Aalborg University Copenhagen
Faculty of Engineering and Science

Department of Architecture, Design and Media Technology
Master Thesis in Lighting Design

Biophilic Dynamic Light Projections

A proposal for the revitalization of socially-inactive urban spaces

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Abstract:

The notion of "biophilia" refers to our innate and genetically determined affinity to nature. Despite having numerous benefits on our well-being and on how we perceive our environments, facts proven by a significant amount of scientific research, biophilia in the sphere of lighting design is a relatively untapped niche.

Therefore, this thesis seeks to investigate the combination of biophilic patterns with modern technology with the intention to implement them in socially-inactive urban spaces as a mean of fast and effective revitalization. The overall goal is to establish new knowledge on creating, implementing and fine-tuning biophilic dynamic light projections.

Through an extensive literature & case study review, design experimentation and atmosphere perception test, valuable knowledge on the notions of "preference for biophilic patterns", "visual complexity", "speed of change" and "value-add of interactivity" was developed. It is concluded that biophilic patterns are more positively perceived than their non-biophilic counterparts. Moreover, overall preference for complexity lies at a low to medium degree, while with speed of change, it is overall determined that a low value is inherently more pleasant, with negative consequences on the perception of atmosphere if increased. Additionally, adding the possibility to interact with the biophilic pattern provides overall better perception of safety and atmosphere. On the creation of patterns, the author recommends solutions based on the size of the space: with video projectors and the software Processing as ideal for small-scale implementation, while gobo projectors are recommended for large-scale projects.

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This thesis would have not been possible without the support of a few people, whom I would like to express my gratitude towards.

To both my supervisors, George Palamas and Georgios Triantafyllidis for their time, dedication and support in times of uncertainty and stress. They have shown great understanding for my passion and direction and have shared their knowledge and encouragements to always challenge myself even with subjects I was not confident with.

To my boyfriend, who has been an active and dedicated part of the test phase and has shown great support for the last three months.

To my family and close friends for their constant support and words of encouragement for the entire duration of my thesis.

Last but not least, to Mikkel Toksværd from Martin Professional for his implication in making this project a reality and for his willingness to lend me products to experiment with.

Reader's Guide

To better navigate the thesis, please review the following indications, as well the the **"Thesis Structure"** scheme presented on the following page.

Citations are made in text using the Harvard citation style and include the author's last name and the year of publication.

Example: (Kellert, 2016)

Quotes are written in *green italic* between quotation marks.

Example: "Material well-being is of great significance, but so, too, are the ways nature can enrich the human capacity for emotional connection, a sense of beauty, our intellectual understanding, and a desire to lead a life of meaning and purpose." (S. Kellert, 2016)

References to figures are written in small, *green italic* letters.

Example: (see Figure 1) / (see Figure 10 on the next page) / (see Figure 14 & Figure 15)

Hyperlinks are written in *grey italic*. Please click on them to open the link. Some figures contain hyperlinks, therefore please check the caption underneath for indications.

Example: click for video demonstration

Other important text (vision, research question) is written in bold, **green** letters.

An "effect database" including videos of the designed patterns, as well as other materials can be accessed at this link: *goo.gl/bNC52a.* On how to navigate through this database, please check "Appendix I".

IDEATE

Step 1: Introduction

Defining the choice of subject from 3 perspective:

-> personal interest
-> previous academic work
-> previous practical work

This helps set the foundation for more precise investigation.

Step 2: Project Scope

Identifying the underlying problem through:

-> expert feedback
-> analysis of spatial context:
socially-inactive urban spaces

Vision

Imagine if...*we can explore our innate attraction to nature to create biophilic dynamic light projections for application in socially-inactive urban spaces with the goal of transforming them into more attractive, pleasant environments.*

=

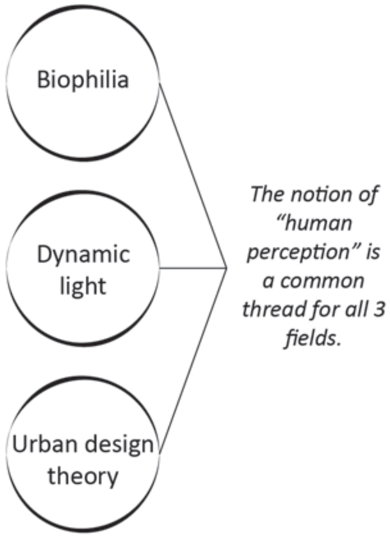
Research Question

How can the use of dynamic light projections based on biophilic design principles attract more public life into socially-inactive urban spaces?

ANALYSE

Step 3: Analysis

Analysis of scientific papers, publications and state-of-the art from the following fields:



Project Goals

-> create small database of biophilic dynamic light projections

-> investigate the "ideal" values for selected parameters: "fine tuning" for application in a socially-inactive urban space

-> make robust recommendations on the basis of the investigation and other scientific work for the findings to be applied in a socially-inactive urban space

TRANSLATE

Step 4: Design

Success criteria

Experimentation:

to achieve a usable design for testing

Video Projectors ⇠ ⇢ *Gobo Projectors*

- development of biophilic patterns
  - controllability of patterns
  - implementing interaction

- controllability of gobo projector
- experimentation with existing gobos

possibilities & restrictions

EVALUATE

Step 5: Test

In order to answer the research question, an investigation into the ideal values for "complexity", "speed of change" and "interactivity" of the patterns is undertaken.

The results of the test are analysed and discussed. Recommendations are made.

COMMUNICATE

Step 6: Final Design

Fine tuning of the patterns to match the findings from the test.

Final recommendations are made on how the findings from this exploratory thesis can be applied to a socially-inactive urban space.

Step 7: Conclusions

Was the research question robustly answered using a structured, problem-based approach?

- Was sufficient knowledge developed?
- Is the knowledge useful?
- Is it applicable?

Step 8: Future Work

Has this exploratory thesis opened up questions that need additional work in order to be robustly answered?

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Chapter 1

Introduction

1.1 Motivation

Now, a few weeks short of graduating as a Lighting Designer, I can reflect at the last two years and admit that thought they have been fruitful, they have also at times been extremely challenging. Trained as a Technical Architect with the skills to solve precise tasks and with a lack of knowledge in creative thinking and design prototyping, I found this education to be a much-needed challenge and the piece that filled the gap I needed to become a more holistic architectural practitioner. Throughout the last three semesters, this education has taken me through the narrative-rich and poetic field of describing and understanding light as a tool to explore emotions and create better environments, through the fascinating world of code and media technology and lastly through the precise and at times, undecipherable notions of light engineering. All three of these fields form, in varying levels of importance, the basis for this master thesis (see Figure 1). A thesis which seeks to explore the fairly new field of dynamic light projections and their use in urban spaces by drawing knowledge from areas such as "experience of light", "biophilia" and "urban design theory". The scope is to use this knowledge to help us, lighting designers, become more in control of the input and experience urban spaces provide at night.

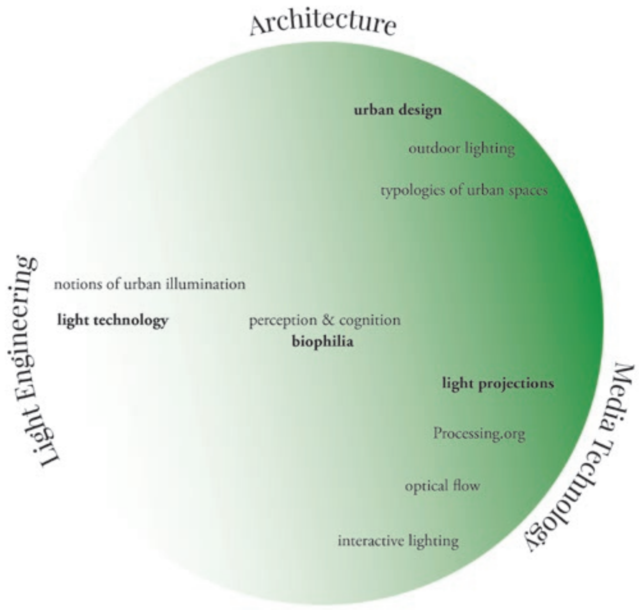


Figure 1. Diagram of the three fields of the M.Sc in Lighting Design education and the areas of studies discussed in this thesis corresponding to each field. (Courtesy of the author).

For the majority of us, students, choosing the focus of a semester-long research is a difficult process. We gather keywords and interests, create mood-boards and given the particularities of this education, we simply look around us and wonder. For me it started with an innate admiration of nature, from which, I am almost certain, I first started becoming interested in the field of lighting design. As a last-semester student in my bachelor education, I carried a rather short and at times, scientifically-questionable research into "Daylight planning in Denmark's residential architecture". Though it lacked many of the robust aspects needed for a true academic paper, I nonetheless developed a deeper understanding and fascination for how daylight shapes our living environments and more so how it affects us at an unconscious level. From here, it was only natural to

Figure 2. Example of functional outdoor lighting scheme. (Courtesy of Santacole.com)

want to understand the field of artificial lighting, as we spend most of our times under its influence and in the absence of daylight.

Prior to spending six months working as a Junior Lighting Design at a local landscape company (SLA A/S), I had little knowledge and interest in outdoor lighting solutions. It doesn't take a trained eye to see that most of the fascinating and documented lighting designs are usually placed in indoor environments. This is possibly due to economic interests – we are more interested in knowing how artificial lighting affects us in those places we spend most of our times in, such as workplaces and our own homes (Calvillo Cortés & Falcón Morales, 2016). When we move outside, the field of lighting design suddenly becomes much more practical and devoid of wonder. Until quite recently, experts in the field of architecture and even lighting design, considered that public lighting was a matter of light engineering and not one of aesthetics. The only exception were usually public squares and shopping districts, in which strong economic considerations made it of utmost importance to research the effect of lighting and provide solutions to boost stimulation and interest that would lead to increased sales and use (Phillips, 2002). Apart from that, our experience of the city, in here referring to the myriad types of other urban spaces, such as pathways, streets and in fact the majority of the urban landscape, were doomed to suffer under lighting conditions that only addressed the public need for visibility and facial recognition with limited and most of the times no considerations for our visual experience of the space at night (see Figure 2).

Going back to my time spent working at SLA A/S, it was there that I saw more innovative outdoor lighting solutions for wide-scale use. Their approach to lighting was more about fulfilling human needs and using the lighting design to support the space at night in a way that would not only provide visibility but also create experiences. In the words of SLA's creative director and founder, Stig L. Andersson:

"I see light as matter. In the same way as others of nature's phenomena it is changeable and atmosphere-creating. Light awakens the aesthetic sense of nature within us and we become aware of how crucial light is to our understanding of the quality of our life. (...)" (Fartadi Scurtu & SLA A/S, 2018)

This focus on the human experience as a design factor for urban lighting design is at the core of my motivation to write this thesis.

"Today, with electricity, there are myriad forms of artificial lighting used to light buildings and landscapes. Unfortunately, many contemporary lighting schemes are all about the light, not the space or the place, and most fail to evoke any poetic or imaginative affect." (Descottes & Ramos, 2011)

Besides the notion of "urban spaces" and in particular urban spaces devoid of wonder, or hereafter referred to as “socially-inactive” urban spaces, this thesis also focuses on the use of biophilia in lighting design, a rather new and unresearched field of application. An entire chapter is devoted to understanding what biophilia is, how it impacts us and how it can be used in the field of lighting design. But for the purpose of introducing the reader into the specific notions explored in this work, biophilia is our innate affinity to all that is “natural” (Wilson, 1984).

The use of “biophilia” in lighting design comes from a personal interest in symbolical representation of nature in the field of architecture and with this thesis, lighting design. I believe that, much like myself, the users of the city can benefit from implementing natural cues into our visual environment. Contemporary architecture seems more and more devoid of biophilic ornamentation, such as it is, for example in the famous works of the Spanish architect, Antonio Gaudi, who was inspired by natural patterns and motifs in both the ornamentation of his buildings and in their structural outlay (see Figure 3 & Figure 4).

Figure 3. The ceiling of the Sagrada Familia in Barcelona, Spain by Spanish architect Antonio Gaudi is adorned with biophilic elements. (Courtesy of TwistedSifter.com)

Figure 4. Spiralling interior staircase of the Casa Batlo by Spanish architect Antonio Gaudi. (Courtesy of Eurosplorin. blogspot.dk)

Our cities, at times, fail to provide us with true connections with nature, though with the example of Copenhagen, I believe authorities are becoming much more appreciative of the positive outcomes of abundant displays of nature in the cities not only as means of reducing CO_2 emissions but also as means of psychological and physiological healing. This is proved by numerous city development plans Copenhagen has supported in the past few years that are focused on extensive integration of nature as a tool to aid both our psychological and physiological affinity to nature and its healing benefits, as well as nature’s capabilities to successfully reduce harmful emissions and protect the city against flooding. One example is “The Soul of Norrebro” – an integrated urban design and climate adaptation plan to revitalize Hans Tavsens Park and Korsgade by SLA A/S, Ramboll, Arki_Lab, Den Nationale Platform for Gadeidræt, Aydin Soei and Social Action (see Figure 5).

Figure 5. “The Soul of Norrebro” rendering. (Courtesy of SLA A/S).

On the other hand, it is my personal belief while researching for this thesis, that there is limited understanding and application of natural symbolism, here referring to visual representation of nature through the power of modern lighting technology (e.g. video projectors, gobo projectors) and its benefits. However, there is already ample research into visual stimuli inspired by nature and how they are linked to increased healing times and relaxation (S. R. Kellert, 2005; Taylor, Spehar, Van Donkelaar, & Hagerhall, 2011; Spehar & Taylor, 2012). The results of these studies clearly show that symbolic representation of nature through lighting can be a valuable tool in attracting attention and creating more pleasant urban environments, hence why I seek with this thesis to create valuable knowledge into this particular niche in the form of a design framework/guideline.

In this sub-chapter, my aim was to guide the reader through a summary of events that I found are pivotal to my motivation for choosing this subject.

1.3 Background work

There are two previous bodies of work that I worked on, both of which have strong connections to the evolution of the research question which is introduced later in this thesis. One of them is a piece of academic work which was developed during my time working as a Junior Lighting Designer for the Danish landscape company SLA A/S (September 2017 - February 2018) and the other one is a gobo projection I did together with a fellow lighting design student for the 1st edition of the Copenhagen Light Festival (January-February 2018). Both of these works are briefly introduced in sections 1.3.1 and 1.3.2 that follow.

I find that the exploration of these two endeavours are important to supplement the interests already outlined in section 1.1 "Motivation".

1.3.1 Academic work: “Nature-Based Lighting” report

For the duration of my practical placement at SLA A/S, I was, besides supporting on lighting design projects, responsible for developing a toolbox that uses the aesthetics of nature as the foundation for lighting design.

"Nature-based lighting is about organizing and implementing emotionally compelling, lighting-inducted atmospheres. It’s about supporting what is familiar in nature, but very rarely encountered in the urban environment: the dapple light filtered by the dense, humid forest canopy, the refreshing touch of the morning sun glow or the smudged light of a falling star, the misty and the distorted reflection of light through water droplets or the dynamic narrative of a late summer sunset. Nature-based lighting is the realization of the "aesthetical sense of nature" through light."
(Fartadi Scurtu & SLA A/S, 2017)

It is clear from the definition of “nature-based lighting” that it is not about imitating nature, not even at a symbolic or abstract level, but rather about learning from the phenomena of nature and creating lighting designs that behave similarly. Now, after much more research into the benefits of actual representation of nature as visual stimuli, I strongly believe that mimicking nature is not only beautiful but also beneficial. I can even go as far as to argue that the approach in the report “Nature-Based Lighting” lacks this fundamental principle in order to be truly holistic. Nonetheless, this body of work is significant because it deals with issues of aesthetics, experience and atmosphere creation, all valid points for this thesis.

1.3.2 Practical work: "Metamorphosis" gobo projection

As part of the Copenhagen Light Festival's 1st edition that took part during the month of February 2018, I was, together with Alice Balboni (a fellow lighting design student and close friend), invited to design a gobo projection by the manufacturing company Martin Professional, which provided the lighting equipment. The canvas of the projection ended up being the inner façade of the Danish Architecture Center (DAC), located (at the time) right on the waterfront in centre Copenhagen. With good visibility from one of the most populated bridges connecting the two parts of the city and from the boat tour of the festival, the location proved to be a great choice and attracted a lot of viewers and attention.

The design of the projection itself focuses on the concept of adaptation and change in the architectural layers of the city of Copenhagen. To cite from our project's description directly:

"[the projection] explores the historical evolution of the skyline of Copenhagen in a colorful, lively display on the facade of the Danish Architecture Center (DAC). With references to its historical roots as a harbour city, the bright and popular facades of Nyhavn and the modern peaks in its skyline, Copenhagen's architectural evolution is morphed into the projection in a fun play of light, colors and the darkness of the night, all in an adaptation that preserves and enhances the beautiful architecture of DAC's home – "Gammel Dok"". (Copenhagenlightfestival.org, 2018)

Although it is not in direct connection with "biophilia", this body of work explores the use of dynamic light projections in an urban context and provided me with practical experience of working with gobo projectors. During the design process, I was undoubtedly challenged by the technology itself, the Exterior Projector 1000 by Martin Professional and the context of the site: a historical building with significant signs of structural deterioration which made it difficult to map the artwork precisely. All these factors have accelerated some of the necessary technological experimentation with using gobo projectors and have given me an idea of how

Figure 6. DAC's inner facade during the projection weekend. In the picture, the final gobo showing the entire architectural evolution of the city of Copenhagen. (Courtesy of the author).

the various parameters of the urban context, such as scale, height, structural considerations and environment play a role into the design and its placement (see Figure 6).

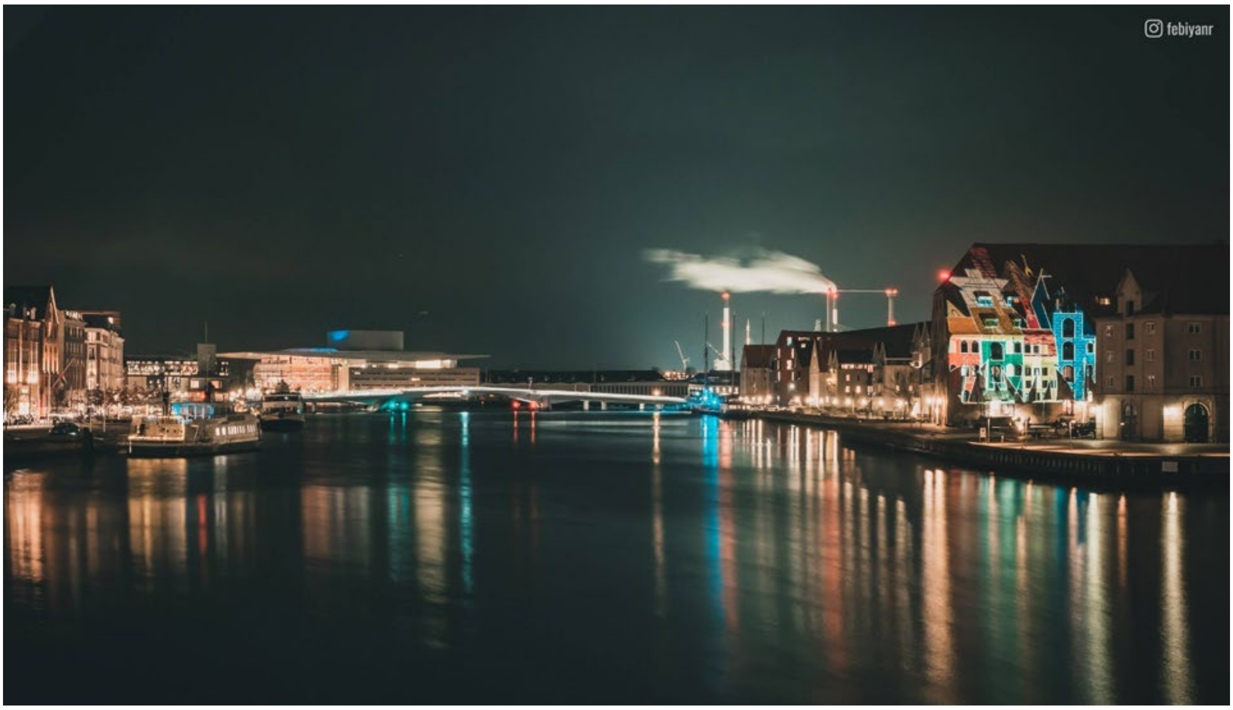


Figure 7. View of the projection from Knippelsbro, Copenhagen. (Courtesy of Febiyan Rachman Photography).

For example, a feedback we received during the two-day display of the projection, was that the level of dynamism (a rotating movement between the gobos, each representing another layer in the architectural evolution of the city) (see Figure 8). was not interesting enough and that people expected a greater level of change in the visuals. This was in line with my initial considerations upon reviewing the use of the projector. However, Martin Professional's two latest gobo projectors: EP500 and EP1000 are capable, together with DMX control, of much more complex dynamic behaviour. Due to the time constrains associated with the gobo projection for the light festival, we were unable to experiment to this degree, hence why the resulting projection used a very basic dynamic behaviour.

Nonetheless, the feedback received is valuable and gobo projectors will be experimented with in this thesis with the scope of creating dynamic light projections that are biophilic - see section 5.3.

Figure 8. The resulting three gobo designs showing the evolution of Copenhagen's skyline throughout its recent history. (Courtesy of the author and Alice Balboni).

Chapter 2

Project Scope

2.1 Problem Identification

The following two sections aim to provide some empirical knowledge valid to the development of this thesis's vision and research question. The arguments brought forward are two-fold: one comes from experts in the field and one from existing research on socially-inactive urban spaces, which in my humble opinion, are the areas of our urban landscape that need the most attention and can benefit from the use of biophilic dynamic light projections.

2.1.1 Expert feedback

Throughout the design phase of the gobo projector presented in section 1.3.2, I came into contact with two professionals activating in the field of lighting design, both from manufacturing companies. I will discuss our conversations on the subject relevant to this thesis referring to them as Expert from Martin Professional and Expert from Gobo.no. They provided great insights into the struggles of the industry regarding the use of light projections, in particular gobo projectors for purposes that go beyond traditional use (see Figure 9). Though examples of more complex, abstract glass gobos are plentiful on popular gobo manufacturers websites, the experts I discussed with still outline that there is limited use of them in dynamic ways (see Figure 10 on the next page).

Figure 9. A standard application of gobo projectors for marketing purposes. (Courtesy of Derksen.com)

In his professional experience, the Expert from Martin Professionals considers that even though the technology is there, namely the Exterior Projectors 500 and 1000, which display various adjustable parameters such as frost, animation disk, prism effect, RGB colour wheel, etc., the lack of research into their potential application and combination with gobos seldom make them a choice for lighting designers. Although they display incredible resiliency and life-time expectancy with minimal maintenance in even the toughest of climates (Martin Professional, 2013), these projectors are often overlooked or used with very generic and unimaginative visuals. He further expresses the need to develop better effects examples, such as a video database and/or graphical representation to make it easier for lighting designers to visualize and present ideas to reluctant clients. I found this point very interesting and with great commercial potentials, hence why throughout the duration of this thesis I aim to video record all my experimentations.

