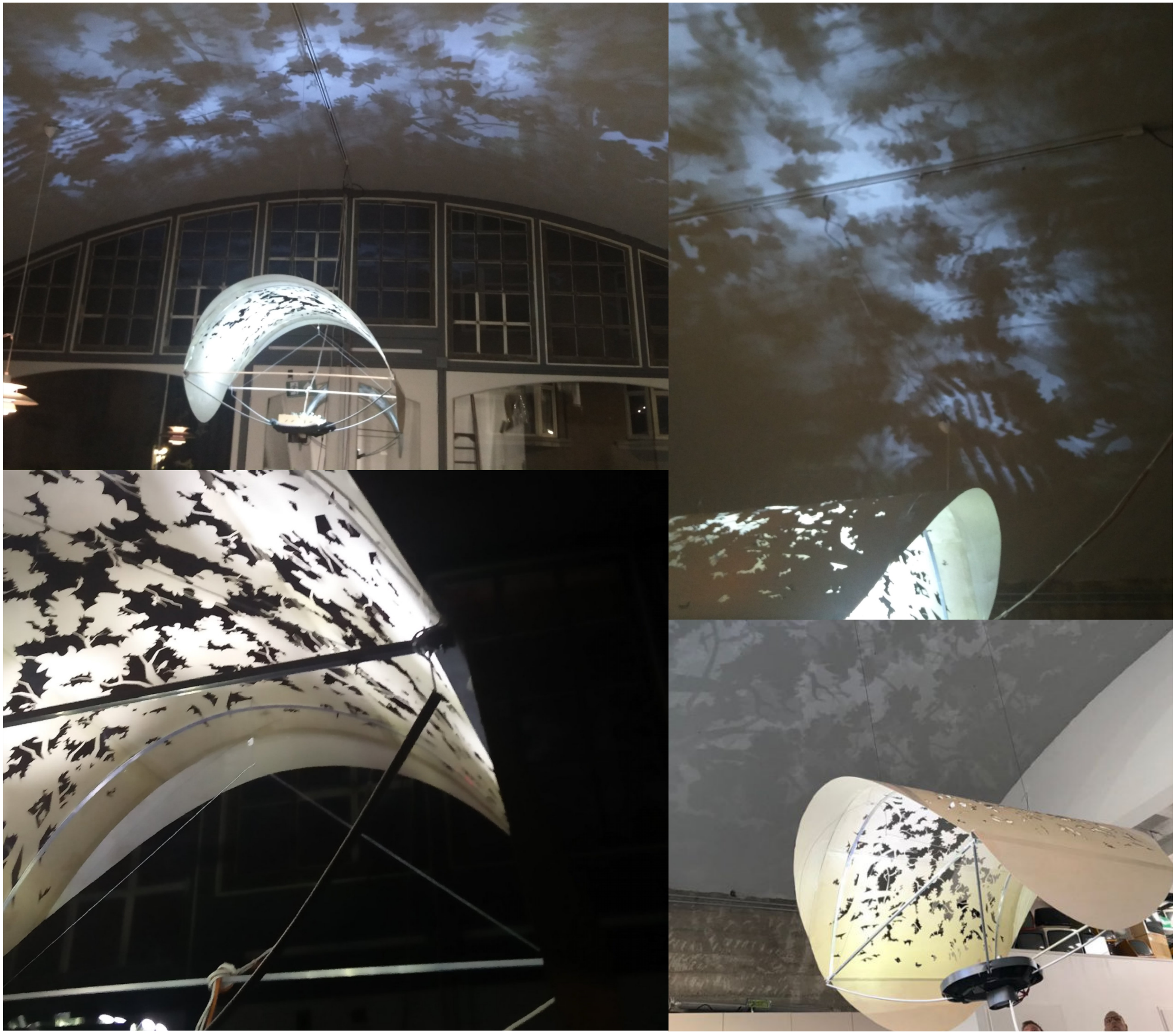
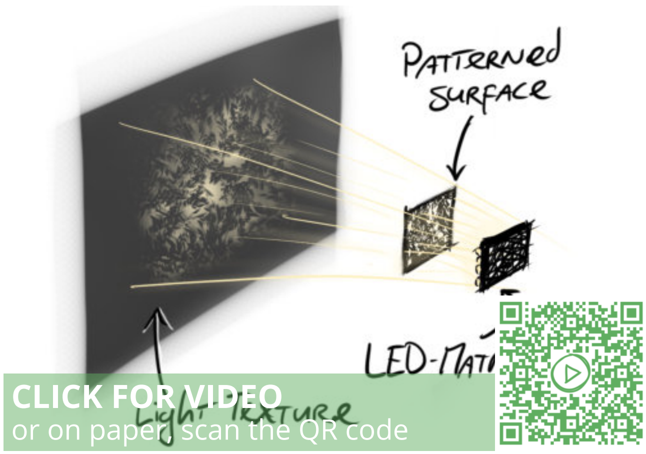