He further outlines that gobo projectors, unlike video projectors are much cheaper on the long run and have a greater potential to become widely implemented as an outdoor lighting solution (see Figure 11).

The Expert from Gobo.no, a Norwegian gobo manufacturing company, with whom I worked closely for the production of the three gobos used for the light festival, had, throughout our conversation, some opinions regarding the state of creativity in using gobo projectors. He had seen, throughout his career at the company, an extensive use of gobo projectors for logo displays and orientation and was pleasantly surprised by the level of detail and visual appeal of our design for the light festival. He initially expressed concern over the production of such detailed artwork on a gobo, which is, surprisingly only 30mm in diameter. The resulting gobos (see Figure 12). showcase the capability of modern printing technology, which in fact led me to the conclusion that the technology of gobo projectors has a fantastic but unfortunately unexplored potential.

The expert feedback presented in this section helped me define some of the outputs of this thesis, which I later detail in section 2.2 "Vision".

Figure 10. Examples of nature-inspired glass gobos. (Courtesy of Rosco.com).

Figure 11. Martin Professional's most advanced and recent exterior gobo projector capable of projecting crisp images from distances of up to 220m. In addition to standard gobo projectors, this model and its earlier sister model can create dynamic effects using an inbuilt animation disk. (Courtesy of MartinProfessional.com).

Figure 12. Photo of the resulting gobos printed on coated glass with a diameter of 30mm. (Courtesy of the author).

2.1.2 Spatial context: Socially-inactive urban spaces

Identifying the context for this master thesis was a lengthy process, in which several possibilities were considered in order to create the best possible framework for carrying a realistic study. Given that the period of research for this work was mainly between March and May of 2018, at which time the sun sets well after 6pm in Copenhagen, it made it difficult to perform a realistic test with willing participants in an outdoor setting. Instead, the decision to focus on socially-inactive urban spaces was in part influenced by the ease of translating the characteristics of such a space into an indoor environment, more precisely, a light laboratory at Aalborg University's Copenhagen Campus and in part by the obvious benefits such a study could bring to the revitalization of socially-inactive urban spaces.

To support the decision of choosing such urban spaces as a contextual focus, I identified several studies describing the characteristics and types of socially-inactive urban spaces, as well as their need for rehabilitation. Further in this study, a more comprehensive analysis of successful urban space planning and the role of lighting in achieving this is undertaken to further support this decision - see section 4.3.

Several studies, but more so the well-established organization "Project for Public Spaces" – a New-York based organization of urban planners and thinkers, identify a successful and social urban space as an environment in which people are provided with possibilities to interact and be active (see Figure 14 on page 10). They pin-point lack of seating, gathering points, improper accessibility, poor visual connection, a tendency to plan for cars and not for people, as well as blank and inactive facades as major contributors to unsuccessful, socially-dead urban public spaces (Project for Public Spaces, 2009). From a lighting design perspective, the same organization underpins the value of urban lighting in several of their articles and studies, reinforcing that although its primary role is to provide night-time visibility, security and safety, *"successful street lighting takes into account the human users of the street"*, because lighting design is responsible for how a space is perceived and hence utilized (Project for Public Spaces, 2008) (see Figure 15 on the next page).

In terms of classification of socially-inactive urban spaces, several studies, including The City of Birmingham's urban rehabilitation study, give fairly vague and open for interpretation information. In principle, a socially-inactive space is one which fails to leave a positive impression on the user and is devoid of social "buzz" – a simply practical environment, in which the major goal is not to bring people together but to take them from point A to point B. Such places can be, but are not limited to: streets, passageways and alleyways (City of Birmingham, 2012). In conditions of poor planning, a socially-inactive urban space can even be a public square (Project for Public Spaces, 2009) (see Figure 13).

On the other hand, successful planning, including light planning, leads to memorable urban spaces, regardless of their classification and role in the overall urban landscape. In the words of Project for Public Spaces:

Figure 13. Examples of issues that make an urban space unsuccessful: impractical or no seating, inactive facades and lack of purpose to spend time in the space. (Courtesy of PPS.org).

"These are the places we remember most vividly, the places where serendipitous things happen, the places we tell stories about."

Today's cities still suffer from the increased planning for cars, which largely happened after WW2, when our cities' streets, which prior to this largely belonged to communities and were the centre for many social activities, political activism and the gathering points of the city, were overtaken by the infrastructure for cars, with little regard to pedestrianism (Mackenzie & Project for Public Spaces, 2015).

Luckily for us, an increased interest in transforming otherwise poorly regarded urban spaces and pedestrianization trends are gaining momentum. In the study undertaken by the City of Birmingham in order to revitalize the city's passages and alleyways, we see places, which are naturally regarded as purely functional, identified as locations with great potential:

"Public investment designed to improve the aesthetics of alleys and passages, such as paving upgrades, the addition of furniture, lighting or landscaping, will attract people to these spaces, and will have revitalization benefits for all adjacent properties." (City of Birmingham, 2012)

It is safe to assume at this point that to focus this thesis on socially-inactive urban spaces has extensive benefits. We know lighting is only a limited part of what makes an urban space great and attractive. However, regardless of all the other elements that go into their planning, lighting is responsible for how urban spaces are

Figure 14. Congress Square, Portland USA - an example of a successful urban space, where citizens are given the opportunity to interact and gather. (Courtesy of Corey Templeton - published on PPS.org).

Figure 15. "Marbles" by Studio Roosegaarde transforms the urban space into a place of gathering through its interactive "blobs" of light. (Courtesy of Studio Roosegaarde).

perceived for an extensive period of the day. Hence poor lighting design has the capacity to affect the overall identity of the urban environment. Furthermore, proper lighting can not only provide the visibility, safety and security aspects needed in the urban environment, but can also shape or completely create a new identity for the space. This is supported by Zumtobel's study on the role of new urban lighting. In it they believe that a new lighting identity can boost interest and diversify the use of the space (Maccheroni & Zumtobel Lighting GmbH, 2017). This is of great importance in the context of socially-inactive urban spaces and the use of lighting to bring more public life into them (see Figure 16).

Figure 16. Lighting design for the Cartier Avenue in Quebec City. The giant lampshades are successfully used to express the identity of the space "and promote the city internationally as a winter capital". (Courtesy of Patrick Mavel Photography - published on arthitectural.com)

2.2 Vision

Imagine if we can explore our innate attraction to nature to create biophilic dynamic light projections for application in socially-inactive urban spaces with the goal of transforming them into more attractive, pleasant environments.

As a result of this body of work, I aim to satisfy the industry gap by creating a small database of biophilic dynamic light effects, supported by a scientific exploration into a selected list of parameters (complexity level, speed of change, interactivity) in order to identify their ideal values for implementation.

This will form a design framework/guideline that can be taken and applied in a socially-inactive urban space or outdoor space with similar properties. Important to mention is that the characteristics of the chosen space are, in general an important contributor to the design process, but this thesis does not address a specific space but rather urban spaces with properties similar to those described in section 2.1.2. It is strongly encouraged that upon choosing an actual space, a further investigation into the architecture of the space, the needs of the client and of the users, the user behaviour and cultural background of the space should be carried to ensure robustness of design. However, preference for investigated parameter values (complexity, speed of change and interactivity) are not believed to change dramatically based on that. This is because the findings of the test are supported by other scientific publications that yield similar trends even though the spatial context is different. Rather, what can be different from space to space are aspects regarding the choice of underlying biophilic pattern, colour and spatial placement.

2.3 Research Question

Based on the vision and the outputs I intend to create, the research question I aim to answer through the rest of the work described in this master thesis is:

How can the use of dynamic light projections based on biophilic design principles attract more public life into socially-inactive urban spaces?

Chapter 3

Methodology

This section presents a brief description of the methods/approaches engaged throughout this thesis with the aim of robustly answering the raised research question.

3.1 Literature Topics

On the basis of the defined vision and research question, three major topics of interest were identified without which it would not have been possible to: *create biophilic visuals | argument the choice of investigated parameters | provide a problem-based and well-argumented case to support the use of biophilic dynamic light projections as a tool for revitalizing socially-inactive urban spaces | formulate recommendations for implementation.*

1. Biophilia – This is necessary in order to scientifically and robustly argument:

•What is biophilia? • What makes a design biophilic? • What is the effect biophilic design has on humans?

The foundation for argumentation is sustained by the findings of Stephen R. Kellert, a pioneer of biophilic design, findings published in a variety of journals, as well as the book – "Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life". Other relevant publications are: "Biophilic Design Aesthetics in Art and Design Education" – by Y. Joye

Additionally, an extensive list of scientific papers from various international journals was also reviewed and discussed.

2. Dynamic light – This is necessary in order to scientifically and robustly argument:

•What is the role of dynamic light in the perception of atmosphere? •How is dynamic light implemented in urban space? •What are the implications of these implementations?

The answers to the above questions are argumented on the basis of several scientific papers investigating the effects and preference for dynamic light. Of great contribution, "The Influence of Lighting Color and Dynamics on Atmosphere Perception and Relaxation" by Wan, S H et al can be mentioned.

3. Urban design theory – This is necessary in order to scientifically and robustly argument:

•What makes an urban space successful? •What are general properties of the human-urban space interaction of relevance in the development of lighting designs? •What is the role of lighting design in the revitalization of urban spaces? •Is there a possibility that biophilic dynamic light projections can improve the atmosphere and appearance of a socially-inactive urban space?

The answers to the above questions are strongly supported by Jan Gehl's urban design theory from his book

"Cities for People" and the extensive work of the American organization "Project for Public Spaces".

In addition to publications, a few relevant case studies are presented to also provide examples of practical applications and their effect. Important to mention is that a common thread throughout the thesis is the notion of "human perception" in response to biophilic design, dynamic light and urban lighting design. This was required in order to understand what we perceive as pleasant and attractive, of importance in deeming the use of biophilic dynamic light projections as significant in the proposed context.

For a full list of reviewed publications, please refer to the "Bibliography" section of this thesis.

3.2 Design Methodology

The 1st step under "design" was to create controllable biophilic patterns for implementation with either video projectors or gobo projectors. To do this, an experiment-based approach was engaged, where I worked on:

- several digital sketches using the software "Processing";
- the use of standard gobos and in-built projector parameters to create biophilic visuals;

This type of "experiment-based" approach is supplemented by the empirical data gathered throughout the review of the literature. This can be seen in the beginning of the design process where the success criteria are set on the basis of the findings presented in the "Analysis" step. All in all, this approach can be categorized under the "problem-based approach" typical of Aalborg University.

3.3 Toolkit

The toolkit can be described as the physical and digital tools used throughout the thesis in order to respond to the research questions. These are:

- Processing software;
- Video projectors;
- Gobo projectors (from Martin Professional);
- Digital camera (for video-registration of experiments and test);

3.4 User-feedback

User-feedback was a very important contributor for assessing the patterns and identifying the correct values of the investigated parameters, as well as establishing if such patterns have the potential to attract people into spaces. To get usable data, a test was carried that evaluated the proposed design and several variations in selected pattern parameters. The test, together with support from other scientific studies helped me robustly conclude on the recommendations and research question.

The user-feedback method was inspired by Ingrid Vogel's research on "Atmosphere Metrics" – dealing with how to scientifically and quantitively assess such an abstract notion as "atmospheres".

Chapter 4
Analysis

4.1 Biophilia

As introduced in the beginning of this thesis, "biophilia", is our innate affinity to the natural world. It was first used by Erich Fromm, a psychologist, to describe our genetical attraction to *"all that is alive and vital"* and was later researched in the context of design, art and architecture by the likes of Stephen R. Kellert and Edward O. Wilson in their work "The Biophilia Hypothesis".

Purpose of the analysis:

Many studies since then have successfully analysed and scientifically tested biophilic designs and our responses to it. The analysis into several of these studies and books is further presented in order to learn how to create biophilic visuals and whether or not they have any substantial psychological and/or physiological benefit that could lead to supporting the choice made as part of this thesis.

4.1.1 Benefits of biophilia

In contrast with "biomimicry" (see Figure 17), which looks at natural processes to solve human problems without necessarily visually mimicking what we see and perceive as natural (S. Kellert, 2016), biophilia relies entirely on visually mimicking nature as a form of strengthening the human-nature connection (see Figure 18 on the next page).

It is important to mention that on the negative side of biophilia is the mimicry of innately dangerous, scary

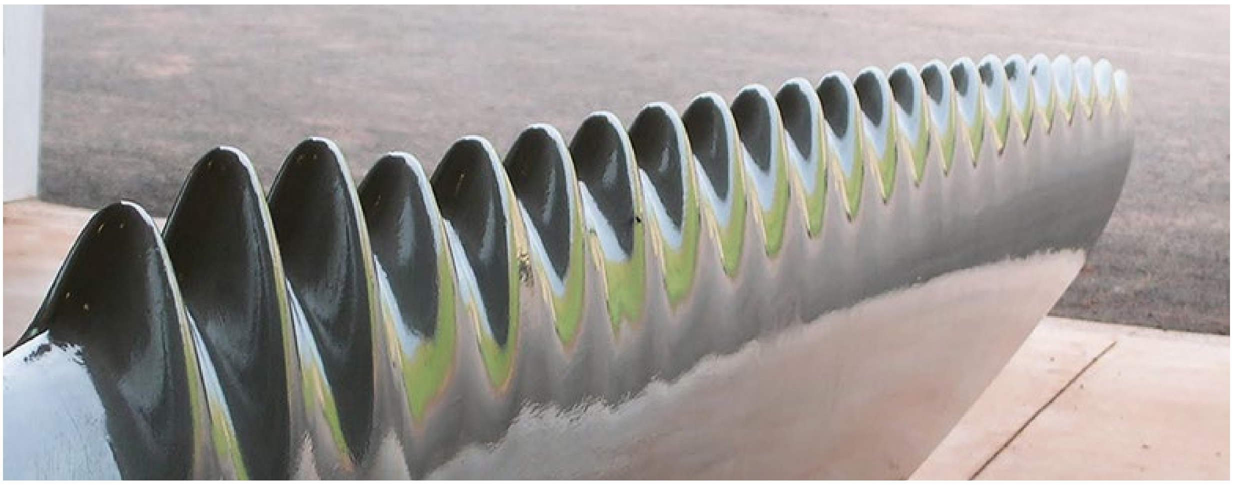


Figure 17. Example of a biomimetic design. A wind turbine blade modelled after the humpback whale's flippers that were proven to reduce drag by 32% and increase lift by 8%. (Courtesy of Bresslergroup.com/blog/biomimetic-product-desig/).

Figure 18. Examples of biophilic design. On the left - actual presence of nature. On the right - symbolic representation of nature in the design of a building façade. (Courtesy of Cognitive Studios & Terrapit Bright Green).

natural elements, such as spiders, bugs, etc.

"If a biomorphic form mimics creatures like snakes or spiders that are perceived by humans as dangerous, they can elicit a fear response — a reaction termed "biophobia." Such designs do not support positive health benefits, and therefore we do not consider them biophilic." (S. Kellert, 2016)

Our human perception of biophilic application is essential to the success of the project. Therefore, we look at nature as an inspiration source two-fold: the material side of it (biomimicry) and the emotional side of it (biophilia).

"Material well-being is of great significance, but so, too, are the ways nature can enrich the human capacity for emotional connection, a sense of beauty, our intellectual understanding, and a desire to lead a life of meaning and purpose." (S. Kellert, 2016)

This is especially of essence with the ongoing increase in urbanization. As a logical consequence of that, we experience less and less direct contact with nature, as in availability of vegetation and nature-made environments. Nevertheless, the field of biophilia goes beyond 1:1 inclusion of nature. It is common knowledge and widely accepted today that representational interpretation of nature through visuals has a similarly positive impact on our well-being (see Figure 19). (S. R. Kellert, 2005):

Figure 19. Another example of symbolical, vicarious application of biophilic design as a glass curtain wall in an airport. (Courtesy of S. Kellert).

"Symbolic or vicarious experience involves no actual contact with real nature, but rather the representation of the natural world through image, picture, video, metaphor, and more."

Browning, Ryan, & Clancy (2014) in their publication "14 Patterns of Biophilic Design" outline that biophilic design has positive effects on stress reduction, improves cognitive function and can even expedite healing. A typically cited reference proving nature's restorative properties is the scientific experiment carried by R. S. Ulrich (1984) in a hospital in Pennsylvania between 1972 and 1981. The study shows 23 of the patients assigned to a room with a view overseeing a natural scene experienced *"shorter postoperative hospital stays, received fewer negative evaluative comments in nurses' notes, and took fewer potent analgesics than 23 matched patients in similar rooms with windows facing a brick building wall."* The study involved patients that suffered the same medical procedure.

This comes to support that not only is biophilia psychologically beneficial, but that is also can improve our physical well-being .

In addition, Orians & Heerwagen (1992) in the famous "savannah hypothesis", argue that humans have developed an innate affinity to savannah-like environments. It is believed our human brain evolved in this environment and up to this day we preserve a preference for the fractal properties of an African savannah environment. Though still widely controversial, the hypothesis brings the argument that the complexity level of the savannah made it ideal for our ancestors to hunt without being seen but still have a clear view of danger – in short it allowed for adaptability and predictability, both of importance when it comes to survival (Joye, 2011). Although survivability does not hold the same degree of danger as millions of years ago, our preference for savannah-like designed environments can be used for its proven psychological benefits in places of high stress, such as workplaces.

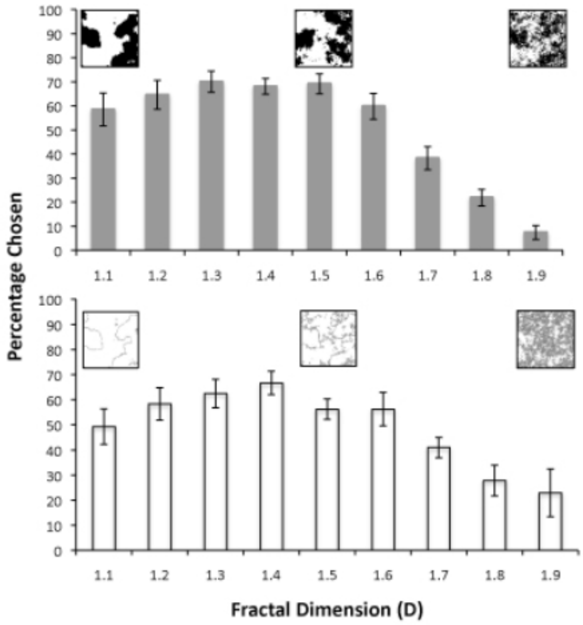


Figure 20. Results of a study carried by B. Spehar and R. Taylor on why we like fractals. Results indicate that our interest peaks from a fractal dimension of 1.3 and 1.5. (Courtesy of B. Spehar & R. Taylor).

In support of the savannah hypothesis, Bies et al., (2016) in their study "Aesthetic Responses to Exact Fractals Driven by Physical Complexity" conclude that with statistical fractals[1] the preference lies at the fractal dimension of 1.3, dimension most prevalent in nature and matching that of the ancestral savannah. The test was carried under the hypothesis that statistical fractals within the range most encountered in nature have stress reducing properties. The test was successful in proving the starting hypothesis. However, similar studies which tried to identify the preferred D value of statistical fractals showed contradicting results. There is somehow of a consensus now that preference peaks for elements with a fractal dimensions (complexity level) within the range of 1.3 and 1.8 (Ryan, Browning, Clancy, Andrews, & Kallianpurkar, 2014) (see Figure 20).

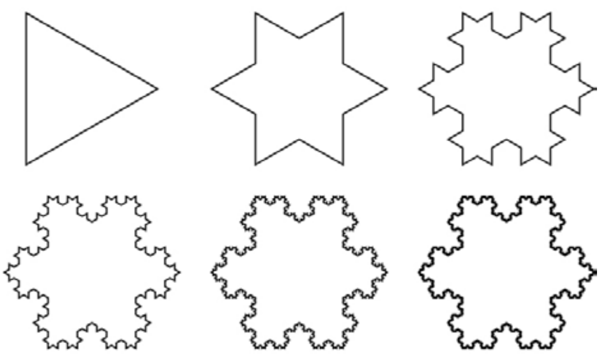


Figure 21. Example of an exact fractal - Koch Snowflake. (Courtesy of oxfordmathcenter.com).

Interestingly enough and in support of my aim to use symbolic and abstract representation of nature, as opposed to exact representation of nature is another research paper on fractal art and preferences: "Fractal Art and Architecture Reduce Physiological Stress". In this study, Salingaros (2012) shows that even though

1 A statistical fractal is one which regardless of the scale it is only self-similar and not identical. Statistical fractals are most prevalent in nature. Think e.g. a tree's branches. On the other hand, exact mathematical fractals are computer generated and regardless of the scale factor they are identical. An example is the Koch Snowflake.

he exposed his participants to a stylized version of the savannah landscape, the responses were still very positive. He argues that:

> *"This reveals that our response is triggered by fractal properties much more than by an accurate representation. As such, the importance of the scenes in creating their physiological response relies squarely upon their mathematical content, and not in some intrinsic or mysterious vitalistic qualities of the natural scenes themselves."*

Last but not least, in addition to the previous studies that tackled areas such as cognitive performance, stress-reduction and well-being, a study on natural patterns (compromising of spiral, branching and fractal patterns) exposed its participants to a virtual reality environment that contained biophilic and non-biophilic visuals (Young & Wodehouse, 2018). The aim of the study was to identify the effect of these patterns on attention responses times, user behaviour and interaction with the surrounding environment. The results show interesting finding, of great relevance to support the application of natural patterns to urban lighting where the goal is to captivate attention and attract people in the space. The final computed data shows that the natural patterns (biophilic patterns) have, in total been viewed 241% longer than their non-biophilic counterparts. Furthermore, the test showed that the natural patterns were also among the top ones in terms of interest. With regards to behaviour in space, given that the interest rates and viewing times peaked with the natural patterns, the participants were also highly influenced by that in the way they navigated the virtual environment – e.g. choosing to skip the non-biophilic pattern in favour of a biophilic one (Young & Wodehouse, 2018) (see Figure 23).

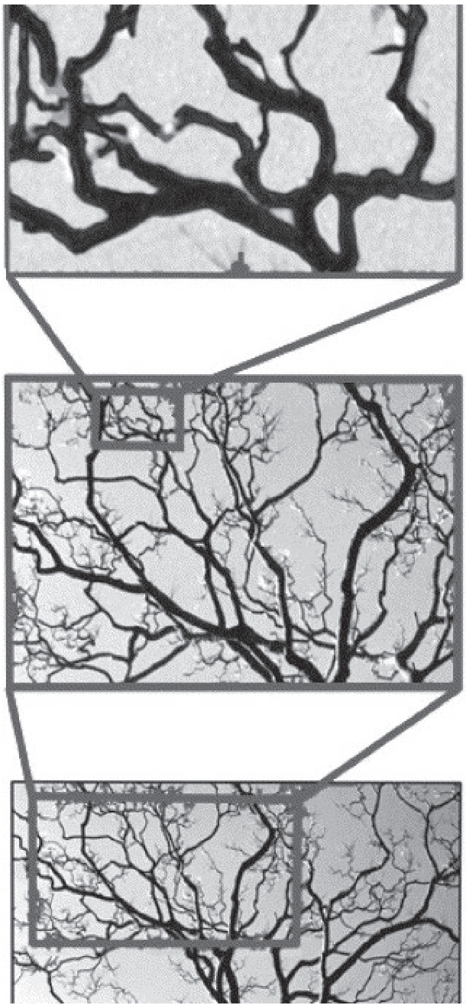


Figure 22. Example of a statistical fractal found in nature. (Courtesy of Science Direct).

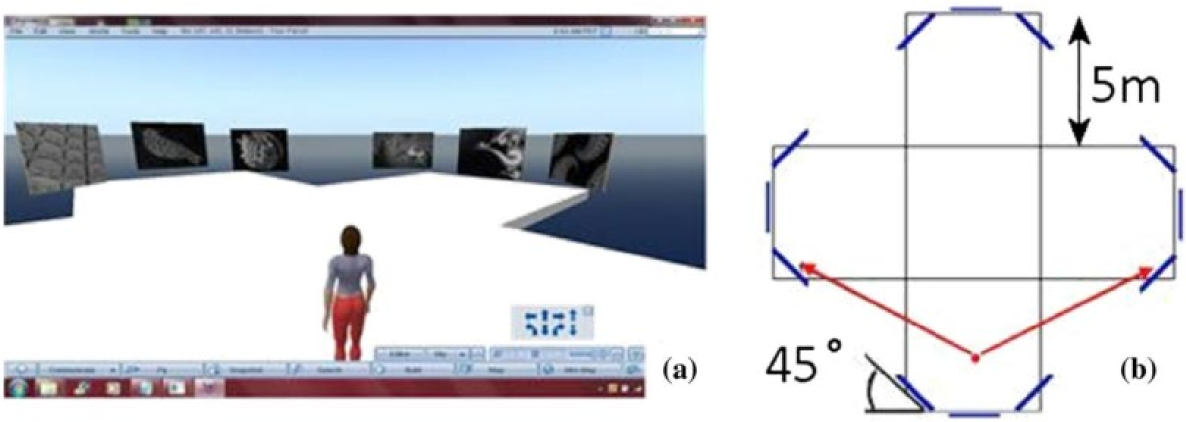


Figure 23. The virtual reality set-up used for the perception test on the application of biophilic vs non-biophilic patterns. (Courtesy of B. Young & A. Wodehouse).

We can hypothesize based on above study that using biophilic patterns as projected lighting can have a positive effect on the usage rate of an urban space that otherwise has little to no incentive to attract attention. If natural patterns have the potential to generate visual interest in a virtual environment, they can potentially generate similar behavioural patterns in a real scenario. This, of course has to be further explored and tested as part of this thesis.

4.1.2 Biophilic design principles

This part will elaborate on what makes a design biophilic. For this, the methodology developed by Stephen R. Kellert in his books and the biophilic conditions outlined in the "14 Patterns of Biophilic Design" book are analysed and presented below. This section is a precursor of the "design criteria" later introduced in this thesis. The analysis into these publications enabled me to objectively and scientifically assess the resulting patterns created as part of the design phase.

Since the publications mentioned above cover application in a wide spectrum of industries, such as architecture, design, engineering and the like, only relevant parameters for the field of lighting design were selected for analysis and discussion.

4.1.2.1 Dimensions, elements and attributes of biophilic design

In his extensive research on the understanding and application of biophilic design, Stephen Kellert identified two basic biophilic dimensions, followed by six biophilic elements and as many as 70 biophilic attributes. They can be categorized as design guidelines for the professionals to understand the practical application of biophilic design in the built environment (S. R. Kellert, 2005).

The dimension of interest in this thesis is the "organic or naturalistic one", described as shapes and forms that either directly or indirectly remind us of nature and inherently stimulate our genetical affinity to it. While direct exposure to nature signifies the presence of vegetation, natural light, actual water, etc., the indirect exposure, which is of interest here, involves vicarious or symbolic representations of nature. This can be achieved using images, videos, sounds or visual ques in the environment that remind of natural arrangements (e.g. designing circulation in a building to mimic an organic shape).

The dimensions are followed by six identified elements, each of them with its own attributes. Again, after the selection of the lighting design-relevant elements and attributes, a total of 5 elements and 14 attributes are presented below:

1. Environmental features:

a. *Colour:* It is believed that the visual availability of colour has a strong potential to attract and excite the human brain. This is attributed to the vast presence of colour in the natural environment. Descottes & Ramos (2011) argue that colour has the capability to give a place a new identity, help with improving its atmosphere and how it is perceived by the users.

"Coloured light can leave us with lasting impressions of a place because we are apt to remember our experiences by the colour in which they were rendered."

b. *Water:* The swaying movement of water and water features in general in the form of visual stimuli appear to elicit a tendency for liking and preference (Roger S Ulrich, 1993) (see Figure 24 on the next page).

c. *Fire:* Though believed to be quite difficult to master, as it can elicit negative feelings if done improperly, fire is subconsciously also associated with warmth, community and comfort (S. Kellert, 2016).

Figure 24. "Momento" installation by Nao Tamura. The installation uses a custom-designed lamp that "creates droplets of water" patterns. (Courtesy of Nao Tadano).

2. *Natural shapes and forms:*

a. Simulation of natural shapes and forms in the design: This biophilic element and its attributes argue that the use of shapes, patterns and motifs found in nature can evoke an innate liking, increase attractiveness and successfully satisfy our biophilic tendencies (S. R. Kellert, 2005).

3. *Natural patterns and processes:*

a. *Sensory variability & Information richness:* Refers to the property of the natural environment to be complex and rich in its abundance of sensuous inputs. Kellert believes that our satisfaction is linked to the complexity level of our environments, with low complexity calling for uninterest and boredom.

b. *Central focal point:* In order to better navigate our environments, it is believed of importance to have a central focal point of reference to help us both physically navigate and mentally comprehend the richness of information and variability in our world.

c. *Complementary contrasts:* The natural world is not all the same shade and complexity, generating better meaning and intelligibility of the environment. The concept of "light zones" (Madsen, 2007) in which it is believed we better navigate and comprehend a space through balanced light contrast can be connected to this attribute (see Figure 25).

d. *Fractals:* (Salingaros, 2012) says that *"human beings are apparently tuned to prefer an environment that has the self-similar properties of a fractal"*. The self-similarity property is attributed by Kellert to successful designs.

e. *Hierarchically organized ratios and scales:* It is important to preserve at least a subtle hierarchical organization of scales and ratios in order to better make sense of what we see. In the absence of hierarchy, we would have complete chaos, which can lead to a feeling of overwhelm.

Figure 25. "Light Zones" in the foyer of Le Corbusier's own apartment in Paris. (Courtesy of Le Courbiser Foundation).

4. *Light and Space* - This element refers to the properties of natural light. Some of its attributes were omitted because of irrelevancy to light projections:

a. *Light and shadow:* Similar to the concept of "light zones" and the attribute "complementary contrast".

b. *Light pools:* Refers to the advantages of using pockets of connected or unconnected light for illumination. Kellert argues that their use can help with improving the feeling of safety and aids in way-findings.

c. *Warm light:* Much like the attribute "fire", it is believed that warm light, especially when surrounded by areas of darkness can foster feelings of protection, security and pleasantness.

5. *Evolved Human-Nature relationship:*

a. *Curiosity and enticement:* Kellert, quoting Kaplan et. al says that *"curiosity reflects the human need for exploration, discovery, mystery and creativity…"*. What this can mean is that a successful design should not entirely reveal itself at once from a distance, but rather leave space for question and mystery for the sake of providing a more meaningful, interesting environment. In this context, "mystery" is described as *"the promise of new information if one could travel deeper into the environment"* (Ikemi, 2005).

b. *Change and metamorphosis:* Maybe of the highest importance in the context of dynamic light projections is our human affinity and need of experiencing change, progression or regression in what we see, hence the choice of only investigating dynamic projections rather than dynamic and static. Similar to how the natural world around us constantly evolves, I hypothesize as part of this thesis that being able to see change in the light behaviour can have a positive effect in the way you perceive the space in which that happens.

4.1.3 Classification of natural patterns

As the basis for understanding the properties of natural patterns, a brief research into their classification is undertaken as part of this section.

As classified by Stevens, P.S. in his 1974 work "Patterns in nature", we can enumerate the following categories of natural patterns:

a. *Symmetry:* as seen in a snowflake, water drop, starfish, tiger stripes, etc.

Figure 26. Examples of symmetry seen in nature. (Courtesy of Merriam-Webster.com, Wikipedia contributor).

b. *Trees and fractals:* the self-similarity properties of a fractal can be found in a variety of natural elements, such as in tree branches, leaves, broccoli, relief, even cloud formation, etc.

c. *Spirals:* as seen in shells, cabbage, animal horns or even in the rotation of simple man-made objects such as a spinning ball (see Figure 27 on the next page).

d. *Chaos, flows, meanders:* often seen in the formation of geographical elements, such as riverbeds and shores, but also in the formation of clouds and in the movement of animals, such as in a snake crawling (see Figure 28 on the next page).

Figure 27. Examples of spirals seen in nature. (Courtesy of RobertHarding and SamWoolfe).

Figure 28. Examples of chaos and meanders seen in nature. (Courtesy of ScienceOfBeing and GranadaBlogs)

e. *Waves and dunes:* waves, dunes, ripples created by wind in the sand, etc.

f. *Bubbles and foam:* seen in the formation of soap bubbles but also at a cellular level in various organisms.

g. *Tessellations:* can be described as more or less identically replicating tiles, given that perfection is rather difficult to find in nature. However, the honeycomb is a good example of an identical tessellation. More examples can be seen in the scales of some animals, such as the pangolin, in the formation of natural crystals and even at a cellular level.

Figure 29. Example of perfect natural tesselation - the honeycomb. (Courtesy of Slate.com).

h. *Cracks:* the tendency of a material to crack in a similar manner upon reaching its breaking point.

i. *Spots and stripes:* Most prevalent in the skin of animals, such as that of zebras, leopards, tigers, giraffes, etc. It is believed that they evolved for survival purposes, such as to camouflage. Mathematician Alan Turing on the subject of morphogenesis[2] proved that given certain conditions, two interacting chemicals can "generate a stable inhomogeneous pattern if one of the substances diffuses much faster than the other." (Khandelwal & Sahni, 2008). Though still disputed, Turing's theory attributes the formation of patterns on the skins of animals to this process - also known as "reaction diffusion". What is more interesting is that following this logic, we can identify an almost infinite number of applications all around us, such as in the formation of galaxies, weather systems and the spread of vegetation across the landscape (Brandon, 2011) (see Figure 31 on the next page).

Outside of the above categories, we can mention the concept of "Perlin Noise", a type of noise developed by Ken Perlin for the purpose of advancing the reproduction of natural phenomena in the field of computer graphics, more specifically for application in the motion picture industry. In short, it helps CGI artists better

2 Morphogenesis is the biological process that causes an organism to develop its shape (Wikipedia)

control the realism factor of natural patterns, such as the control of the random distribution of textures as seen in nature in elements such as clouds, fire, water, etc. (The Processing Foundation, 2017). Furthermore, another example of a "procedural texture"[3] is the algorithm entitled "Worley Noise" used to replicate the apparent randomness of natural pattern distribution seen in cellular noise, water, etc. (Worley, 1996).

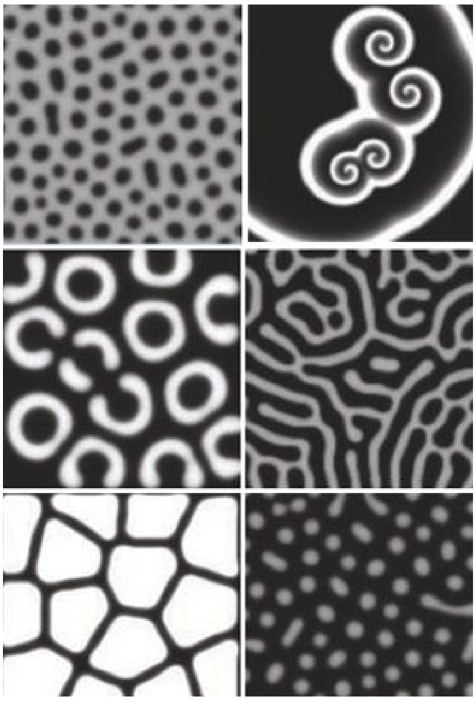


Figure 31. Example of typical Turing patterns. Patterns are obtained depending on the diffusion properties. (Courtesy of Algorithmic-Worlds.net).

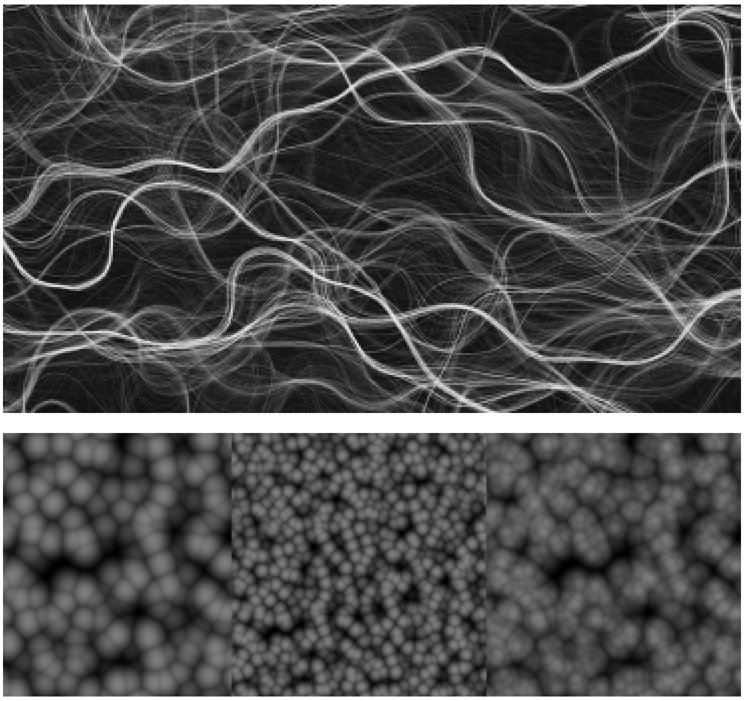


Figure 30. On the top, example of Perlin Noise. On the bottom, example of Worley Noise. (Courtesy of Pierpaololucarelli.com and Gamedev.stackexchange.com)

4.2 Dynamic light

The notion of "dynamic light" is touched upon in the presentation and short analysis of the dimensions, elements and attributes of what makes a design biophilic.

Why is this analysis necessary?

There is considerable proof that we are more likely to feel attracted by something that moves and it is for certain not a surprise or a new notion. Therefore, what this section seeks to investigate is how dynamic light affects the perceived atmosphere of the space and whether it has a positive or negative effect on our experience of the urban environment.

4.2.1 Perception of dynamic light

Light is a strong tool to shape our perception of a space and thus the way we choose to use it. Light has been long used to give sensibility and meaning to architectural spaces, guide our eyes to the most relevant information and not least, help shape the emotional and atmospheric meaning of the space. What I find fascinating about light is its strong capabilities of generating desired atmospheres. Following Gernot Böhme's theory on "atmospheres", we can understand the importance of creating atmospheres using light for the sole

3 In the field of computer graphics, a procedural texture is one that is created on the basis of a mathematical algorithm rather than the result of stored data (Wikipedia, n.d.-b)

purpose of instilling a certain mood and experience in the users. He gives the example of a stage artist, in charge of transcending the realm of subjectivity with its lighting design in order to communicate the overall same message to the entire audience:

"For the stage set artist must relate them to a wider audience, which can experience the atmosphere generated on the stage in, by and large, the same way. It is, after all, the purpose of the stage set to provide the atmospheric background to the action, to attune the spectators to the theatrical performance and to provide the actors with a sounding board for what they present. The art of the stage set therefore demonstrates from the side of praxis that atmospheres are something quasi-objective." (Böhme, 2013)

In the realm of urban planning, we can think of ourselves in a similar manner to the stage artist – our audiences are large and diverse. Moreover, they are constantly on the move, never for too long in one space and regard the urban environment as a transitional space between their homes and their workplaces. There is limited emotional connection and the interactions are merely functional. With this comes an immense pressure for us as lighting designers to deliver on the concept of making "atmospheres".

If in its majority we think of urban lighting or even lighting design in general as a static experience, constantly the same, dynamic lighting on the other hand is capable of creating a fluid, always surprising experience. Making "atmospheres" in the public realm thus can become an adaptive experience with dynamic light capable of shaping the aspect of buildings, the spatial perception of a space and in the case of dynamic light and digital technology, add the platform for visual communication towards the users (Nielsen & Delman, 2017). The increased likeliness for the dynamic lighting experience can be attributed to our innate affection and attraction to change and metamorphosis. In the realm of public space to use dynamic light is not only a capable solution to constantly upgrade the experience of the space, but to also tackle issues related to light pollution and energy efficiency. In a world in which public lighting is a major polluter, cities are becoming more and more aware of the advantages of incorporating dynamic and intelligent light systems to control many of the light's parameters for better overall efficiency. Such parameters are usually limited to intensity of the light source, number of on/off luminaires and maybe in certain cases, colour temperature. Though this has a purely functional approach, it is nevertheless successful at reaching its intended goal, with many examples seen all over the world.

The beauty of this is, as seen by (Jackson et al., 2015) that *"boundaries shift and hierarchies are fluid"* which relates very much to the perception of space, architecture and surrounding environment. This is the element of wonder that dynamic light can bring. Therefore, the combination of biophilic patterns with the dynamic light behaviour seems like a natural choice to generate a strong visual stimulus for increased pleasantness of desolated urban spaces.

When it comes to the perception of using dynamic light behaviour and its influence on the space, an experiment carried by researchers at the University of Leeds, UK shows that a medium speed of change *"offers the most likely and preferred atmosphere".* Contrary, a very slow dynamic in the light behaviour was more attributed to a "living-room" type environment and hence less appropriate for use in a more dynamic environment, such as a urban space (Wang Bsc et al., 2013).

Another study, this time on measuring the perceived atmosphere of a space under different degrees of dynamic light, shows that *"smaller amplitudes of change as well as slower light variations were seen as more attractive, showing a preference for subtle dynamics."* (Sekulovski, Seuntiens, & Hartog, 2011). Though both experiments were carried in a similarly controlled environment, the first one had "colour" as a secondary parameter of change in connection with the change in the dynamics of light. The effect of colour on perception of space is well documented but not of interest in this thesis. Nevertheless, colour has a strong effect on how we assess our environments and the way in which they make us feel, hence why we can attribute the difference in results between the two studies to the addition of a second parameter.

The difference in observations for the preferred degree of dynamics in the light behaviour opens up a very interesting research opportunity. It can be assumed that the preferred dynamics level is influenced by all the other external and related factors such as colour, properties of the environment in which it is placed, etc, hence why it is of importance to investigate the parameter “speed of change/dynamics of light” in combination with the biophilic patterns and the environment which most mimics the socially-inactive urban spaces.

On the subject of dynamic light in urban spaces, a study by Paredes, Ko, Calle-Ortiz, & Canny (2016) highlights interesting findings in the sphere of perceived safety and preference. In a controlled environment, they created a light installation that responds to the speed of the users. While multiple parameters were investigated to assess which trigger time and position were considered ideal to foster a feeling of pleasantness and comfort, of interest here is that 67% of the participants agreed that a system of dynamic-interactive lighting would have a positive effect on their desire to walk more during the night. They associated the responsiveness and dynamics of the light with a feeling of control and increased predictability of their environments, which only naturally lead to improved feeling of safety. Tying this to the emotional response and perception of space, the authors conclude that, dynamic light that changes in response to the user (e.g. by increasing the intensity of the light sources) has an overall positive emotional impact on them.

To conclude on the perception and effect of dynamic light as an active component of the urban lighting scheme, Zumtobel’s study on the new role of public lighting outlines that dynamics in light can not only support the fight against light pollution and increased energy consumption, but also aid humans’ circadian rhythm (by adjusting CCT over a predefined timespan), control their walking routes through the city and the perceived pleasantness of a space. This is in connection to the power of alternating dynamics, speed, colour temperature, etc. to affect the emotional response in the users and their interaction with the public space (Maccheroni & Zumtobel Lighting GmbH, 2017).

4.3 Urban design theory

Purpose of the analysis:

This section aims to supplement sub-chapter 2.1.2 "Context: Socially-inactive urban spaces "with examples of what good urban planning is and how lighting design plays a role in changing the aspect of urban spaces.

4.3.1 The role of light in urban revitalization

As already discussed in the earlier sections of this thesis, lighting design for outdoor application is in its vast majority a field of functional solutions with the first and foremost intent of meeting rigid standards and providing illumination for safety purposes.

It is therefore of essence in today’s fast-paced urban life, for lighting specialists, urban planners and other relevant practitioners to explore the city and its users with a holistic, robust approach. Innovators are already there, paving the way for an industry that, though traditionally purely engineer-oriented is slowly becoming more focused on the notion of aesthetics and human emotion (see Figure 32 & Figure 33).

Figure 32. Proposal from the French company Concepto for the City of Lille. The concept proposes the use of portable light lamps so that the citi dwellers can interact with the public space at their own pace and matching their own needs. (Courtesy of Concepto).

Figure 33. Concepto's winning competition for Shanghai's riverbeds incorporates bioluminescent elements into the water as one of the sourcer of public lighting. (Courtesy of Concepto).

Figure 34. The interactive public light sculpture "The Heart of the City" pulsates according to the beat of the people. Its aim is to create a community experience "an expansion of their [the people's] heart shared with others". (Courtesy of Anaisafranco.com)

To understand why light and lighting designers play an important role in the development of our cities and more-so in the improvement of their appearance is quite easy. Light in the city is responsible for providing illumination, for proper identification and orientation and if done well, for creating spatial identity. Though initially limited to expanding the use of the space through the night, lighting design in outdoor space creates the possibility for people to perform various activities and interact with their environments in ways never seen before (see Figure 34).