Figure 5.6 _ Prototype of the chandelier, hanging from the arched ceiling at the office of Beersnielsen Lighting Designers

Atmosphere and dynamics

The atmosphere in a forest is influenced by many things, but one essential element in this atmosphere is the dynamic aspect of it. In this light texture design the dynamics is applied to the brightness contrast of the texture, which is the main visual quality responsible for the atmosphere in the space.

The dynamics in this design are created by dynamically controlling the LED matrix. The use of a matrix of LEDs causes a second layer of light texture to emerge. There is the graphical pattern created by the laser-cut surface as the main light texture; but the grid of the LED matrix causes a grid pattern as a second less evident layer in the light texture. Animation 5.7 illustrates both layers in the light texture. It is this secondary grid layer that is dynamic, where contrast is continually changing according to the input video material of nature. Video 5.8 shows the dynamic of the prototype (next page).



Animation 5.7 _ Two light texture layers

This dynamic differs from nature, in the sense that the light source is dynamic rather than the object casting the shadows. In nature, the light source (the sun) is more or less static*[1], whereas the object is dynamic (tree branches waving in the wind).

However, generally speaking the dynamics in nature are experienced peripherally; meaning one notices something moving in the corners of the eye. The movement is perceived, but the details are not, unless looking at it directly. This means that for experiencing a naturally dynamic ambiance, it matters that the movement resembles natural movement, but the detail of how this movement is created is of less importance.

The experience of an atmosphere in a space is also experienced peripherally; when working, or dining, or in social activities, one's attention is on the task, but the atmosphere in the space is still perceived peripherally.

The intention of the dynamic of the chandelier is to be peripherally perceived as natural. Influencing the atmospheric quality of the lighting in the space, by creating natural dynamic movement in the grid layer of the light texture. The static appearance of the graphic layer of the light texture helps to integrate with the also static nature of the architecture.

*[1]: *of course the sun also moves throughout the day, and there is clouds moving, so in that sence the light source in nature is also dynamic. However, the dominant dynamic is the movement of (in this case) the tree branches and leaves.*

5.7 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/sgl9hauepcqhk5v/Animation5.7.gif?dl=0

Video 5.8 _ Prototype of the chandelier, hanging from the arched ceiling at the office of Beersnielsen Lighting Designers

5.8 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/rho90q0yz2t0yel/Video5.8.mp4?dl=0

5.3 _ Technical design

The light/shadow projections are created following the same basic principle as the first experiments shown in chapter 4.1. There is a light source, a patterned material, and a ceiling surface to project on. (figure 5.2, p.53)

There are three important parameters to consider when creating light/shadow projections on this scale, when following this basic principle:

- The brightness of the light source;
- The size of the light source;
- The ratio of the distances between light source, pattern, and ceiling.