For the purpose of this thesis it is thus important to understand the value-add of regenerative lighting design applications in the urban space. *Can lighting design alone sustain the aesthetic improvement of a space that is otherwise uninteresting, dangerous or purely functional?*

As a starting point in this analysis, we can take the case of the Athenian neighbourhood “Kypseli”. Following the 2008 world financial crisis, many of Athens’s streets, especially those in low-income neighbourhoods became dimmer and dingier as the result of citizens turning off their doorway lamps. In response to this, streets became less attractive and people’s perception of public safety took a turn for the worse. The volunteer group "Light for Kypseli" has, for the last few years pushed towards a massive implementation of LED light bulbs due to their limited energy consumption properties and decreased costs. This has not only improved the feeling of safety but most importantly has given the impression that the space is well-taken care of, which as a result built a better sense of community. Though the organization emphasises that there are many other elements of the urban space that can be improved, new lighting has nonetheless proved to be an immediate, practical solution to the problem of the neighbourhood giving it a new face, identity and extending its use well through the night (O'Sullivan & CityLab, 2017).

Figure 35. Photos of the Kypseli neighbourhood after the implementation of LED lights. (Courtesy of CityLab.com).

Another example and more in-line with the intention of this master thesis is the lighting design for the Opera House Lane in New Zealand. The location, a pathway between two buildings was the typical example of a poorly-regarded, socially-inactive space before the implementation of the new, colourful lighting design. The project is part of a larger municipal intention to reinvent and refresh the aspect of run-down public spaces, with improved lighting and street art as the immediate and cheapest solutions. The project set-out without a clear brief, but the intention from the beginning was to create something different and *"bring some theatre and magic out into an otherwise under-utilised urban space".* The solution is a series of "Chandelier" luminaires with moving heads, one of which is capable of projecting gobos on the ground in funny, surprising patterns. The lighting scenes and patterns are triggered by movement and thus provide the platform for play and the curiosity and incitement to spend more time in the space. The integration of the interactive, play factor is based on the CPTED principles (Crime Prevention Through Environmental Design) that among others, believe that giving the users a reason to stay in the space longer through proper design can decrease crime and improve the feeling of safety (S&T Lighting, 2017).

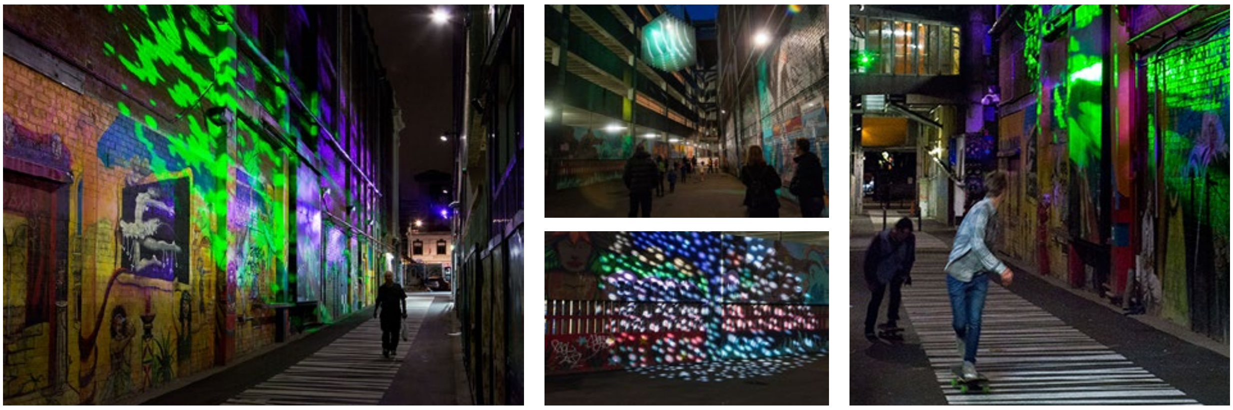


Figure 36. Photos of the Opera House Lane Project. (Courtesy of S&T Lighting, New Zealand).

On the new role of urban lighting, Arup, in their booklet “Lighting the urban night-time” outline that:

“Urban lighting isn’t just about meeting safety needs through code compliance or achieving an aesthetic effect. It presents a significant opportunity to fundamentally improve the quality of life of urban citizens. Properly considered, lighting can positively impact the ‘total architecture’ of our cities; reinforcing urban design principles, enhancing cultural experiences and encouraging social interaction.” – Florence Lam, Global Lighting Design Leader at Arup.

They applied their design principles on the role of urban lighting to a pilot project in Cartagena, Colombia in a UNESCO “world-heritage” site named "Getsemani". The intention behind the project is to prove how lighting can aid in urban revitalization and make a place safer, more inviting and attractive, all without tampering with its historical roots. The final lighting design, a lamp called “Universal Lamp” is the result of community workshops, with the current residents of Getsemani participating in creating the lamps that now light up their doorways, pathways and squares. Extremely successful at relighting and providing a “face-lift” to the night-time environment of Getsemani, the “Universal Lamp” and how it came to be gave the entire neighbourhood a sense of ownership, pride and community (Arup, 2016).

“The clearest indication was that the lighting was popular. [Locals] immediately recognized the lighting as embodying what made a successful street for them: the right levels of light, meaningful color, lively ambience, respect for darkness, historical reference. The placement of the lanterns was in keeping with the normal “rhythm” or distribution of social gatherings up and down the streets of Getsemaní, and therefore supported the way in which people generally “read” these streets. Lighting their street meant that it was noticed, was politically legible, that people actually cared about their street enough to materially attend to it. This was a very powerful kind of visibility.” - Dr. Don Slater of Configuring Light Program, London School of Economics

Figure 37. Photos of the Getsemani lighting project and its impact on the community. (Courtesy of ConfiguringLight.org).

It is safe to assume the importance of light in the rehabilitation of urban spaces. One of the easiest elements to address when looking at reconfiguring the public space, light has the power to completely transform the perception of the space. Though only one of the many other aspects of the urban environment that can contribute to urban revitalization, lighting can nevertheless provide a strong platform for change, ownership and attractiveness as was proven in the examples presented above.

4.3.2 Design considerations in urban spaces

Another important aspect when addressing issues of design related to the urban space, regardless of its scale or properties is understanding the principles of visual perception and human-space interaction. To get a glimpse into these implications, a brief study was carried on the work of renowned Danish urbanist Jan Gehl. This section is supposed to provide an introductory platform for taking the results of this study and applying them on a specific urban place. More in detail analysis of the space is required, but Jan Gehl's work draws on generalities applicable to varying typologies of urban spaces.

For decades, Jan Gehl has worked towards educating officials on the importance of the urban space and how pivotal it is to preserve a sense of scale and human-environment relationship to create what he calls "a successful urban space". Special attention in his studies is brought to the way humans perceive their environments - at their own average pace and how complexity and visual stimuli are of great importance in the hierarchical distribution of elements in the urban landscape. Regardless of the dynamics of a space, Gehl draws attention to what he calls "the 5km/h architecture". This is the average speed at which pedestrians travel through the city and hence the speed at which their interactions with the urban elements, light being one of them takes place. It is important to consider your audience and whether the fleeting moment of interaction between the light and the user makes sense in the approximated timeframe it takes the urban life participant to interact with it. This, Gehl believes, is a significant contributor to the perceived attractiveness of a space (Gehl, 2010).

"Five km/h architecture is based on a cornucopia of sensory impressions, spaces are small, buildings are close together and the combination of detail, faces and activities contributes to the rich and intense sensory experience."
- Jan Gehl – Cities for People

Figure 38. The scale of the light and of the street in the Getsemani project. (Courtesy of ConfiguringLight.org).

An example of a 5km/h architecture in terms of lighting design can be the above mentioned Getsemani neighbourhood, where the light provides a sense of intimacy and considers the scale of the space. Rather than implementing standard public illumination, often-times suitable for places of high dynamism, the Getsemani project limits the scale of the light and creates "pockets" of illumination with great respect to the architecture and the users.

In the same book, "Cities for People", Gehl continues to elaborate on the important aspects of good urban planning and lands on the issue of "visual complexity". He concludes that a successful and exciting urban space provides a spectrum of visual interest through varying degrees of complexity.

"[...] wealth of detail and information. Walks become more interesting and meaningful, time passes quickly and

distances seem shorter. However, where there are no interesting edges to skirt or where ground floors are closed and monotonous, walks seem long and impoverished in terms of experience. The whole process can become so meaningless and tiring that people give up walking altogether. [...] – Jan Gehl – Cities for People

His assumption is interesting and important in the context of dynamic lighting in urban spaces as a possible source of visual stimulation. *Can dynamic biophilic patterns provide the necessary visual input to keep us entertained and curious?* Gehl, drawing on knowledge from other studies goes on to say that:

"Physiological studies of people in a room with no stimulation show that our senses need stimulation at fairly short intervals of four to five seconds, which appears to ensure a reasonable balance between too few and too many stimuli." – Jan Gehl – Cities for People

Dynamic light patterns with a biophilic undertone could, as in the case of the Opera House Lane project in New Zealand, incite interest because of their constantly changing nature and provide the frequency of stimulation that Gehl talks about in his work.

He adds another aspect, that of "breaking-down" the space and the experience into "manageable segments", so that people stop, appreciate and have something to look forward to. In terms of lighting design this can be interpreted as "pockets of light".

4.4 Additional case studies: existing applications of biophilic light in urban spaces

Two additional case studies are brought forward and analysed because of their successful combination of light, nature inspiration and urban life revitalization.

4.4.1 "Broken Light" – by Daglicht & Vorm

An example of social rejuvenation and identification through the use of light is the project "Broken Light". A custom-made solution with lamps sitting at a height of 6m, the project provides intricate illumination in the forms of patterns inspired by birds and flowers. Instead of only illuminating the ground, the motifs slowly fade onto the façade with respect to the openings as to not create unnecessary glare. "Broken Light" was so successful it completely changed the image of the previously crime-rife street into a fascinating exploration of patterns and visual experiences (Jones, 2012).

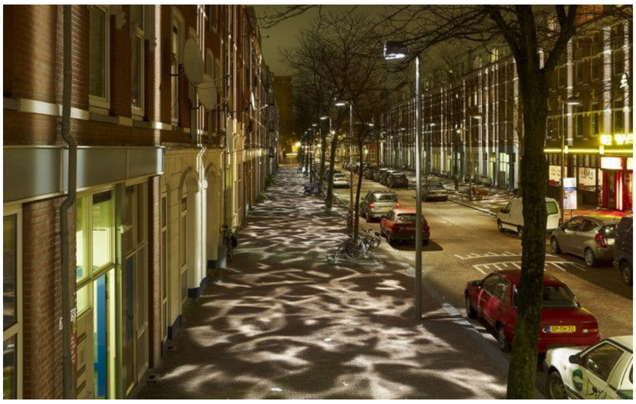


Figure 39. Photos of the "Broken Light" public lighting project. (Courtesy of Rudolf Teunissen).

4.4.2 “Flora” – by Philipp Artus

“Flora” is a computer-generated algorithm that self-generates sinuous waves of flower-like shapes in the form of light projections. Fully controllable by the viewers and fully-parametrized, the installation is described as a *“visual instrument that mirrors the personality of the player. It’s an artwork that generates creativity."* It shows that interactive pieces of lighting in the city can have positive effects on people’s engagement with the urban space (Holmes, 2017).

Figure 40. Photos of the "Flora" light projection. (Courtesy of Philipp Artus).

4.5 Summary of “Analysis” section

To summarize the findings of the “Analysis” phase, the following important aspects relevant to the overall scheme of creating, implementing, fine tuning and not least strengthening the robustness of combining biophilic design principles, with dynamic light projection in a socially-inactive urban space are brought forward:

1. Biophilic design is inherently pleasant and can improve attention-response times and the perceived pleasantness of the surrounding environment.

2. Symbolical representation of nature as visual stimuli is proven to yield similarly positive results to actual replication of nature.

3. Biophilic design is based on visual reminiscence or replication of natural cues (patterns, motifs, movements). Replication of inherently dangerous natural elements (spiders, snakes, etc.) is not considered biophilic.

4. There is no clear consensus on the preferred degree of speed of change in light. Further investigation is needed, but some recommendations on using natural movements are outlined in several studies.

5. Lighting design is often successfully used to improve urban spaces, create a new identity or simply help with improving the feeling of safety. This is attributed to its degree of contribution to the perception of space and atmosphere.

6. Dynamic and intelligent light is not only more sustainable but can also provide the visual stimulation needed for users to maintain interest in the urban space.

Chapter 5

Design

The following chapter will document the steps taken to propose a usable design for testing purposes. The design of the biophilic patterns and their behaviour is in response to the findings analysed in the "Analysis" section of this thesis. The design goal at this point is to ensure their properties match the recommendations of previous works on the subjects of biophilic design, urban lighting and human perception.

5.1 Success criteria

The success criteria are established to ensure the proposed design is in line with existing scientific knowledge analysed as part of this thesis, as well as with the intentions of the author. Another dimension to the criteria can be added when taking the findings of this thesis for application in a specific urban space. This dimension can concern the architectural, cultural and client-specific needs of the predefined space, but for the purpose of this thesis we are only concerned with creating and fine-tuning the aspect and behaviour of the biophilic dynamic light patterns and not with their implementation into a specific urban space.

5.1.1 Criterion 1: Form

Criterion 1, "Form" refers to the visual aspect of the patterns, which as a starting point, needs to stem from natural shapes and behaviours. Given that the symbolic or abstract representation of nature has similar positive effects on our interest rate and how we perceive a space, a certain level of distortion and abstract expressivity is encouraged in the development of the patterns.

Requirement supported by the findings of Stephan Kellert on biophilic design principles.

5.1.2 Criterion 2: Variability

Criterion 2 "Variability" refers to the behaviour of both the light and of the pattern itself. Dynamic properties in the overall experience of the light is considered to be innately more attractive. For this matter, light parameters such as colour, speed, complexity and others can be considered to generate visual interest in the lighting design.

Requirement supported by the findings of D. Sekulovski and P. Seuntiens's research, as well as those of Stephan Kellert.

5.1.3 Criterion 3: Interactivity

Criterion 3 “Interactivity” refers to the capacity of the light patterns to interact with the urban life participants. This is proposed in order to foster a sense of curiosity, enticement and control. Interactivity should be considered in the context of an urban space, therefore a space of great scale and complexity.

Requirement supported by analysis of the case studies – “Flora” and “Opera House Lane”.

5.2 Experimentation phase using video projectors

5.2.1 Design approach

In order to create the biophilic patterns and gain full controllability of their parameters for the purpose of later testing various iterations, a wide spectrum of possibilities was initially considered. The criteria for the selection of the design toolkit were rather simple:

- A tool that would require a relatively short learning curve given the time constrains associated with this thesis.

- A tool that would give the author full controllability over selected parameters such as colour, scale, complexity, speed, etc.

- A tool capable of association with a camera to generate interactivity with the user.

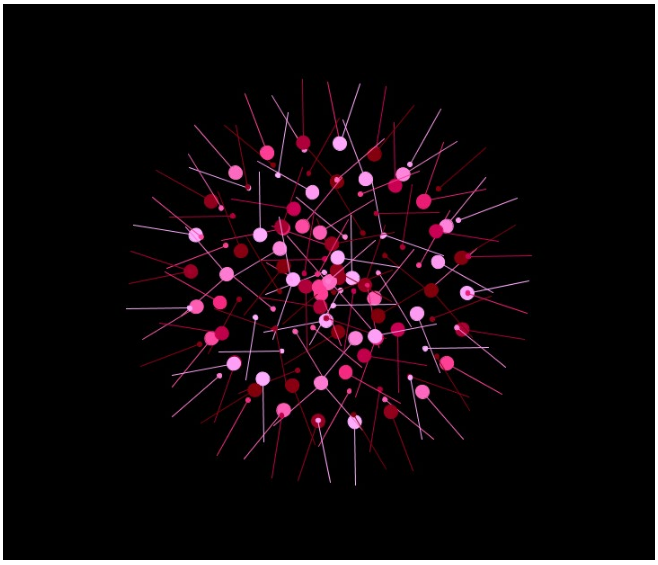


Figure 41.One of the starting points of the early Processing experimentation phase. (Code courtesy of https://www.openprocessing.org/sketch/157288).

Though I initially put some consideration into becoming familiar with video mapping software, such as TouchDesigner and MadMapper, I soon realized the limitations imposed by not having sufficient time to explore all possibilities of both software. The major disqualifying factor was the complexity of establishing a proper connection between a camera (in this case my laptop’s webcam) and the software as well as fine-tuning the interactivity model to suit my design intentions. The decision was to use Processing, a “flexible software sketchbook” with a primary application in the spectrum of visual design. In short, Processing enables artists everywhere to code their ideas into visual outputs with relative minimal knowledge of advance programming language. Furthermore, it is an open-source software with a great online support platform and open-source library of examples.

This allowed me to experiment on the basis of several selected Processing sketches, to which various other controllable parameters were added to achieve patterns that were either a direct representation or a symbolical representation of a natural shape (see Figure 41). It is important to consider that it is not only about the visual but also about its behaviour. A too abrupt, unnatural change in the pattern could have opposite effects compared to those intended.

5.2.2 Development of the underlying patterns

The underlying patterns, as in the state of the patterns without the possibility to control their parameters of interest, started from several existing Processing sketches found on the open-source online platform: open-processing.org. Careful attention was given to selecting patterns that though initially might have not been biophilic in their design, at least presented a workable code that could further be edited or even added to another code written by the author. What this implies is that some of the selected patterns first exhibited geometric

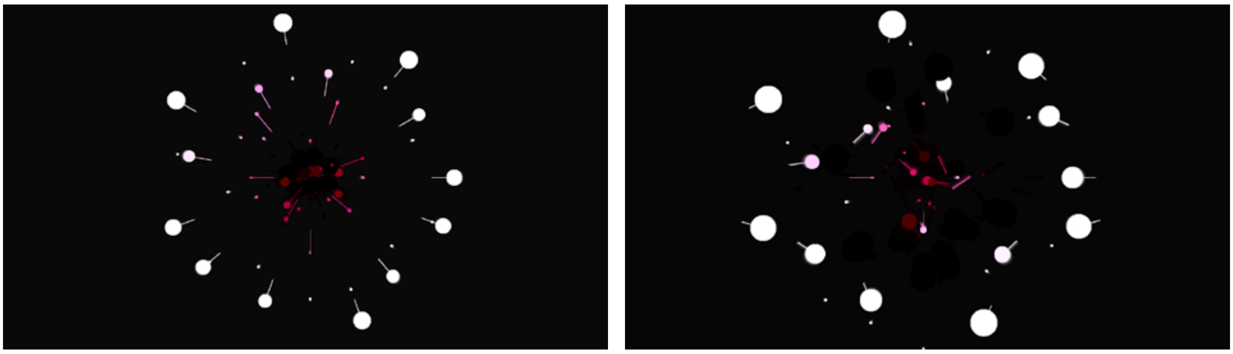


Figure 42. From original code (shown on previous page), to more fluid, organic shapes. (Click on each image for video).

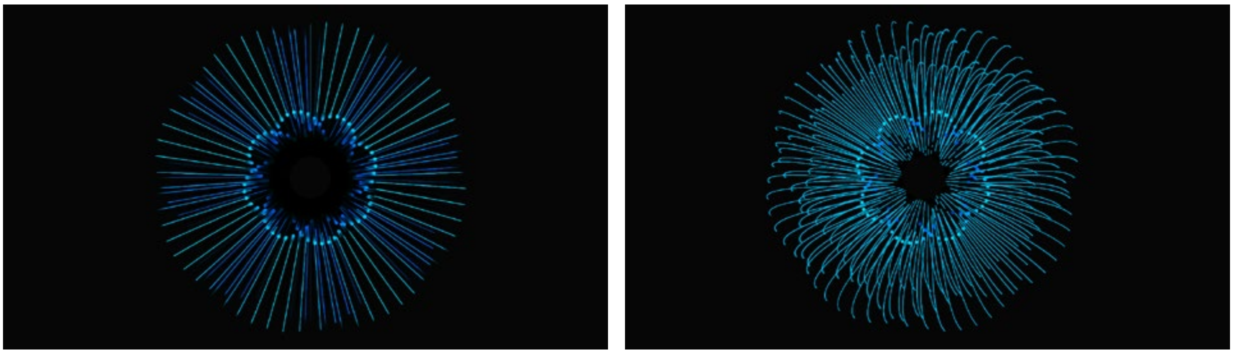


Figure 43. A second possibility using the same underlying code. (Click on each image for video).

Figure 44. Starting point of one of the biophilic patterns. (Code courtesy of https://www.openprocessing.org/sketch/119704).

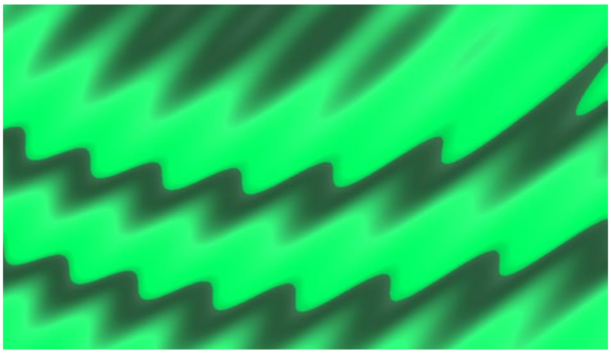


Figure 45. Pattern modified to resemble flowing water movements. (Click on image for video).

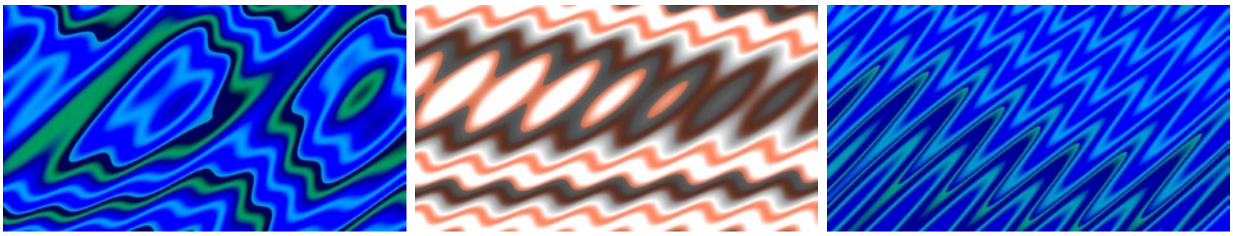


Figure 46. More alternatives starting from the same initial code.

shapes, but might have had extremely fluid, natural behaviours, which I was later able to implement together with more organic, nature-like shapes.

```
void draw() {
  float yOff = 10;

  loadPixels();
  for (int x = 0; x < width; x++) {
    float xOff = 10;
    for (int y = 0; y < height; y++) {
      float hue = map(noise(xOff*2, yOff*2, zOff*2), 0, 1, -252, 100); // noise is responsible for loading and controlling the Perlin Noise
      pixels[y * width + x] = color(abs(hue) % 360, 100, 300);
      xOff += zoom;
    }
    yOff += zoom;
  }
```

Figure 47. Screen grab of Perlin Heat Map code showing how the "Perlin Noise" is generated when introducing the syntax "noise".

Exceptions are for those codes involving mathematical equations pre-set into Processing such as “Perlin Noise” (see Figure 47). The code for this was taken and tweaked to allow for controllability of selected patterns for the scope of this thesis.

As a result of the experimentation phase, the following 13 fully controllable biophilic patterns emerged:

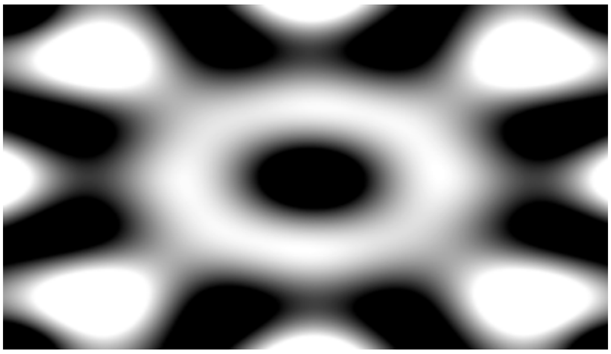


Figure 48. Pattern 1_Reaction-Diffusion.

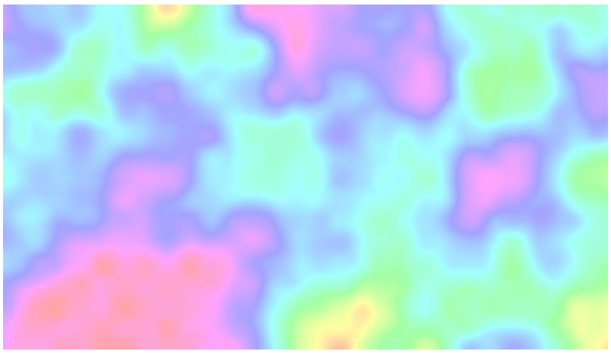


Figure 49. Pattern 2_Perlin Heat Map.

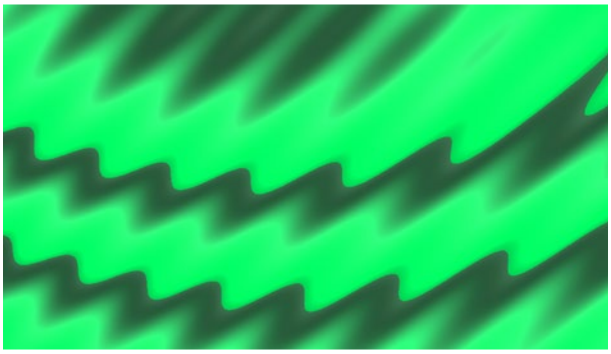


Figure 50. Pattern 3_Plasma.

Figure 51. Pattern 4_Abstract Zebra Stripes.

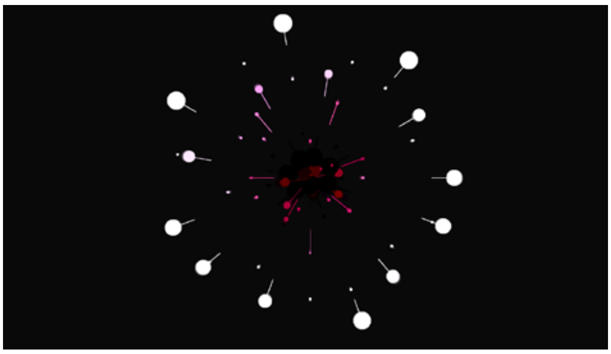


Figure 52. Pattern 5_Particles.

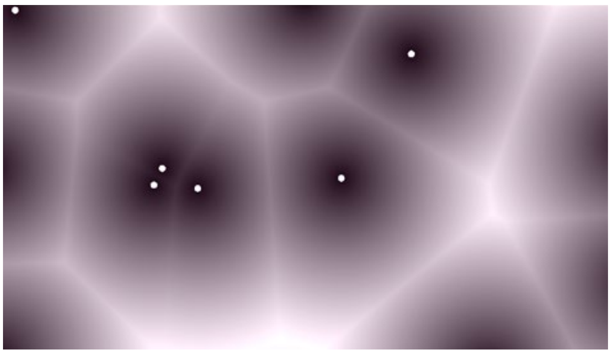


Figure 53. Pattern 6_Celullar Noise.

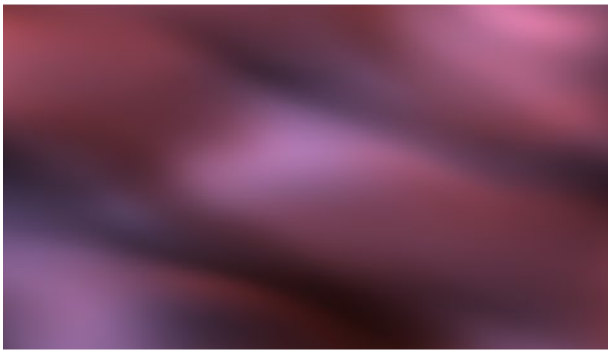


Figure 54. Pattern 7_Sky.

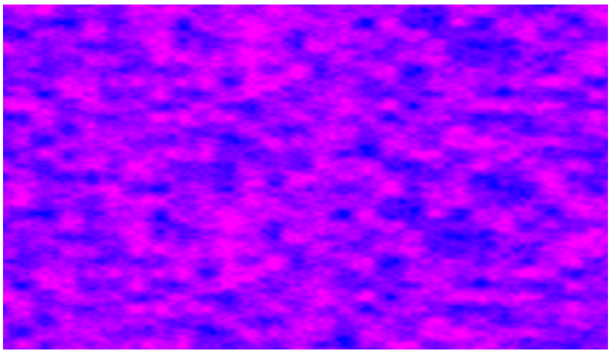


Figure 55. Pattern 8_Sky formattion.

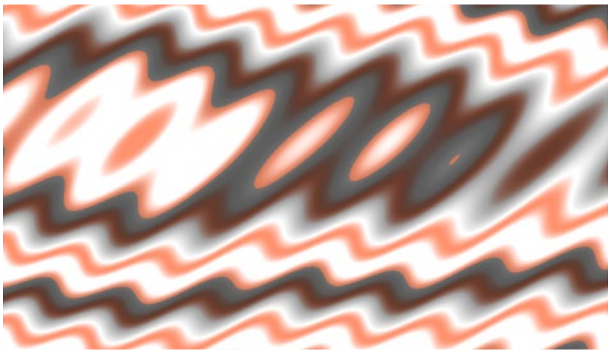


Figure 56. Pattern 9_Plasma 2.

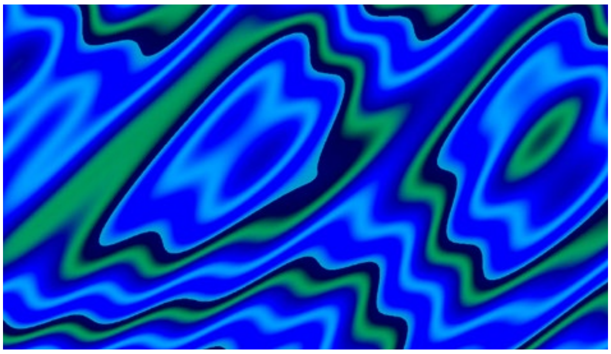


Figure 57. Pattern 10_Water drops.

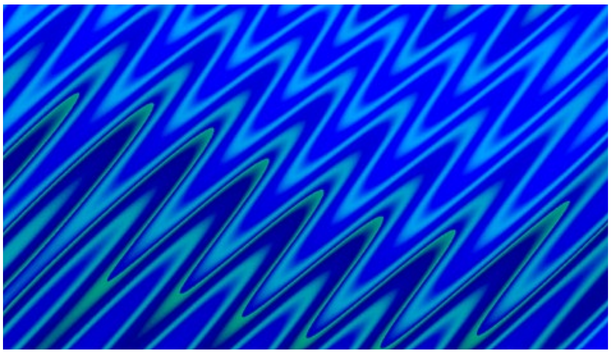


Figure 58. Pattern 11_Plasma 3.

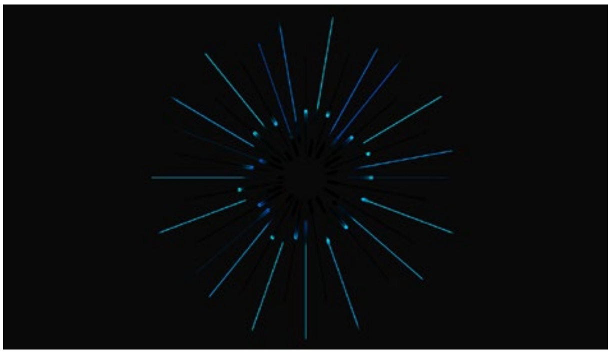


Figure 59. Pattern 12_Flower.

Figure 60. Pattern 13_Waves.

Click on each figure to see a video demonstration of the pattern.

For more visuals and videos, please check Appendices I and III.

5.2.3 Controllable parameters: Speed & Complexity

Up until this point in this thesis, several hypotheses were initiated to underline my final intentions. My interests are in both creating a small database of fully-controllable biophilic effects, as well as in fine-tuning pre-selected parameters in conformity with scientific findings which are investigated as part of an extensive test introduced later in this thesis - see section 6. For the scope of this test, the biophilic patterns generated in Processing need to be controllable in terms of complexity, speed and interactivity. Parameters such as colour and light intensity are outside the scope of this thesis due to the impossibility of tackling the number of variables and results a test of this dimensions would have yielded.

The interest in speed of change and complexity is curious because of the contradicting scientific findings on the subject, information already analysed in this thesis. Furthermore, the presumption that the values of these parameters would differ significantly between a socially-inactive and a socially-active urban space also triggered the interest. I believe that in a dynamic, popular and already attractive urban space, the effect of these light patterns would be minimal and that they would only add visual clutter to an otherwise successful place. This can be sustained by the fact that with an already successful urban space, where people naturally gather and have other elements to look at, the addition of complex lighting design is not quite necessary. On the other hand, in a socially-inactive urban space, they would have a major impact on beautification, identity and perceived atmosphere. This was already established by analysing existing applications in the previous chapter.

Therefore, the parameters "speed of change" and "complexity" were chosen for implementation in all Processing sketches. For that, the Processing coding language provides various possibilities, but the simplest and most effect one was looking into:

- frameCount – for specifying the speed of the pattern
- xf – for specifying the scale of the pattern (to set the pattern complexity)

Though the values are not identical for each sketch due to the way the sketch is built, I created three distinct iterations for each pattern (please check "Appendix I" and "Appendix III"):

- A low – medium – high degree of complexity
- A low – medium – high degree of speed of change

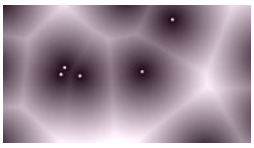


Figure 61. Low complexity of pattern "Cellular Noise".

The assessment of these pre-defined values/levels was carried in a qualitative, rather subjective approach, due to the lack of other more appropriate methods. We understand "low complexity" (see Figure 61) as a minimal amount of visual information.

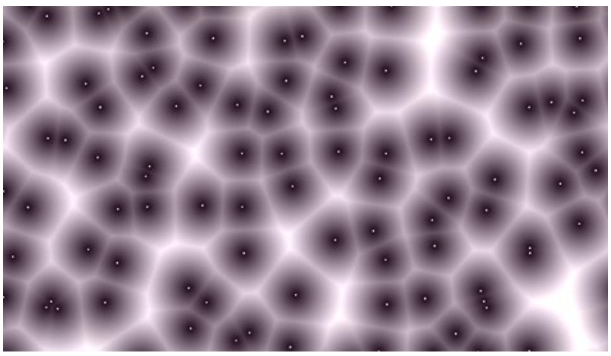


Figure 62. Medium complexity of pattern "Cellular Noise".

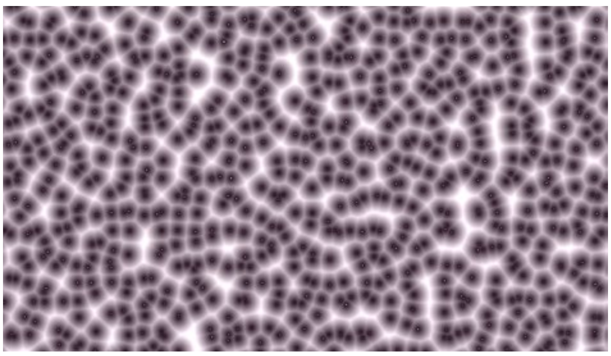


Figure 63. High complexity of pattern "Cellular Noise".

We understand "high complexity" (see Figure 63 on the previous page) as a great level of visual complexity, at the complete opposite of "low complexity" for the viewer to be able to understand the change. "Medium complexity" (see Figure 62 on the previous page) is always in-between the two values.

For speed, we understand "low speed of change" as a slightly perceptible movement, easy to ignore if not specifically looking at the pattern - *click for video demonstration.*

On the other hand, we understand "high speed of change" *(click for video demonstration)* as a very rapid, fundamentally opposite effect of "low speed of change". It is visually hard to miss in the line of sight. Again, "medium speed of change" is always in-between the two values *(click for video demonstration).*

5.2.4 Implementing interactivity

5.2.4.1 Generating interactivity: brief analysis of possibilities

To match the complexity required for motion tracking in the urban space and provide valuable usable feedback to create a seamless interaction between the users and the dynamic light patterns, commonly-used technology for outdoor application was investigated.

1. Heat and motion detection

Infrared sensors are widely use in outdoor lighting design systems. An IR sensor measures the heat of a passive object and can also detect the motion of the object in the space. One very basic application is in on/off outdoor lighting application: when heat is detected the light turns on. This type of technology can very well be used to create the interactivity model proposed as part of this thesis since values from an IR sensor can be averaged and thus thresholds for activating the interactivity can be easily created and used. Still, attention should be given to the detection accuracy of the IR sensor (read more in the following sub-section on "Optical flow detection"). However, practical implementation for testing purposes would have required both an IR sensor and an Arduino board. Therefore, the notion of "optical flow" is further investigated due to its immediate accessibility and streamlined process of implementation into Processing (reference is made to section 5.2.4.3 "Optical flow in Processing: OpenCV Library").

2. Optical flow detection

Optical flow[1] is heavily used in robotics for image processing and navigation control including motion detection, object segmentation, time-to-contact information, luminance, etc. An easy to understand example is in obstacle detection for cars with parking-assistance. In summary, optical flow gives us the information related to the direction of movement of an object as a value, which can then be used as part of Processing to introduce an "if statement" that, using the values from the received optical flow, tells the dynamic light pattern to act according to its defined instructions.

Figure 64. Example of optical flow sensor. (Courtesy of AliExpress seller).

In comparison with other available sensors for motion detection

1 Optical flow is the pattern of apparent motion of objects, surfaces and edges caused by the relative motion between an observer and a scene.

for implementation in outdoor lighting (such as the IR sensor), an optical flow sensor has a higher detection accuracy and is thus more suitable for multi-use scenes (Aslani & Mahdavi-Nasab, 2013). Optical flow sensors are also heavily utilized in traffic cameras to, for example count the number of moving vehicles and their direction (see Figure 64 on the previous page).

For our interactivity model, optical flow can match the requirements. To trigger the desired interaction, we need to know an average degree of movement and direction, which is suitable for spaces where more people can interact at the same time. Creating an average optical flow value can thus limit a chaotic interactivity.

5.2.4.2 Potential technology to capture optical-flow: brief analysis

For physical application in an urban space, an optical flow sensor would suffice in reading the optical flow and triggering the interaction. However, for carrying the test in the controlled environment, several other technological options were investigated, since an optical flow sensor would have required unnecessary extra work with an Arduino board. Below the Kinect sensor, Zed Camera and typical webcam are investigated as potentials for replicating the study I carried. All of them are suitable solutions to use in a controlled environment.

1. Kinect

Kinect is a sensor which allows the users to interact with a computer using gestures. It is capable of tracking your entire body and can be easily connected to Processing through one of the available libraries, such as OpenKinect. In addition to functioning like a typical web-came, the Kinect also provides a depth map. What

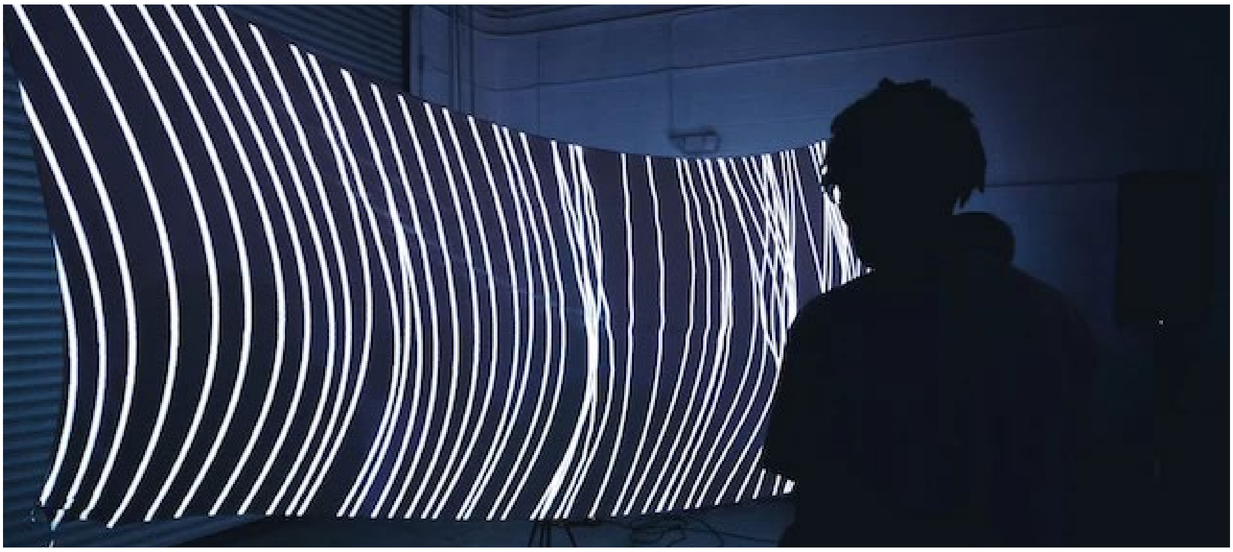


Figure 65."Strings", a light projection that uses the Kinect sensor to interact with the users. When presence is sensed, the lines "wiggle", following the user. The art was generated using Processing. (Courtesy of Eccoscreen.xyz)

this means is that for every pixel identified, the Kinect measures distances from the sensor (Shiffman, n.d.). Once the data from the Kinect can be easily understood in Processing, many other fun applications can be developed such as skeleton tracking and many forms of interactivity (see Figure 65).

Although it is a highly complex motion-tracking solution with vast capabilities and existing applications at the edge of media-technology and lighting, Kinect still has difficulties in properly tracking a high number of users at the same time. With this consideration in mind, Kinect is more appropriate for small applications – such as interactive media walls rather than full-scale urban lighting. Still, for the scope of the test, in which only one person at a time is asked to interact with the fixture, Kinect would have sufficed. However, a simpler solution that does not require a more complex installation process is to use a simple laptop webcam.

2. Zed Camera

Another example of a motion tracking device is a Zed Camera. In addition to what Kinect does, a Zed Camera has a much higher depth perception range of up to 20 meters. Furthermore, the Zed Camera is the world's fastest depth detection camera which makes it a suitable solution for a complex, dynamic environment such as an urban space. However, its price might not be feasible for massive application, as an optical flow sensor is much cheaper and smaller (see Figure 66).

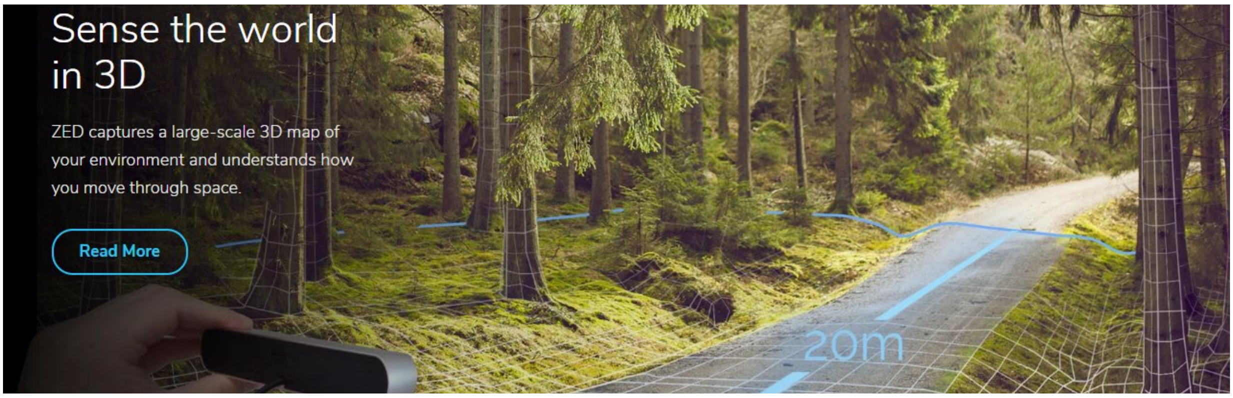


Figure 66.A Zed Camera is capable of complex and large-scale 3D mapping of the environment with a detection range of up to 20m making it ideal for urban environments. (Courtesy of StereoLabs).

3. Webcam

The most hands-on solution, effective and cheap for the purpose of testing the interaction model in the controller environment is a typical computer webcam. Since we are only interested in the optical flow values, the small resolution of the webcam is no impediment, rather an advantage to avoid lag between the webcam and the Processing sketch. The disadvantage of a typical laptop webcam is that it is not infrared, hence some background lighting is required for it to be able to detect movement. If you plan to replicate the experimentations and test but do not want to add any additional background light into your controlled environment, it is then necessary to look into a camera with infrared, such as the Kinect or Zed Camera.

5.2.4.3 Optical flow in Processing: OpenCV Library

Given its immediate availability and ease of implementation, the decision of which technology to use to generate the optical flow values, leaned towards the typical computer webcam. The laptop's webcam, a Lenovo EasyCamera was used. Processing has its inbuilt video capturing library, which can generate optical flow. An example of such a code can be found in the source code of this sketch: *https://www.openprocessing.org/sketch/84287* .

However, the optical flow example provided in the library OpenCV was found to be much more intuitive and customizable. OpenCV is an open-source computer vision library that is suitable for real-time applications due to its computational efficiency. The OpenCV library that can be downloaded and installed into Processing comes with various examples which can be used to perform an endless array of computer vision-based tasks. In the interest of the interaction model suitable for the application intended in this thesis, the Optical Flow example in the library was analysed.