Brightness

The brightness is important when there is daylight entering the space. Sunlight is very bright, and can easily overpower the lighting effect of the chandelier, if the light source is not powerful enough. The experiments in chapter 4 already clearly demonstrated the limitations of an insufficiently bright light source in daylight conditions. The light source used is a 30W extra high power LED (Cree XHP70*[1]). It has a sufficiently high light output (max. 4000 lumen) to still be visible in most daylight conditions (except the most bright sunny days), and is sufficiently small to create crisp shadow projections. (figure 5.9)

Figure 5.9 _ Cree XHP70, 30W extra high power led, 7x7mm

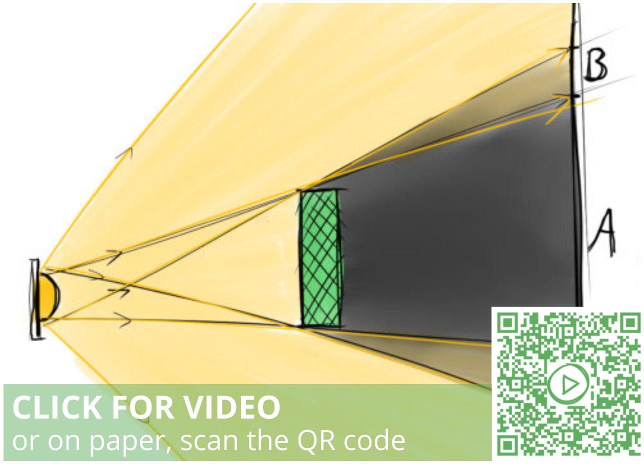
Size of the light source

Animation 5.10 shows why the size of the light source is important. In shadow area 'A' all light is blocked, in shadow area 'B' only part of the light is blocked by the object that casts the shadow. Area 'B' is basically a blurry border of the shadow projection. The smaller the light source is, the smaller the blurry shadow area 'B' is, and the crispier the shadow projection will be. Hence, the light source needs to be as small as possible to create an as crisp image as possible.

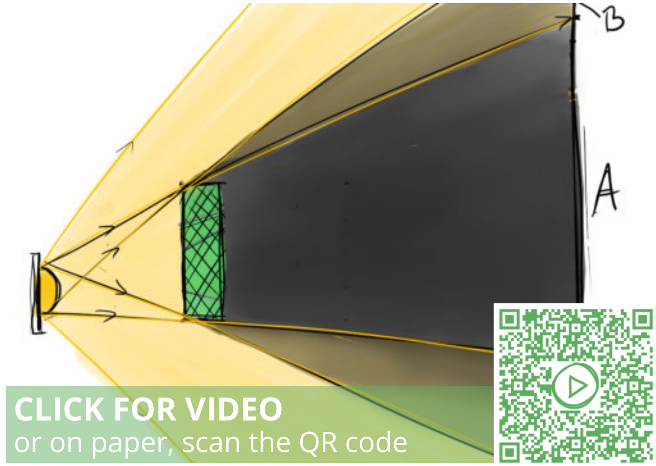
Distances of light source, pattern and projection

Animation 5.11 shows a similar animation, showing the difference in the relative position of the object that casts the shadow projection. The closer the object is to the light source, the bigger the blurry area of the shadow projections will get. It is thus important to create some distance

*[1] *Cree XLamp XHP70: http://www.cree.com/led-components/products/xlamp-leds-arrays/xlamp-xhp70*



Animation 5.10 _ Smaller and larger light source



Animation 5.11 _ Distance of object to light source

between the pattern and the light source in order to create a crispy projection.

There are of course limitations to increasing this distance. It does not make a lot of sense to maximize the space between the light source and the pattern, for creating a crisp shadow projection, because it will have an impact on the resulting size of the chandelier, which has practical and aesthetic limitations in its architectural context.

In order to optimize this ratio, it was simply tried out in practice, by using an LED and a pattern to create a shadow projection, and then reducing the distance to the minimum that would still (subjectively) create an acceptably crisp projection. Video 5.12 shows this experiment on a smaller scale, to demonstrate the effect.

LED matrix

The dynamic effect is generated by digitally controlling a matrix of the selected extra high power LEDs. In the conclusions of chapter 4, the resolution of this matrix was mentioned as a limiting factor. However, due to the cost of the extra high power LEDs (~10 euro per piece), the matrix was

Video 5.12 _ Crispness by distance light source

5.10 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/6r4qp3oqn1f8v1b/Animation5.10.gif?dl=0
5.11 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/gch8f3qpuv1o153/Animation5.11.gif?dl=0
5.12 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/fw49419k97q0bda/Video5.12.mp4?dl=0

not scaled up, but rather scaled down to 5x6 LEDs. 30 LEDs is an acceptable number to still create a convincing dynamic effect. Enough to show a proof of concept on a full 1:1 architectural scale, but not allowing for more complicated dynamics with multiple layers as described in chapter 4.3.