OpticalFlow_testing

```
import gab.opencv.*;
import processing.video.*;
import java.awt.*;

Capture video;
OpenCV opencv;

void setup() {
  size(640, 480);
  video = new Capture(this, 640, 480); //responsible of capturing live feed
  opencv = new OpenCV(this, 640, 480); //translating the live feed
  video.start();
}

void draw() {
  scale(1);
  background(0);
  opencv.loadImage(video);
  opencv.calculateOpticalFlow();

  translate(video.width,640,480);
  stroke(255);
  strokeWeight(0.5);

 opencv.drawOpticalFlow();

  PVector aveFlow = opencv.getAverageFlow();
  int flowScale = 50;
```

Figure 67. First part of the code responsible for initiating the necessary libraries, getting the live feed and drawing the optical flow (Courtesy of the author).

```

 println(aveFlow.x);
 stroke(255);
 strokeWeight(5);
 fill(100,100*aveFlow.x,100*aveFlow.y);
 line(video.width/2, video.height/2, video.width/2 + aveFlow.x*flowScale, video.height/2 + aveFlow.y*flowScale); //draws a vector as the average optical flow
}

void captureEvent(Capture c) {
  c.read();
}
```

```
1.4752368
-1.2397645
-1.2671189
-0.7570851
```

Figure 68. Second part of the code responsible for drawing a vector line for the detected average optical flow (Courtesy of the author).

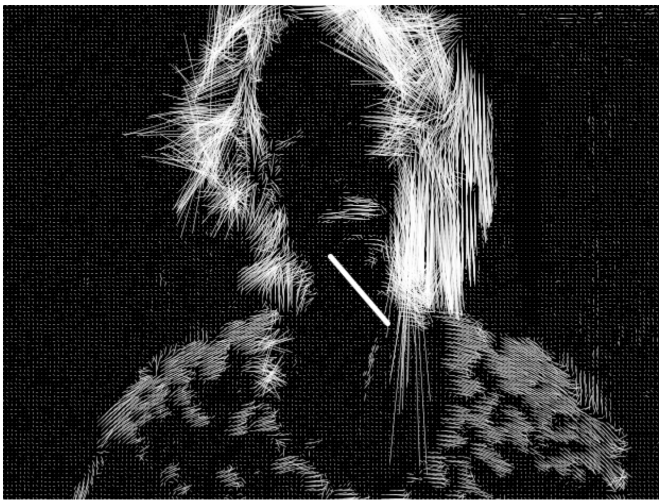


Figure 69. Visual output of the code, showing the author and the drawn vector line. (Courtesy of the author).

The example comes with a pre-loaded video example on which optical flow is detected and drawn as a vector line on the screen. The first step was replacing the pre-loaded video with a live camera feed. The first iteration of the code is broken down into the two screen grabs above for better understanding (see Figure 67 & Figure 68).

The second task was in implementing the optical flow detection code into one of the biophilic dynamic light patterns codes. For experimentation purposes, the "Pattern_1_Reaction-Diffusion" sketch was selected. The intention behind the code was to:

1. Hide the resulting optical flow real-time camera feed so it does not interact with the actual pattern.

2. Instead of drawing a vector for the detected average optical flow, to affect some of the pattern's parameters.

This was achieved over an extensive experimentation phase. In short, the values identified by the optical flow were analysed to identify which would be the minimum value to trigger the interaction, as well as the maximum one. After some considerations, a minimum value of 0.5 was selected because anything below that implied an almost non-stop triggered interaction. Due to the sketch being tested by maximum 1-2 people at a time, in an otherwise very static environment, this minimal value might need to be increased for urban application. The maximum value for the interaction to be triggered was set at 10, since values above that were not identified when experimented with. Again, this value might need to be increased for a more information-rich environment.

The final model of interaction is created on the basis of calculating the optical flow and introducing the following "if-statement":

```
PVector newFlow = new PVector(abs(aveFlow.x), abs(aveFlow.y));

 if (0.5 < newFlow.x && newFlow.x< 10) {
```

5.2.4.4 Proposed interactivity model

Click here for a video demonstration of the proposed interactivity model.

When the optical flow is in between these two values, the following actions take place:

1. The colour/intensity of the pattern changes. Though the change is instantaneous, the effect fades out as the user steps away from the camera and hence the optical flow values drop below the minimum threshold of 0.5. The fade is possible using a function called "boolean" in Processing, which has a true/false value.

```
if (0.5 < newFlow.x && newFlow.x< 10) {
  // set boolean to true when user triggers interaction
  startFade = true;
  // reset starting fading amount
  fadingAmount = 150;
```

The above code is accompanied by an additional "if statement" that draws a vector of another colour, set with transparency to change the colour of the pattern.

```
if (startFade) {
  // set color with fadingAmount
  fill(0, 50, 255, fadingAmount);
  noStroke();
  rect(0, 0, 1366, 768);
```

```
    // decrease fadingAmount
    fadingAmount -= 2;
    // if fadingAmount is 0, set startFade to false and cancels this 'if-statement', and wait for a new user trigger
    if (fadingAmount <= 0) startFade = false;
  }
```

2. The speed of change in the pattern. The same "boolean" function is used to make the changes in the speed. A similar fade out property is applied to create the smooth interaction.

3. For some of the patterns (e.g. "Reaction Diffusion"), the complexity/scale factor was also influenced by the trigger. This was not possible to implement in all sketches because regardless of the fade amount, the change in scale was very unnatural so it was decided to only selectively use the change in complexity/scale on those patterns on which it had a positive visual effect.

Overall, the interactivity model implies that a user, or several of them can walk in front of the webcam and see the triggered interaction instantaneously on the screen. As they walk away, the effect fades out and waits to be triggered once more by another user.

5.3 Experimentation phase using gobo projectors

One medium-beam Exterior Projector 500 (hereafter referred to as EP500) from Martin Professional was used to carry some basic experiments. The scope of these experiments was to identify the potentials of the gobo projector to create abstract biophilic visuals using only the standard gobos that come together with the projector and the available controllable parameters. Gobo projectors are very resilient and on the long-run, cheaper to implement in urban spaces as public illumination. However, with video projectors, the artwork is fast and easy to implement, while with gobo projectors the artwork first needs to be printed on either steel or coated glass. This entails an additional cost of approximately 2.000-2.500 dkk/gobo.

The EP 500 can be controlled using Martin's digital DMX controller "M-PC", through a Martin USB-to-DMX device that can then be connected straight to the projector. For controlling several projectors at once, a DMX splitter is required. However, in order to address each fixture individually, an ArtNet DMX interface is needed. For experimentation, I only had access to a DMX splitter without the ArtNet interface, which made it quite difficult to experiment with multiple projectors and control them individually. Therefore, this section will show the possibilities using only one projector.

5.3.1 Controllable parameters

The EP500 comes with the following effects / controllable parameters:

• Strobe / shutter function: allowing for ON/OFF and SLOW/FAST shutter effect.

• Dimming: going from 0% to 100%.

• Colour wheel: pre-set to Red, Magenta, Yellow, Green, Dark Blue, CTO, Cyan and Orange, as well as the possibility to rotate the wheel be-

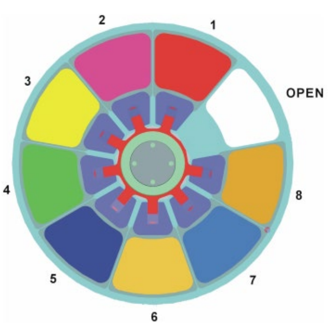


Figure 70. Colour wheel in-built into the EP500. (Courtesy of Martin Professional).

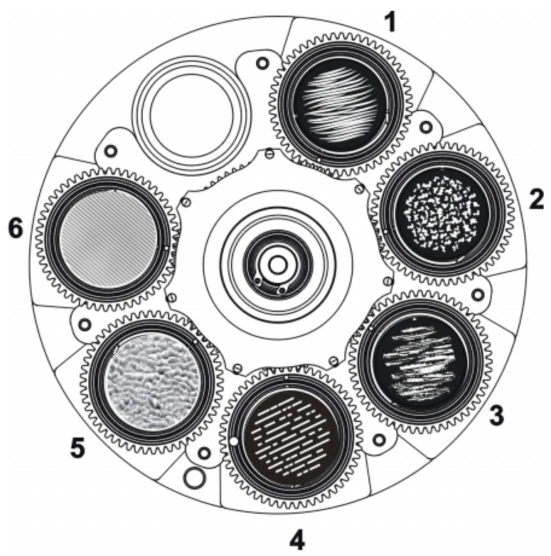


Figure 71. The in-built rotating gobo wheel inside the EP500, as well as the 6 standard gobos used for experimentation. (Courtesy of Martin Professional).

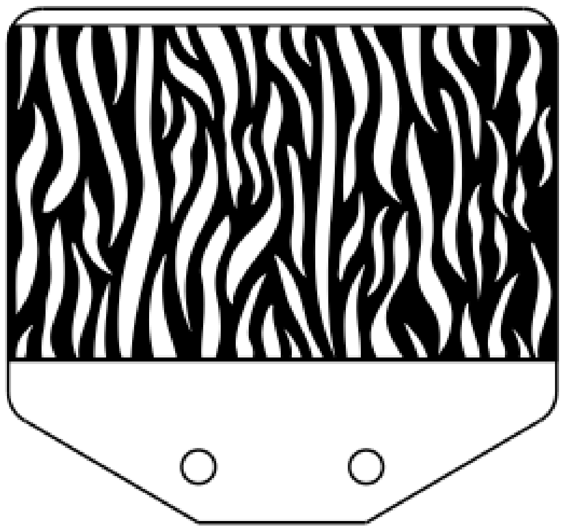


Figure 72. Animation disk in-built into the EP500. (Courtesy of Martin Professional).

tween colours and create "split-effects" (see Figure 70 on the previous page).

• Gobos: "Grass Lines", "Organic Delight", "Brush It", "Light Lines", "Ripple Structure Glass", "Lined Effect Glass". The gobos can be rotated or set to an indexed position, allowing for precise mapping as shown at the beginning of this thesis (see Figure 71).

• Animation effect: Is an in-built template that can be used together with the gobos and colours to create dynamic effects. Though limited, basic movement effects mimicking flames, wind and water can be achieved rather easily (see Figure 72).

• Prism: The fixtures comes equipped with one 4-faced and one 3-faced prism that can be rotated and deployed to split the beam into multiple facets.

• Frost: Frost levels going from 0% to 100% can be deployed, however not simultaneously with the "prism" effect.

• Focus: Let's you adjust the sharpness of the projection. A very sharp value is more appropriate for precise mapping, while the diffuse value can create more abstract shapes.

5.3.2 Resulting effects

Below, various iterations are displayed showing how the various parameters can affect the visuals. Three abstract biophilic effects together with the respective values for each parameter are displayed at the end. This represents a framework for how personalized 2D artwork can be incorporated and altered using the in-built parameters.

Click on each title for video demonstration.

1. Wind-blown grass effect | 2. Flames effect | 3. Water movements effect | 4. Other experiments

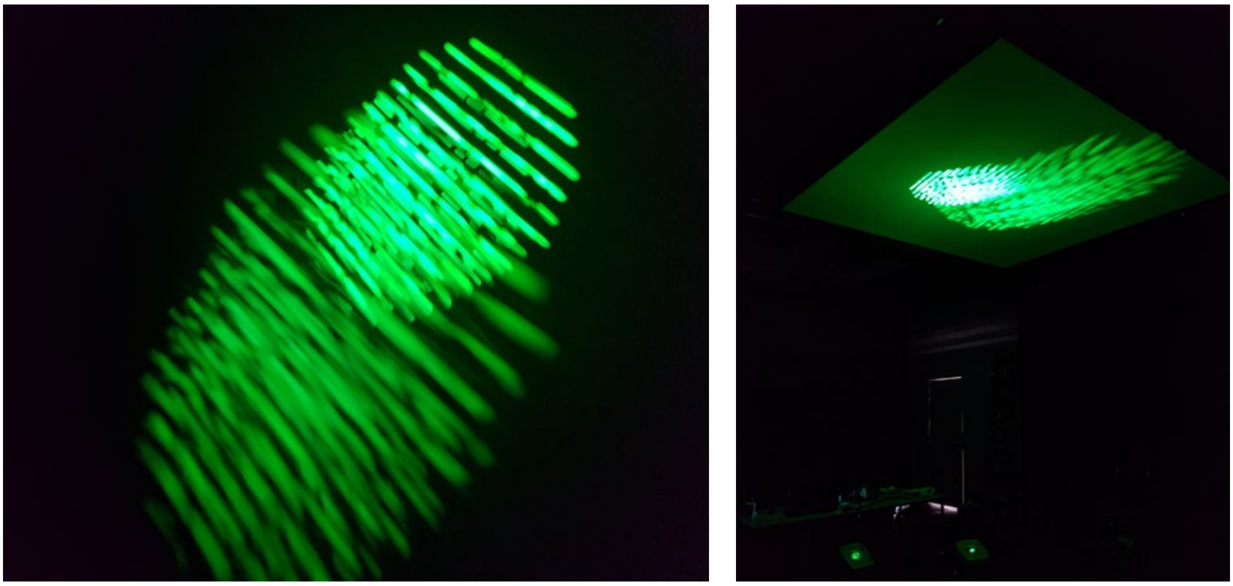
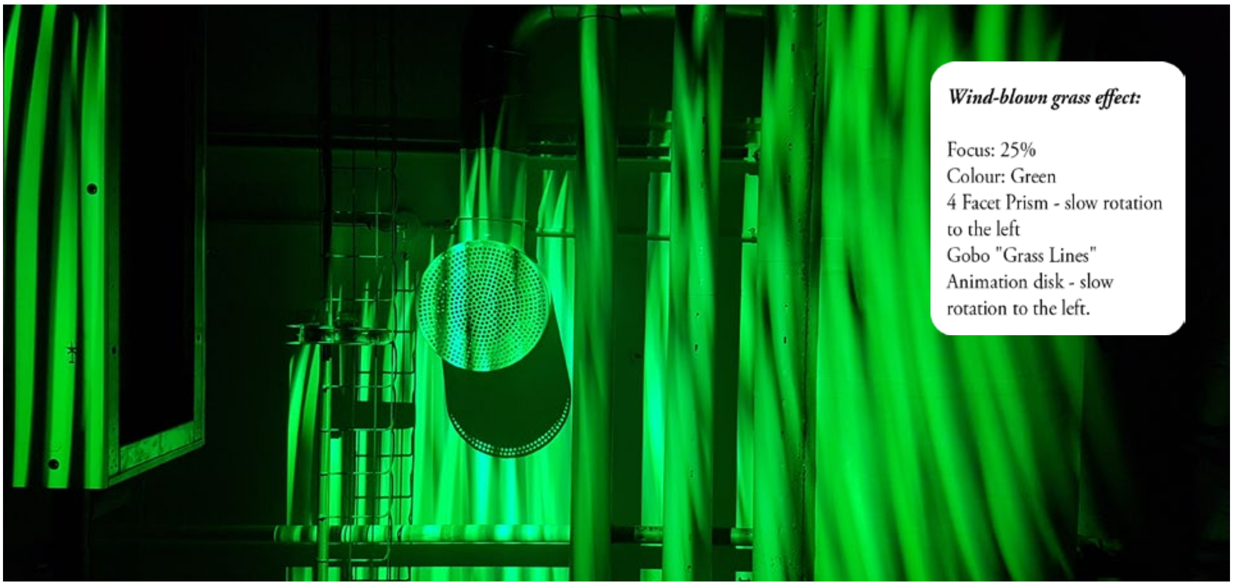
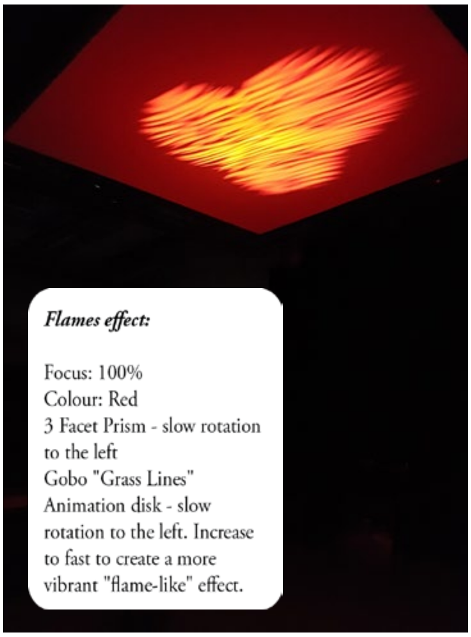


Figure 73. Photos of the "Wind-blown grass effect", using both available projectors. (Courtesy of the author).





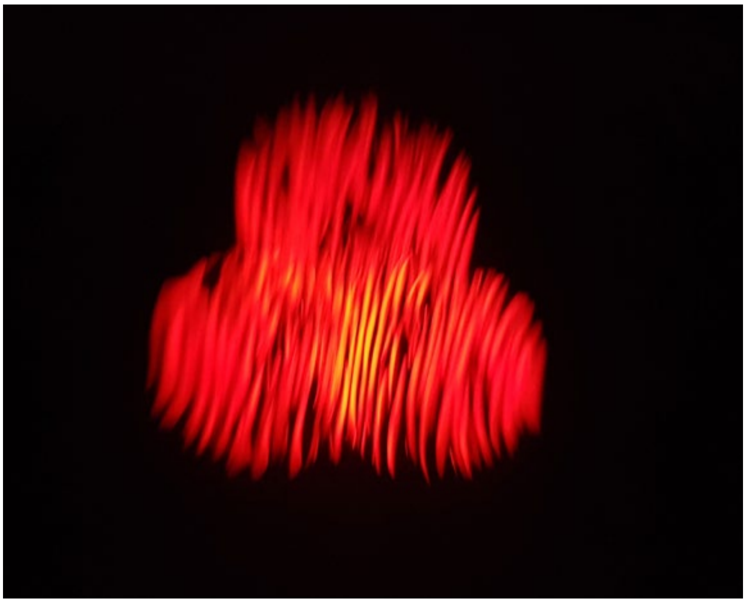


Figure 74. Photos of the "Flames effect". (Courtesy of the author).

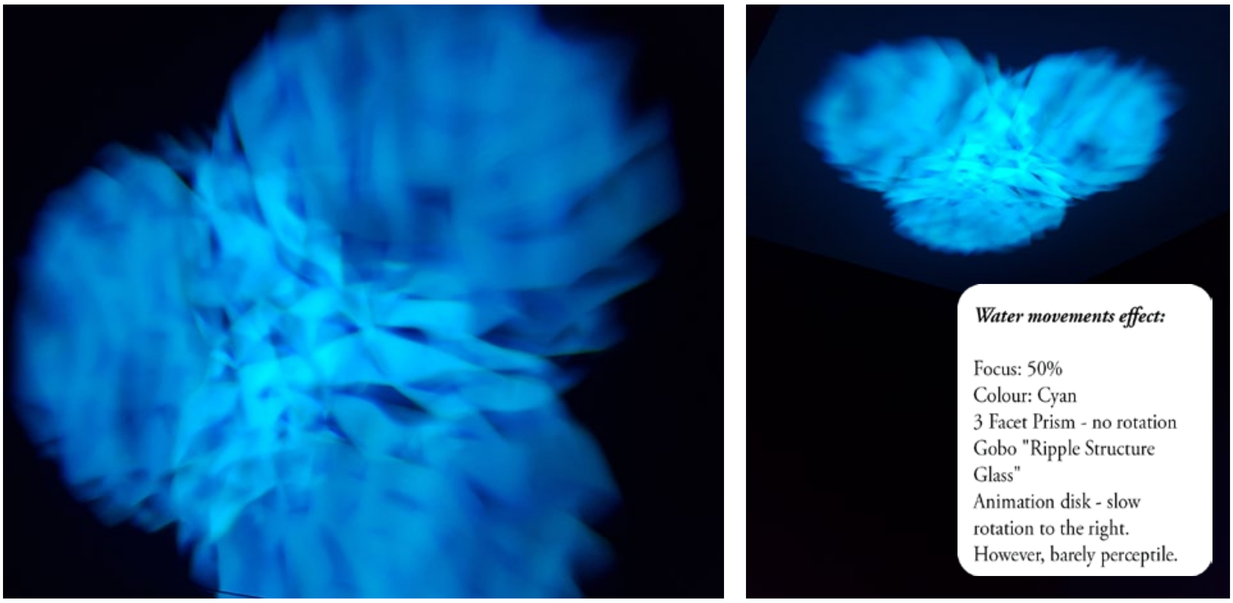


Figure 75. Photos of the "Water Movements" effect. (Courtesy of the author).

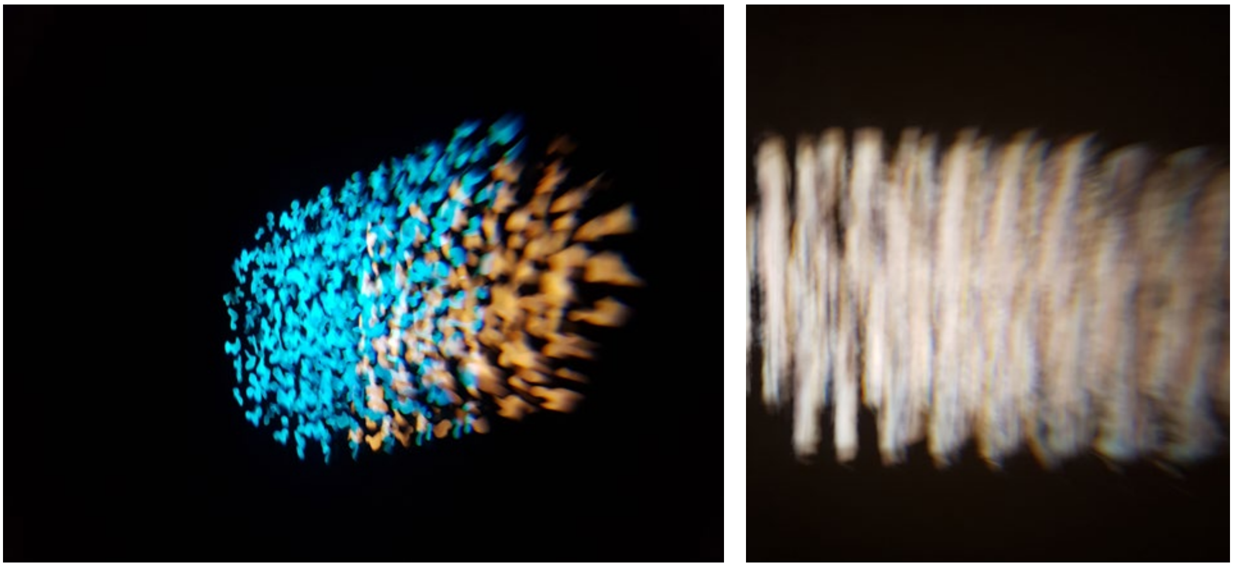


Figure 76. Above more photos of the experimentation phase using the gobo projectors. (Courtesy of the author).