The principle used in the chandelier is similar to the experiments in chapter 4, however there is one crucial difference that has an effect on the resulting light texture: the distance between the light source and the patterned surface.

In the experiments of chapter 4, the patterned surface was positioned quite close to the light source (a few centimeters). As a result, when one LED in the matrix lights up, only part of the patterned surface is illuminated. When the dynamic is played on the matrix, the light moves around over the patterned surface. (figure 5.13a)

Due to the larger distance between the LED matrix and the patterned surface in the chandelier (required to create a crisp projection on this scale), the beam of a single LED lights up nearly the entire patterned surface, rather than just a part of it (figure 5.13b). Hence when dynamic, the light does not move around over the surface like in the first experiments, but rather it creates a lot of overlapping projections.

Figure 5.14 shows the resulting projection in practice, when using 3 LEDs (early prototype). There is so much overlap in the projections that it is not very recognizable anymore - even just using 3 LEDs. In order to solve this problem, the beams of the LEDs are narrowed by placing short tubes on top of the LEDs. The narrower beam makes sure only part of the surface is illuminated by one LED, just like in the original experiments. Since the patterned surface is curved, the LED's need to be aimed to the right part of the surface (figure 5.15). The resulting effect can be seen in video 5.16, showing an early version of the prototype with 6 LEDs with tubes.

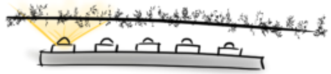


Figure 5.13a _ Patterned surface close to light source

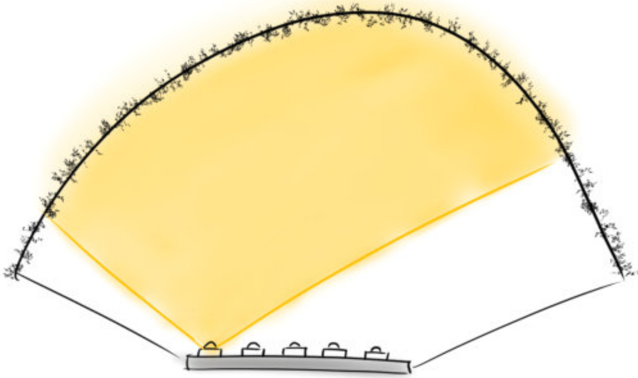


Figure 5.13b _ Patterned surface far from light source

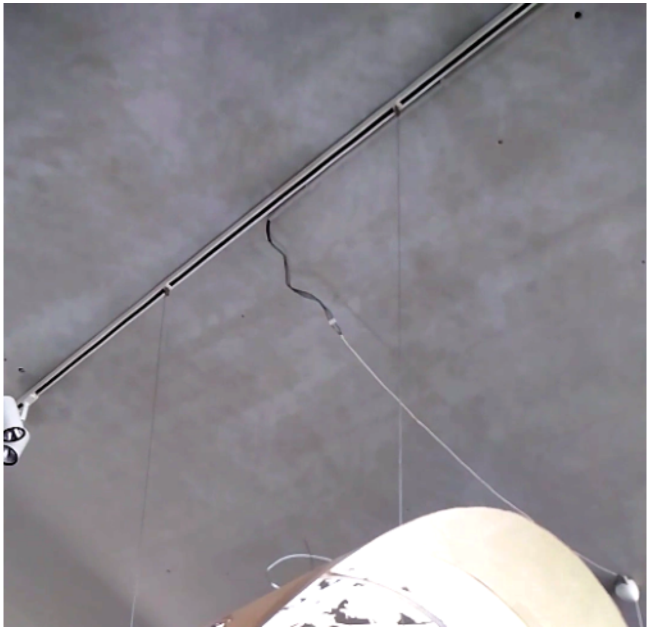


Figure 5.14 _ Many overlapping projections make the pattern unrecognizable

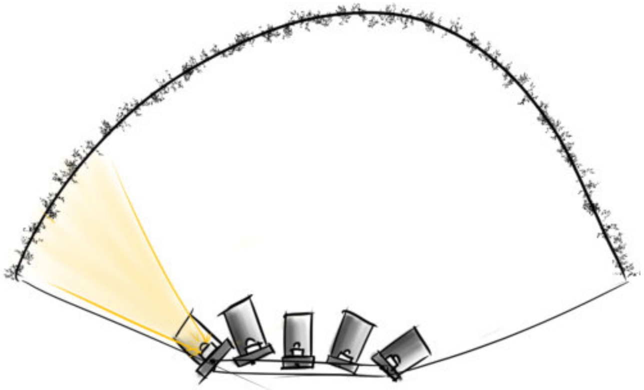
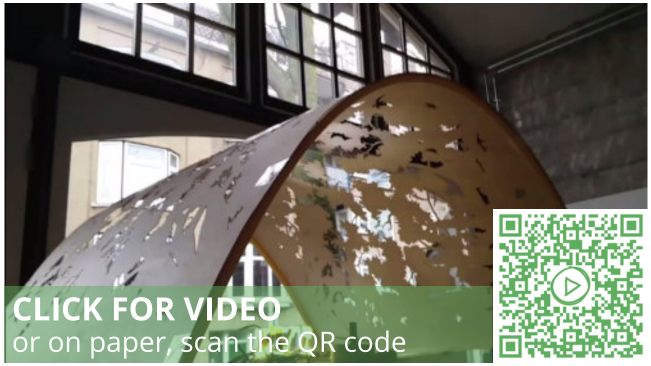


Figure 5.15 _ Tubes narrow the light bundle of the LED, preventing overlap in the projections.



Video 5.16 _ Prototype with 6 LEDs with tubes

Construction

From all previously determined parameters, a construction similar in the basics to figure 5.15 follows. Figure 5.17 shows a picture of the resulting LED matrix. 4mm thick aluminum strips were used to mount the LEDs to ensure sufficient heat dissipation for the LEDs. Tubes are placed on a separate strip on top of the LEDs. The strips can be aimed in the direction of the curvature of the pattern and ceiling. In the other direction, the tubes are mounted at a fixed angle.

5.4 _ Digital control system

For the chandelier a slightly different control system is used than in the experiments of chapter 4. Rather than using an Arduino microcontroller, a DMX controller is used. There are three basic reasons for switching to DMX.

Firstly, DMX is an industry standard digital proto-

5.15 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/nb6o4zl2a4idldr/Video5.16.mp4?dl=0 col for controlling dynamic lighting. Hence a lot of different standard hardware and software is available for any imaginable DMX system. Making the chandelier DMX controllable, means that it can be controlled with any DMX hardware and software, besides the MAX 7 programming used in this project.

Figure 5.17 _ Construction of the LED matrix. On top without tubes, bottom with tubes.

Secondly, it is less complicated than arduino. All the standard equipment that exists for DMX, does not exist for Arduino. Arduino is a micro controller, tailored to DIY/hobby projects; this means that any standard hardware available, is mostly tailored to this same segment as well. This is great for small scale and inexpensive prototyping, like the experiments done in chapter 4; but for a large scale professional installation, it only adds unnecessary complexity (like for example the need for circuitry, specifically designed for the project).

Thirdly, an Arduino is a microcontroller. Meaning it is meant to do any task that it is assigned, rather than specifically being designed for lighting control. This means it needs to be programmed according to how it will be used, adding an additional layer of programming. By using DMX, this extra programming complexity is avoided.

Figure 5.18 shows a schematic of the control system used. The USB/DMX interface is a device that translates the USB signal from the computer, to a DMX signal for the control system. This device could potentially also be used to record what the computer is sending to it. Then to be able to playback the recorded lighting dynamic, without the need for connecting a computer constantly. The DMX controller translates the DMX signal to 30 individual electrical signals that control the LEDs.

Any other DMX software would work in this system as well. Any other DMX device could be connected to the USB/DMX interface or to the DMX controller directly, if for example manual control is desired. The system could also be extended with other DMX controllable fixtures, for example for functional lighting (spots) - which then could be controlled through the same software.