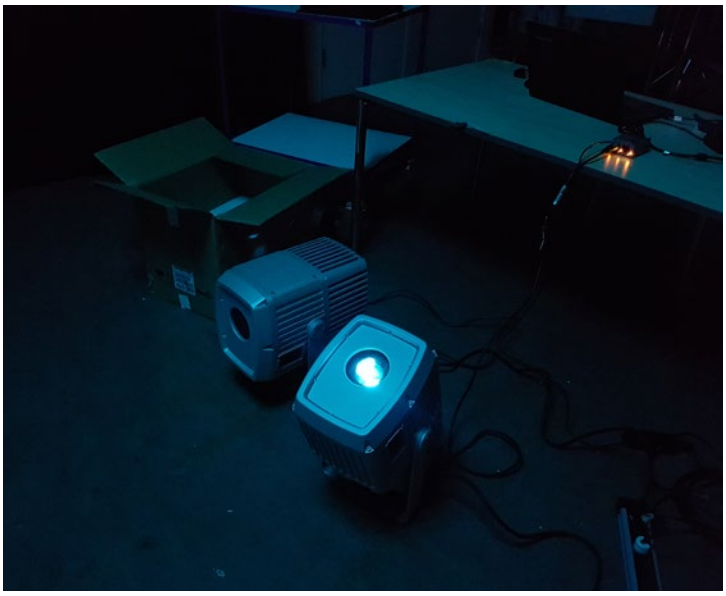


Figure 77. The EP500 projector in action during the experimentation phase. The movable bracket allows to rapidly change projection angle.

5.4 Recommendations for creating and implementing biophilic dynamic light projections

CREATION

Option 1:

Advantages: creative freedom, experimentation is fast and easy, full controllability of proposed parameters.

Disadvantages: requires some coding experience, more applicable for small implementations, rather than full-scale urban lighting, powerful outdoor video projectors are very expensive.

Option 2:

Advantages: suitable for full-scale urban implementation, resilient, energy-efficient

Disadvantages: immediate experimentation with created effect not possible, additional costs for printing design as gobo, limited dynamic behaviour.

Recommendation depends on the scale of the implementation.
Small-scale: option 1
Large-scale: option 2

TECHNICAL IMPLEMENTATION

To generate interactivity:

Optical-flow sensor: reliable and high accurancy. → Recommended regardless of scale due to price and effectivness.

IR sensor: good but not as accurate.

Zed Camera: great quality, suitable for dynamic environments but expensive for mass implementation.

Chapter 6

Test

6.1 Hypotheses

Throughout this research, a few simple hypotheses were raised in response to intriguing or contradictory scientific findings – some form the basis of this scientific test. Considering the complexity of implementation of dynamic light projections, there are many possible parameters to consider: e.g. colour, spatial placement, intensity of the light source, etc. However, of interest in this test are "complexity", "speed of change" and "interactivity". This is a 1st step-proposal in what can be a more extensive study on the various other parameters of biophilic dynamic light projections that can have an impact on the perceived atmosphere of a socially-inactive urban space.

This test is necessary to create the design framework for using biophilic dynamic light projections in spaces with a low level of attractiveness. It is intended to provide some valuable knowledge on fine tuning the proposed parameters to what people perceive as more pleasant. The findings are then expected to work as the foundation for any interested party to apply them on their given space. However, it is important to stress that this thesis and test do not analyse and deal with the exact properties of a chosen place, but rather with generalities common to all socially-inactive urban spaces (findings taken from relevant literature in the field). The findings both of this test and of the thesis in general should be read as guidelines/framework for working with biophilic dynamic light projections in spaces with similar properties to our proposed context. Further analysis into your given space might shed light on aspects relevant to the choice of underlying pattern, spatial placement of the pattern and behaviour of users that might influence the interactivity model.

To build a holistic, robust test, four hypotheses were proposed:

I. Overall, biophilic patterns have a more *positive effect* on the atmosphere of a space compared to non-biophilic patterns.

II. *Increasing the "complexity"* of the biophilic dynamic light projections has a *positive effect* on the perceived atmosphere of the place - making it more cosy, pleasant/hospitable and relaxing.

III. *Increasing the "speed of change"* of the biophilic dynamic light projections has a *negative effect* on the perceived atmosphere of the place - making it less cosy, pleasant/hospitable and relaxing.

IV. *Adding interactivity* to the biophilic dynamic light projections has *potential in positively affecting* the perceived safety and overall perception of an urban space.

6.2 Applied Methods

6.2.1 Evaluating perceived atmosphere

To investigate the effect of the patterns and how changing the values of some of their parameters influences the atmosphere of a space from the perspective of the users, a study was carried to identify relevant measuring methods. Though the notions of "perception" and "atmosphere" signal qualitative research, I was interested in gaining quantitative data in order to draw significant and applicable conclusions. On "perceived atmosphere", Ingrid Vogel's "Atmosphere Metrics" methodology seemed to match the formulation of the hypotheses presented earlier. Vogel's methodology compromises of a series of adjectives most prevalent in describing the perceived atmosphere of a place under different light scenarios. Developed as part of an initial study in which a significant number of participants were asked to describe the atmosphere of a given space with their own words, Vogels et all. (2017) compromised the findings into a table of 38 usable terms. These are both negative and positive terms, grouped into 4 major dimensions: cosiness, liveliness, tenseness and detachment (Stokkermans, Vogels, de Kort, & Heynderickx, 2017). The method involves using these adjectives together with either a 5 or 7-point Likert scale (depending on the level of change between the viewed scenarios) in the form of a questionnaire given to the participant.

Several lighting design studies since then have used shorter versions of their atmosphere metrics questionnaire to help understand the effect of different light scenarios on the perceived atmosphere of a space.

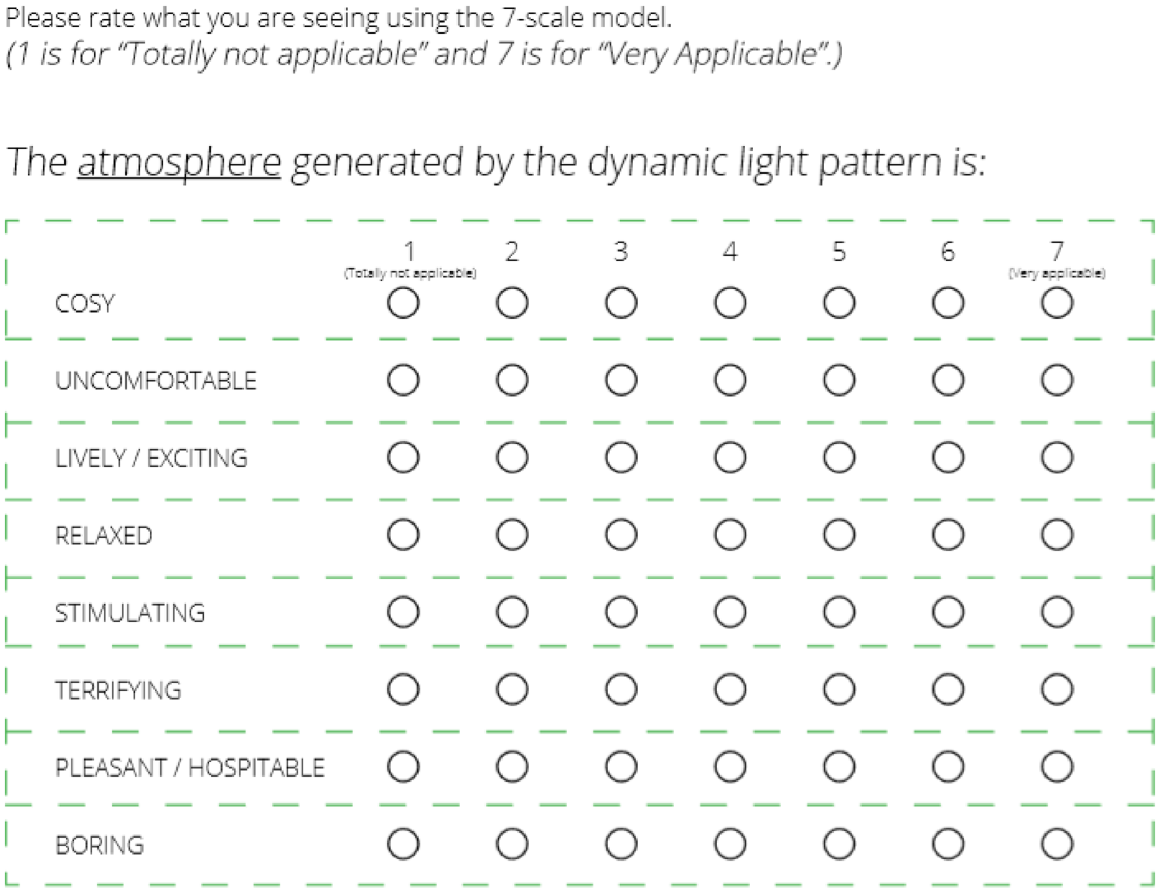
Final questionnaire (see Figure 78 on the next page).

To minimize the duration of the test and maintain a steady level of interest throughout the long list of visual stimuli presented, 8 adjectives were selected from Vogels et all.(2017)'s adjective list. This list contains negative, positive and neutral/situational adjectives together with a 7-point Likert scale for assessment. Given the low-medium-high scenarios for each parameter, the 7-point Likert scale was considered more appropriate compared to the 5-point scale alternative. This is to give the participants a wider range of possibility to express differentiation (if any) between the three variations. A 5-point scale could have potentially yielded unsatisfactory results and reliability in a case where the participant is subjected to this extent of variability (Colman, Norris, & Preston, 1997).

The final list of selected adjectives is:

Positive	Negative	Neutral / Situational
cosy	uncomfortable	stimulating
relaxed	terrifying	lively/exciting
pleasant/hospitable	boring	

"Stimulating" and "lively/exciting" were categorized as "neutral/situational" because they can, depending on the situation and context, generate negative, unnecessary feelings of anxiety, fear, over-stimulation and excitement, possibility that is not further explored as part of this test.


Please rate what you are seeing using the 7-scale model.
(1 is for "Totally not applicable" and 7 is for "Very Applicable".)

The atmosphere generated by the dynamic light pattern is:

	1 (Totally not applicable)	2	3	4	5	6	7 (Very applicable)
COSY	○	○	○	○	○	○	○
UNCOMFORTABLE	○	○	○	○	○	○	○
LIVELY / EXCITING	○	○	○	○	○	○	○
RELAXED	○	○	○	○	○	○	○
STIMULATING	○	○	○	○	○	○	○
TERRIFYING	○	○	○	○	○	○	○
PLEASANT / HOSPITABLE	○	○	○	○	○	○	○
BORING	○	○	○	○	○	○	○

Figure 78.Final questionnaire asking the participant to rate the "atmosphere" generated by what they were seeing as part of the experiment.

6.2.2 Usability test

An assessment questionnaire in the form of four usability and applicability questions was developed for the last part of the test in which the interaction model is evaluated. The interest is in evaluating the interactivity model from a simple user-product perspective and its application in a given context.

A "usability test" method is a reliable technique generally used in the testing of user-centred interactive design. This is a valuable approach because it provides immediate information as to how the persons use and evaluate the system. The first two questions of this questionnaire are therefore addressing the usability of the interaction model. The scope is to understand if it works as intended or if it might need further adjusting. Again, a 7-point Likert scale was combined with the questionnaire. However, after the test, I believe a 5-point scale would have sufficed for this type of questionnaire. The intention was though in preserving a level of uniformity to avoid confusion.

Usability questions:

1. I was immediately aware of the change in the light pattern: *Totally disagree (1) – Neither agree nor disagree (4) – Totally agree (7).*

2. It is very intuitive that the change in the light pattern is generated by my own movements: *Totally disagree (1) – Neither agree nor disagree (4) – Totally agree (7).*

In addition to the usability question, two additional questions about the applicability of the interaction model in an urban space and its effect on perceived safety and overall atmosphere and experience were added. This was done in order to address the proposed hypothesis and understand the value-add of the model.

Applicability questions:

1. Interactivity with urban lighting has a positive effect on how I assess the safety of an urban space: *Totally disagree (1) – Neither agree nor disagree (4) – Totally agree (7).*

2. Interactivity with urban lighting has a positive effect on my overall experience and perception of the urban space: *Totally disagree (1) – Neither agree nor disagree (4) – Totally agree (7).*

6.3 Final selection of biophilic patterns

For this test, only Processing-based biophilic patterns were selected. This is because with gobo projectors, the process of modifying parameters is slightly more time consuming, hence it would have prolonged the test time. Furthermore, the impossibility of implementing interaction with the gobo projectors due to lack of equipment and knowledge, was also a major contributor to this decision. Therefore, to carry the test, the following Processing sketches were selected:

Biophilic patterns with controllable "complexity" and "speed of change" parameters (click on each for a video showing the various tested iterations):

Sketch_1_Reaction Diffusion | Sketch_2_Perlin Heat Map | Sketch_3_Plasma | Sketch_4_Abstract Zebra Stripes | Sketch_5_Particles | Sketch_6_Celullar Noise | Sketch_7_Sky

Biophilic patterns with implemented "interactivity" – only for a limited number of patterns the code for interactivity was used as the underlying pattern was not of interest in this task. However, to avoid bias, we needed more than one to randomize between the participants:

Interactive_sketch_1_Reaction Diffusion | Interactive_sketch_2_Perlin Heat Map | Interactive_sketch_3_Plasma | Interactive_sketch_4_Abstract Zebra Stripes

Click here for a video demonstration of the interactivity model.

Non-biophilic patterns to set the baseline and answer the 1st hypothesis. These sketches were taken without any further editing directly from openprocessing.org. Credit is given within the code and below each figure to its respective author (click on each to view the pattern):

- *Non-biophilic_Pattern 1*
- *Non-biophilic_Pattern 2*
- *Non-biophilic_Pattern 3*
- *Non-biophilic_Pattern 4*

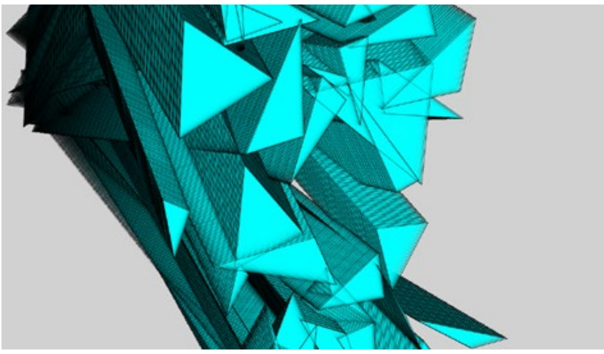


Figure 80. Non-biophilic_Pattern_1

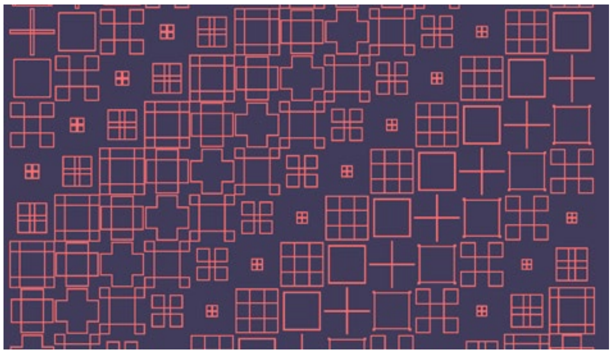


Figure 81. Non-biophilic_Pattern_2

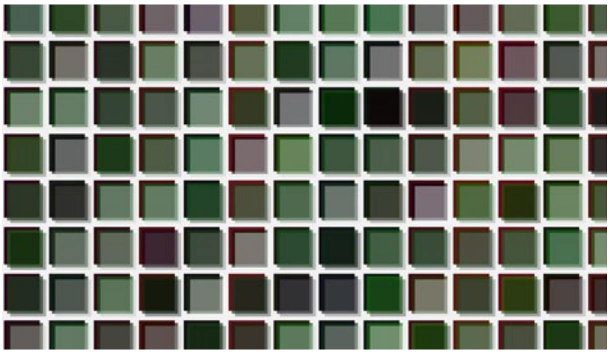


Figure 82. Non-biophilic_Pattern_3

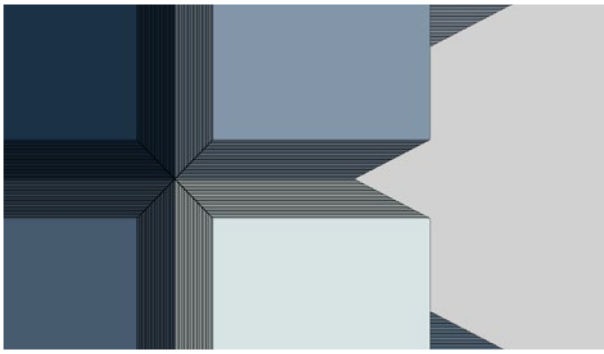


Figure 83. Non-biophilic_Pattern_4

6.4 Experimental Room

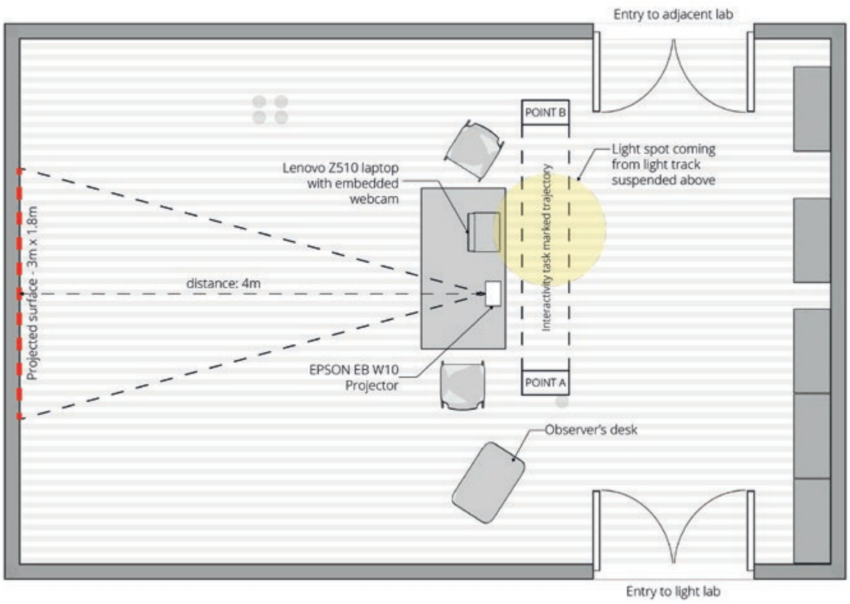


Figure 79. Illustration showing the set-up of the experimental room for the duration of test. (Courtesy of the author).

The experiment took place in the LightLab located in the main building of Aalborg's University Copenhagen Campus. The room is roughly 5.5m in width and 8.5m in length with a ceiling height of approximately 3.5m. The standard set-up of the room is very simple, with only a few cupboards located on the right-hand side and a light track suspended above the left side of the room. For the test, a minimal reshuffling was necessary. The experimental room included a table, two chairs, a standing desk for the observer to perform the required tasks, a marked trajectory on the floor for the interactivity task, and the projector and laptop (see Figure 79).

6.5 Procedure

The final test compromised of 5 distinct tasks, which are described in detail in the following sections. In total, 23 participants aged between 20-35 participated in the test. The majority of them were students at various programs at Aalborg University Copenhagen (e.g. lighting design, civil engineering and medialogy). A handful of them were working in the field of architecture and only 2 of them were working in unrelated fields (business and sustainability). The test was carried over the course of two days: May 8th and May 10th 2018 between 9:00AM and 5:00PM.

6.5.1 Test & Context Introduction

The test started with an introduction of the tasks, the scope of the test and the context. Given the circumstances and location of the testing (the light lab at AAU CPH), a proper visual and verbal introduction of the context was required to put the participants into the proper mindset for assessing the atmosphere. To achieve this, the participant alone was invited into the room. As a start, a series of photos depicting socially-inactive, unattractive urban spaces were shown on the projection surface indicated in section 6.4 (see Figure 84). At the same time, the observer read the following text:

"The scope of this test is to evaluate the atmosphere created by using nature-inspired patterns as public illumination for places in our cities that are not very attractive and that lack social activity. Imagine you are walking through such a place: you might already have an example in your mind – it might be a space that offers nothing to attract you, it's usually not very dynamic and you might just use it to get from A to B. You have little to no reasons to stop and it's not the type of place you would voluntarily hang out in. The photographs you see in front of you are examples of such urban places. Please keep this in your mind for the tasks that follow. You will be asked to rate the atmosphere created by a series of dynamic light patterns. Imagine their use in such places when you assess the atmosphere."

Figure 84. Above some of the examples of socially-inactive urban spaces shown during the context introduction. (From top left to bottom right: UrbanFinland.com, Kirkearkitektur.dk, Urbanspacearchive.com, Publicspace.org).

In addition to the above, they were instructed that the test involved filling up a series of rating questionnaires for each iteration shown by the observer. They were free to ask questions and free to either sit or stand for the duration of the test.

To constantly remind them of the context shown at the beginning of the test, paper prints of the socially-inactive urban spaces presented were placed on the table in front of them.

6.5.2 Fine tuning evaluated parameters: tasks 1, 2, 3 and 4

The rating questionnaire presented as part of section 6.2.1 was used for the first 4 tasks of the test. In total, 7 copies of this questionnaire were handed to the participant at the beginning of task 1. For each participant, a different Processing sketch was used for every task on a random basis. However, the test was carried in the same sequence of tasks for each participant – whether this generated some bias is unexplored at this point.

6.5.2.1 Task 1

The test started with establishing a baseline. This was done by displaying a non-biophilic pattern on the projected surface. The participant had as much time as needed to observe the pattern and fill-up the rating questionnaire. Once done, the participant had to hand in the completed questionnaire to the observer and be ready to move to the following task. For each of the rating questionnaires, the observer had the task of filling in information regarding the evaluated task and name of the Processing sketch rated (see Figure 85).

BELOW TO BE FILLED BY THE OBSERVER NOT PARTICIPANT:

Underline the evaluated parameter:
non-biophilic pattern / complexity 1 / complexity 2 / complexity 3 / speed 1 / speed 2 / speed 3

Selected underlying pattern: ....

Figure 85. Bottom of the rating questionnaire the observer had to fill in for each task.

6.5.2.2 Task 2

To complement task 1, a biophilic pattern randomly selected from the database presented in section 6.3 was selected. On the basis of this pattern (set at its generic state: low complexity and speed of change), the participant had once again to reply to the rating questionnaire and follow the same procedure as with task 1.

6.5.2.3 Task 3

For task 3, parameter "complexity" was investigated. Of importance is that the other two parameters "speed of change" and "interactivity" were not influenced as part of this task and thus remained in their generic state: low speed of change and interactivity OFF.

Using the same selected biophilic pattern from task 2, which the participant already rated in its generic state, the observer proceeded to perform the following changes:

• Increase “complexity” to medium and ask the participant to rate this scenario using the same procedure.