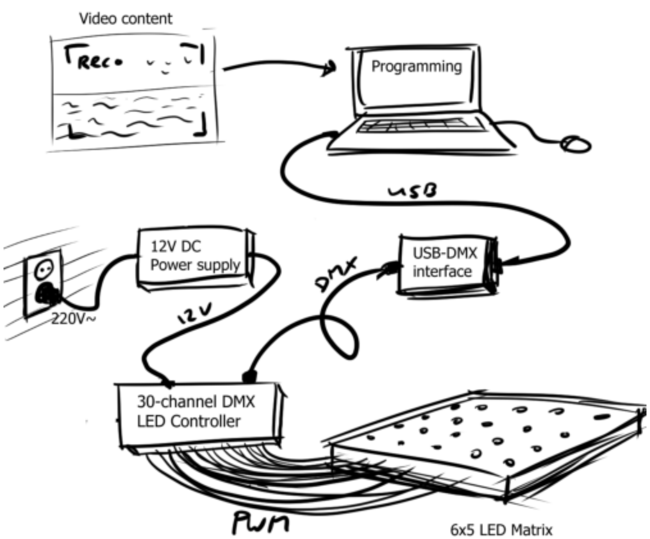


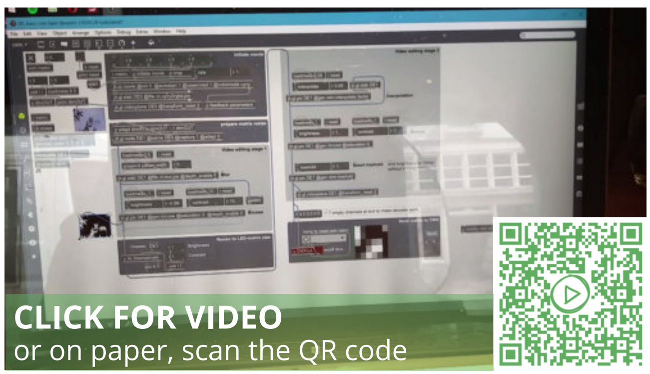
Figure 5.18 _ Schematic of the DMX controlled system

Programming

As mentioned in the practical conclusions of chapter 4, the efficiency in programming was a bottleneck in the first experiments. For this prototype, the necessary leap in programming was made, moving from CPU to GPU objects. This managed to reduced the load on the CPU by 50%, enabling to process the video with a higher quality. Meaning, less visual information is lost during reducing the video from its original resolution to the resolution of the matrix. Additionally, the effect could be smoothened out better, reducing any jumpy noise in the effect. Video 5.19 shows the screen of the programming.

5.5 _ Evaluation of the prototype

There are still some technical issues in the prototype that should be corrected in further development of the concept, as well as some potential



Video 5.19 _ Screen of MAX programming

5.19 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/los8d2gdmoc1g0g/Video5.19.mp4?dl=0 technical improvements, additions and fine tuning to the concept that could be explored.

DMX Controller

The leap in programming removed the bottleneck on the digital side of the system. However, the choice of hardware is still not allowing for a completely smooth dynamic as intended. One disadvantage of using DMX protocol is that professional DMX hardware is quite expensive. For prototyping purpose a relatively cheap DMX controller was used, which has some consequences for the quality of the lighting effect. There is a flickering emerging when specific DMX channels are used simultaneously - which is presumably caused by interference in the PWM*[1] frequency of those channels. Video 5.20 shows a dynamic where the flickering is particularly noticeable.

The flickering is now minimized by selecting a type of dynamic where not all of the LEDs are used at the same time, as to minimize the overlap of interfering DMX channels. But to truly resolve the problem, a high quality DMX controller will need to be used; this is not a component to save on, in case budget is exceeded.

Aiming the LEDs

The current configuration of LEDs and tubes requires the LEDs to be aimed correctly at the patterned surface, so the entire surface is covered, with as little overlap as possible.

Video 5.20 _ Flickering in dynamic effect

In the prototype a 5x6 LED matrix was built; however, it turned out there was too much overlap in the light in the 6-LED direction. In one direction the LEDs could be aimed, in the other a fixed angle was used for the tubes. This was too small an angle. In the end, only 4x5 LEDs were used, to prevent too much overlap, and make sure the light texture remains recognizable.

This highlights the importance of carefully aiming the LEDs. And in case of using a larger LED matrix (for example 10x10 as was recommended in chapter 4), then the size of the beams should be carefully determined as well. There are limitations to how narrow a beam can be made, which

*[1] *LEDs are often not dimmed by reducing the power, but by switching them on and off at a high frequency, not detectable by the human eye - this is called PWM (pulse width modulation). If not executed properly, visible flicker can occur.*

5.20 - If the QR-code does not work, navigate to: https://www.dropbox.com/s/om866uss67lhlwm/Video5.20.mp4?dl=0 also limits the amount of LEDs that can be used without creating overlap. For future development this should be an important point of attention.

Resolution of the dynamic effect

The prototype of the chandelier is a proof of concept that dynamic light texture effects can be created on a large architectural scale, using the principle of a digitally controlled LED matrix.

Due to the limitations of the prototype - a smaller 6x5 resolution, and flicker caused by the DMX controller - the dynamic effect from the experiments in chapter 4.2 could not be further explored on the same level of refinement and complexity. However, it showed that a smaller resolution of 6x5 LEDs is sufficient to create a basic natural dynamic. This simpler dynamic is still convincing due to the large scale - the dynamic can be experienced on a similar scale as in nature. On a smaller scale like the experiments of chapter 4, the details of a refined and complex dynamic are easier to observe, and thus more important to be convincing. On a large scale, the dynamic is experienced mainly peripherally, making small details in the movement less important.

Real-time dynamic effect

One thing that has not had a lot of attention yet during this project, is repetition in the dynamics. Right now, video material of about half a minute long is used, which loops once it is finished. The transition between the loops is not smooth, and the duration of 30 seconds is too short - the repetition in the dynamic will be noticeable quite soon. It has already been mentioned that this duration needs to be in accordance with an average stay of a person in that space.

However, there is one more solution, that might be interesting to explore: real time video material. If a camera is placed somewhere outside the visitor center, recording a specific frame of nature (a waving branch for example, or the cloudy sky); then this video can be directly routed to the programming of the chandelier. Making the dynamic of the chandelier directly related to the dynamic of the nature outside.

There will be some challenges in finding the right framing of the video, and in adjusting the programming according to the incoming video material. It would however fit very well with the general concept of the chandelier; continuing the character and atmosphere of the outside nature park, indoors to the visitor center.

5.6 _ Evaluation of design approach

The project for the visitor center of de Hoge Veluwe, is a very logical and natural case for the biophilic design approach to be applied, due to the nature of the park. This makes it a good case

to showcase the practical application of the biophilic design approach.
However, where this design approach might have most value, is in cases where the biophilic experience of nature is lacking, rather than a nature reserve park environment where it is present by default. It would be interesting to explore other design cases, where a link with the local natural environment is not as obvious.
Specifically the first of the four guidelines was not fully put to the test in this design case: *Style creates character.* The guideline states that the style of the light texture should first and foremost fit with the character of the *architecture*. In this case, the character of the architecture follows from its role as a visitor center for a nature reserve park. The natural style of the light texture fits with that natural character.
However, in any other case, the character of the architecture might not quite be so aligned with its natural environment. The guideline suggests that the style of the light texture should be in accordance with the architecture, also if that dictates a non-natural style.

The dynamic effect in the design case is convincing, partly also because of the natural style of the light texture. It would be interesting to explore if the dynamic would be sufficient to convey a convincing biophilic element on its own, despite the style being for example quite geometric.
This combination of a geometric style with a natural dynamic was explored in the experiments of chapter 4, but would be interesting to explore on the same architectural scale as the chandelier as well, since the difference in scale has shown to also make a difference in the experience of the dynamic effect.

Biophilic lighting design in general
The design approach of chapter 3 is specifically tailored to the design of light textures in an architectural context. The 4 guidelines are quite specific to light texture as a lighting effect. However the basic principle of biophilic design as integrated design on an architectural and environmental level, could be applied to lighting design in general as well. It would certainly be interesting to explore if similar guidelines could be formulated for other lighting effects described by Signify’s framework of light content design.

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