• After this was finished, move to increase the “complexity” to high and again ask the participant to perform the same rating exercise.

6.5.2.4 Task 4

For task 4, parameter “speed of change” was investigated. A new biophilic pattern was randomly selected and the participant subjected to its three different values for speed of change one at a time.

The same procedure as with task 3 was performed.

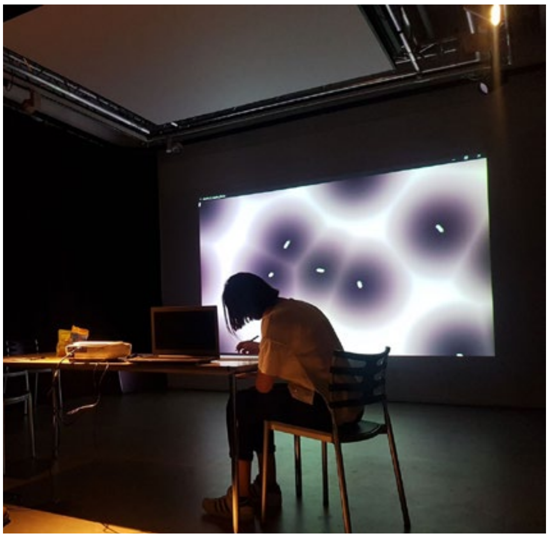


Figure 86. Photo of one of the participants filling in the rating questionnaire for one of the tasks.

6.5.3 Usability of the interactivity model

For the last task of the test, the participant was asked to position himself at the point marked as “Point A” seen in section 6.4.

In the meantime, the observer randomly picked one of the Processing sketches with embedded interaction. Once the sketch initialized properly, the participant was asked to walk at his normal speed to the opposing and perpendicular point marked “Point B”. In reply to where to look at during this task, the observer instructed the participant to act naturally but remain aware of the projected surface.

The trajectory marked on the ground forced the participant to pass in front of the laptop and through the spot of light directed in front of the device. However, the laptop’s screen was turned off, therefore the participant was not aware of its immediate implication in the task.

As soon as they walked the trajectory from A to B and B to A, the participant was handed the four questions on a piece of paper and asked to read them. They were also instructed that if needed, they could walk the trajectory again. As soon as they were able to answer them, the test was finished and the participant thanked for his/her involvement. In total, the duration of the test was approximately 15 minutes / participant.

Figure 88. Photo of the experimental room and the pattern "Sky" displayed on the projection surface.

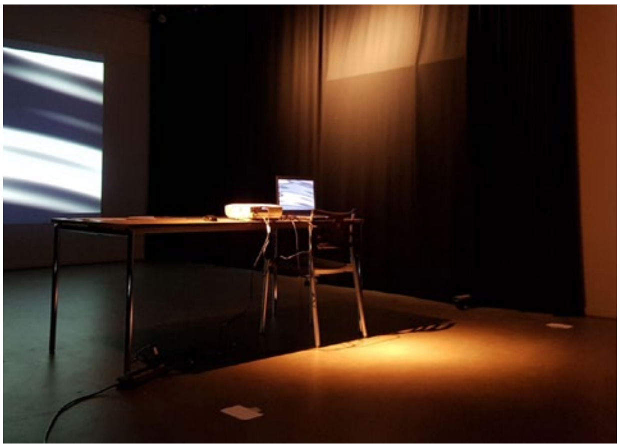


Figure 87. Photo showing the "light spot" and walking trajectory for the interactivity task.

6.6 Results

6.6.1 Setting a baseline: non-biophilic vs biophilic patterns

To understand the differences between the perceived atmosphere ratings when exposed to non-biophilic patterns as opposed to biophilic patterns, averages of the 7-point Likert scale for each adjective were drawn from the data file. For the non-biophilic patterns this was straight-forward, while for the biophilic patterns the ratings were taken only for those times when the patterns were set to their generic state (low complexity, low speed of change and no interaction). The final ratings in average Likert scale values are shown in (see Figure 89).

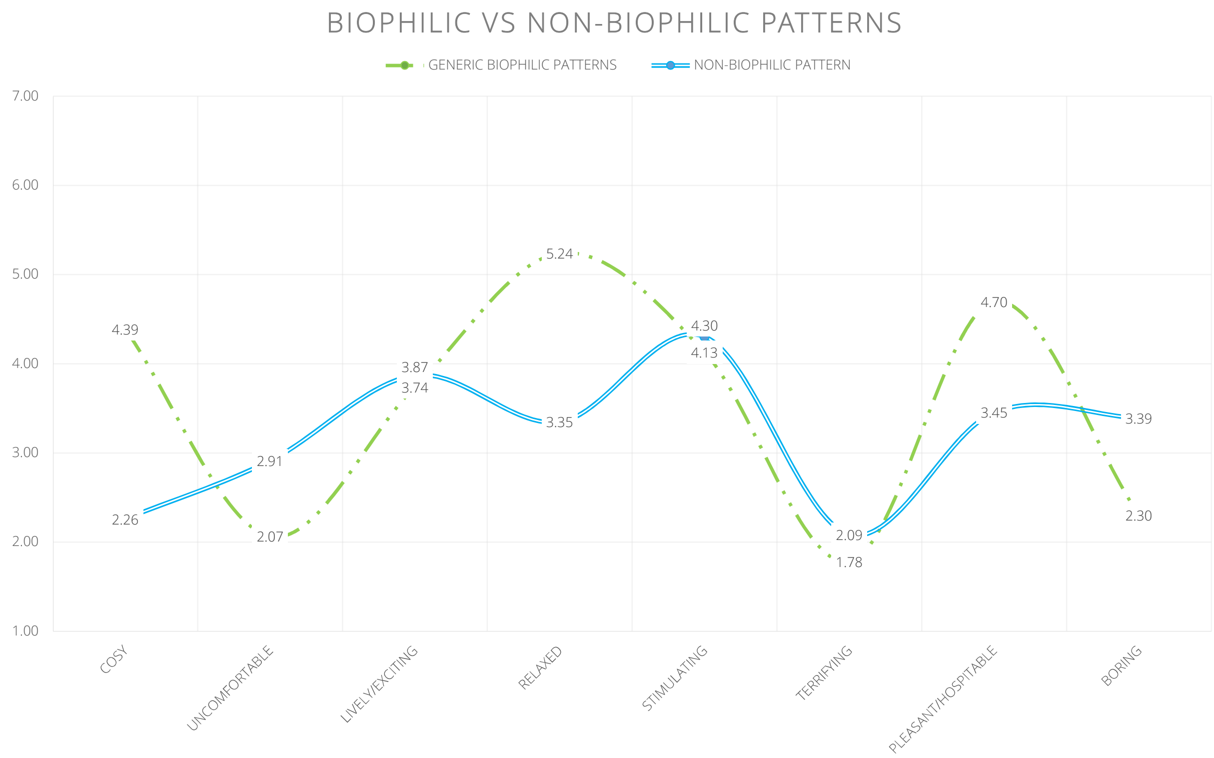


Figure 89. Graph showing the perceived atmosphere rating for biophilic patterns (marked in green) and non-biophilic patterns (marked in blue). The numbers are averages of the 7-point Likert scale.

The results clearly show that for the positive adjectives: cosy, relaxed, pleasant/hospitable, the degree of agreement/applicability is on all three of them higher for biophilic patterns compared to non-biophilic patterns. For the negative adjectives: uncomfortable, terrifying and boring, we can see a predominant disagreement/inapplicability for both the biophilic and non-biophilic patterns. However, for the "boring" parameter, there is some difference between the two types of patterns, with non-biophilic ones being rated as creating a more boring atmosphere. The highest rating difference is seen in the adjective "cosy" where there is a clear 2.13 points increase between the two types of patterns. As clearly shown, the results help us conclude that overall, the biophilic patterns have a more positive effect on the perceived atmosphere of the space. This comes to accept the proposed hypothesis:

"Overall, biophilic patterns have a more positive effect on the atmosphere of a space compared to non-biophilic patterns."

This claim is also strongly supported as part of the analysis section of this thesis in all of the investigated publications.

6.6.2 Complexity: perceived atmosphere under low-medium-high complexity

To understand the effect different levels of complexity have on the perceived atmosphere of the space, a similar average value was calculated for each adjective under low, medium and high complexity levels. The data was then tabulated and can be visualized in (see Figure 90).

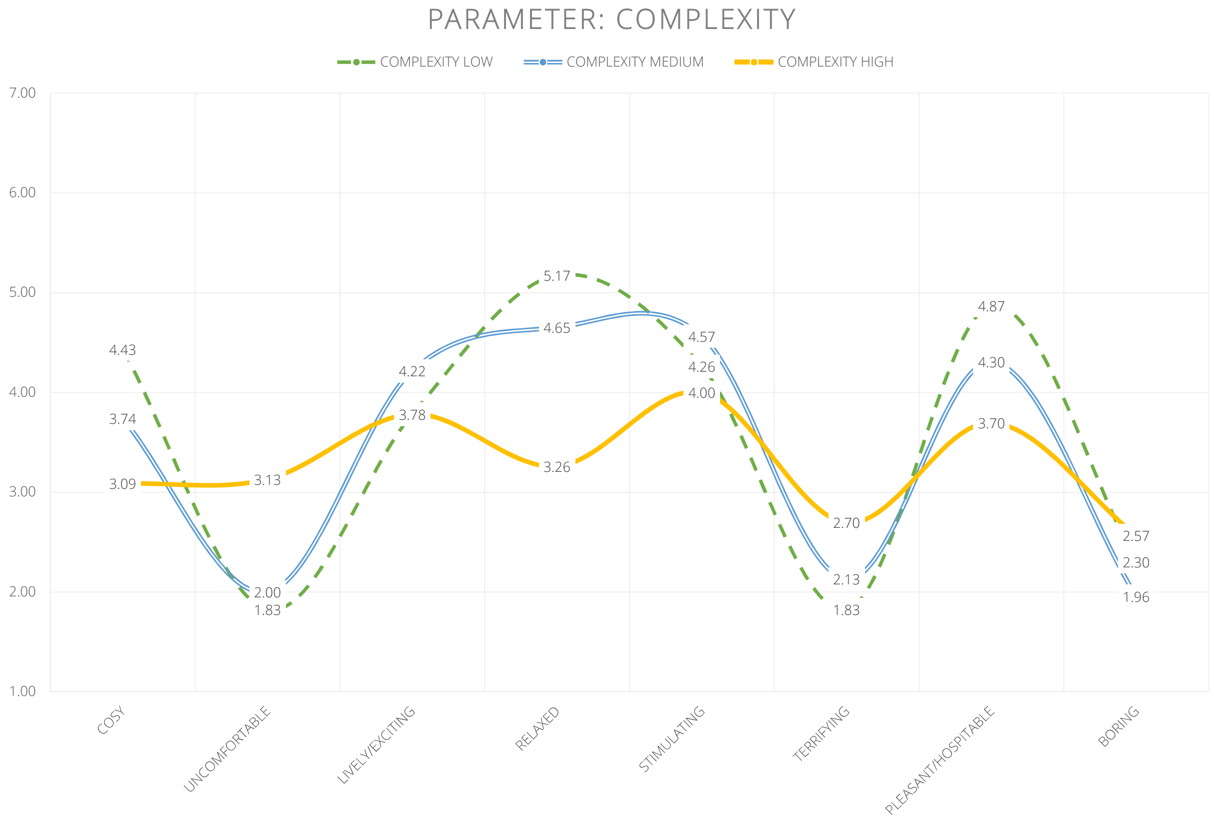


Figure 90. Graph showing the differences in perceived atmosphere for each adjective under the 3 different complexity levels: low-medium-high.

When considering the positive adjectives: cosy, relaxed and pleasant/hospitable, the results show that for complexity set at "low" the ratings are most applicable, while at the opposite end, for complexity set at "high" the ratings for the positive adjectives are much lower on the Likert scale.

For the adjective "cosy":

To calculate the statistical significance, a one-way ANOVA was performed for the adjective "cosy" for the 3-complexity values side-by-side. A resulting $p<0.05$ (=0.0217) shows that there is statistical significance to support an effect on the "cosiness" factor of the perceived atmosphere when changing between the different levels of complexity This implies the null hypothesis that "there is no effect on the cosiness factor at different levels of complexity" can be rejected.

A separate one-way ANOVA for the adjective "cosy" was performed only for the data gathered for low and medium complexity, as it is difficult to assess the importance of change in ratings only by looking at the graph. This yielded a $p>0.05$ (=0.1770) which proves that there is no statistically significant change in the "cosiness" factor of perceived atmosphere between the two values of complexity. The greatest statistical significance is between the low and high complexity values, with a p-value of 0.0076. This translates into a clear effect between the "cosiness" factor of the perceived atmosphere at a low and high complexity level.

For the adjective "relaxed":

A p-value of 0.0002 shows a clear correlation between changes in complexity level and effect on the "relaxation" factor of the perceived atmosphere.

For the adjective "pleasant/hospitable":

A same one-way ANOVA approach was performed for adjective "pleasant/hospitable". When looking at all 3-complexity values side-by-side, a $p>0.05$ (=0.0512) resulted. This indicates weak evidence against the null hypothesis of "no effect" for the "pleasant/hospitable" adjective. However, a separate one-way ANOVA was calculated for low and high complexity values for the adjective "pleasant/hospitable". This yielded a $p<0.05$ (=0.0161). This proves a significant effect on the "pleasantness/hospitability" factor of the perceived atmosphere when going from low to high complexity.

In conclusion, although there is statistical significance to support that there is an effect on the way the atmosphere is perceived under the 3-complexity values, the change is negative as the complexity increases. This means our proposed hypothesis cannot be accepted:

"Increasing the complexity of the biophilic dynamic light projections has a positive effect on the perceived atmosphere of the place - making it more cosy, pleasant/hospitable and relaxing.".

Given that statistically speaking there is no strong effect going from low to medium, we can conclude that the ideal value for complexity to generate positive results on the perception of atmosphere is "low". However, considering the similarities in ratings between low and medium values of complexity on the positive adjectives, it can be proposed that a medium complexity level can generate similar experiences in the space. This can further be supported by the trends seen in the adjectives "lively/exciting" and "stimulating", where the applicability peaks for the medium complexity (see Figure 91) – however of no great statistical significant with a $p>0.05$ between low and medium complexity. This comes to encourage that the use of both low and medium complexity in biophilic patterns can be explored by lighting designers without the fear of creating a radical change for the worse in the perceived atmosphere. The findings of this section are also supported by the biophilic design principles of S. Kellert on visual complexity, in which he states that:

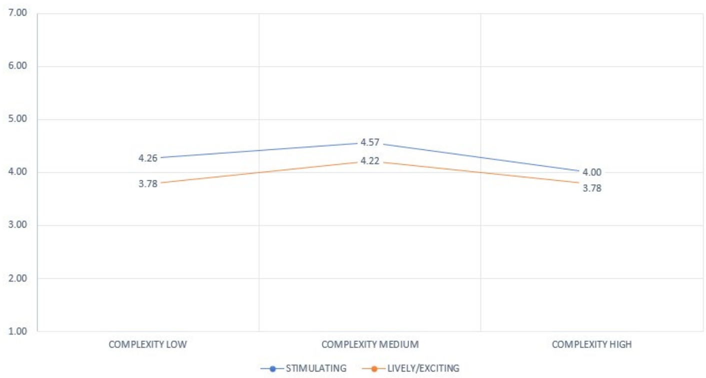


Figure 91.Graph showing the rating values for adjectives "stimulating" and "lively/exciting" with the applicability peaking for both at a "medium" complexity level.

"[…] complexity reflects occurrence of detail and variability. Excessive complexity can also be troublesome, making it difficult to assimilate detail and sometimes leading to a sense of chaos. Designs that effectively meld order with complexity tend to be successful, stimulating the desire for variety but in ways that seem controlled and comprehensible."

6.6.3 Speed of change: perceived atmosphere under low-medium-high speed of change

For the positive adjectives: cosy, relaxed and pleasant/hospitable, the results clearly show their applicability peaks with the speed of change set to "low". In opposition, at a speed of change set to "high", the applicability of the positive adjectives drops. On the negative adjectives: uncomfortable and terrifying, the applicability drops at the low speed of change. Interestingly enough, on the neutral/situational adjectives "lively/exciting" and "stimulating", the data shows very similar applicability levels for the medium and high speed levels, with almost no difference at all. This can mean the change of speed between medium and high was not that great to significantly alter the perceived atmosphere (see Figure 92).

For the adjective "cosy":

A one-way ANOVA test was performed on:

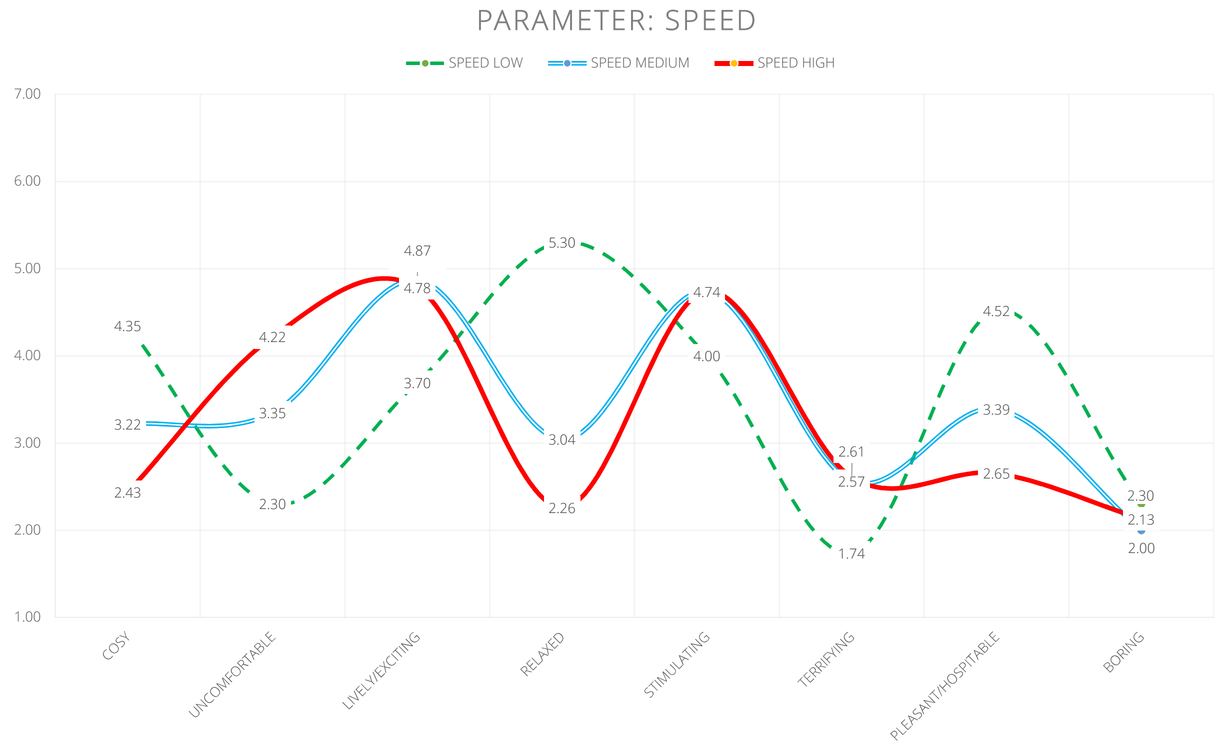


Figure 92. Graph showing the perceived atmosphere under the 3 different degrees of speed: low-medium-high.

- The 3-speed values side-by-side: $p<0.05$ (=0.0004)
- The low and medium speed of change: $p<0.05$ (=0.0279)
- The low and high speed of change: $p<0.05$ (=0.0002)

All three ANOVA tests show the null hypothesis "there is no effect on the cosiness factor when changing between different levels of speed of change" can be rejected.

For the adjective "relaxed":

No further statistical calculation was applied since it was clear from the data, as well as scientific knowledge presented in the "analysis" phase that the faster the speed the less relaxing it is (Wang Bsc et al., 2013).

For the adjective "pleasant/hospitable":

A one-way ANOVA test was performed on:

- The 3-speed values side-by-side: $p<0.05$ (=0.0002)
- The low and medium speed of change: $p<0.05$ (=0.0133)
- The low and high speed of change: $p<0.05$ (=0.00006)

All three ANOVA tests show that the null hypothesis "there is no effect on the pleasantness/hospitability factor when changing between different levels of speed of change" can be rejected.

Overall, for speed of change, the conclusions are easier to draw from the graph itself. It is clear that increasing the speed of change, even from low to medium has an overall negative effect on the perception of atmosphere. This comes from looking into both the positive and negative adjectives. On the neutral/situational adjectives, we see the "stimulating" factor drops for a low speed of change and stabilizes from medium to high. However, the intention is to attract more public life into socially-inactive urban spaces and have people spend more time in the space. A constant medium-high speed of change might provoke over stimulation. In fact, going back to the analysis section of this thesis, we are innately more attracted to natural movements and a slow speed is overall more preferred (Wang Bsc et al., 2013).

We can conclude that our proposed hypothesis can be accepted:

"Increasing the speed of change of the biophilic dynamic light projections has a negative effect on the perceived atmosphere of the place - making it less cosy, pleasant/hospitable and relaxing."

The recommendation is for lighting designers to explore slow, natural movements for urban spaces. As opposed to the "complexity" parameter, where both low and medium values can yield similar results, this is not the case for "speed of change".

6.6.4 Interactivity model: usability and application in an urban space

For questions 1, 3 and 4, we identified a similar degree of agreement for the proposed statements. People moderately-strongly agreed that they were immediately aware of the change in the light pattern. A similar agreement level on *"Interactivity with urban lighting has a positive effect on how I assess the safety of an urban space"*, leads us to the conclusion that people were able to transpose themselves into the given context, as well as agree that it does indeed have a positive effect on how they perceive the safety of a space. A similar model of interaction to the one tested in this study also proved that it made people feel safer in the space (Paredes et al., 2016).

For the statement *"Interactivity with urban lighting has a positive effect on my overall experience and perception* *of the urban space"* it seems that people again agreed on a moderate to strong level. This is implicitly similar to the perceived safety described by Paredes et al. (2016) in their study and hence can be understood as a good addition to urban lighting from an emotional, atmosphere-creating perspective as well. This comes in addition to the obvious sustainable and economic implications interactive lighting provides.

For question 2, on awareness that the change is created by their own bodies moving, the participants were, in their majority rating this as neutral. This might be because the laptop's screen was turned off and they could not immediately understand it was them passing that caused the change. However, most of the participants decided to walk the trajectory a second time, but the statement is phrased in such a way that it requires them to answer whether or not it was intuitive on their first try. Regardless, this might imply a further need to fine tune the interactive model, or for the purpose of application in urban spaces, this might be disregarded completely. I believe this type of awareness is more applicable to interactive light art, rather than functional outdoor lighting.

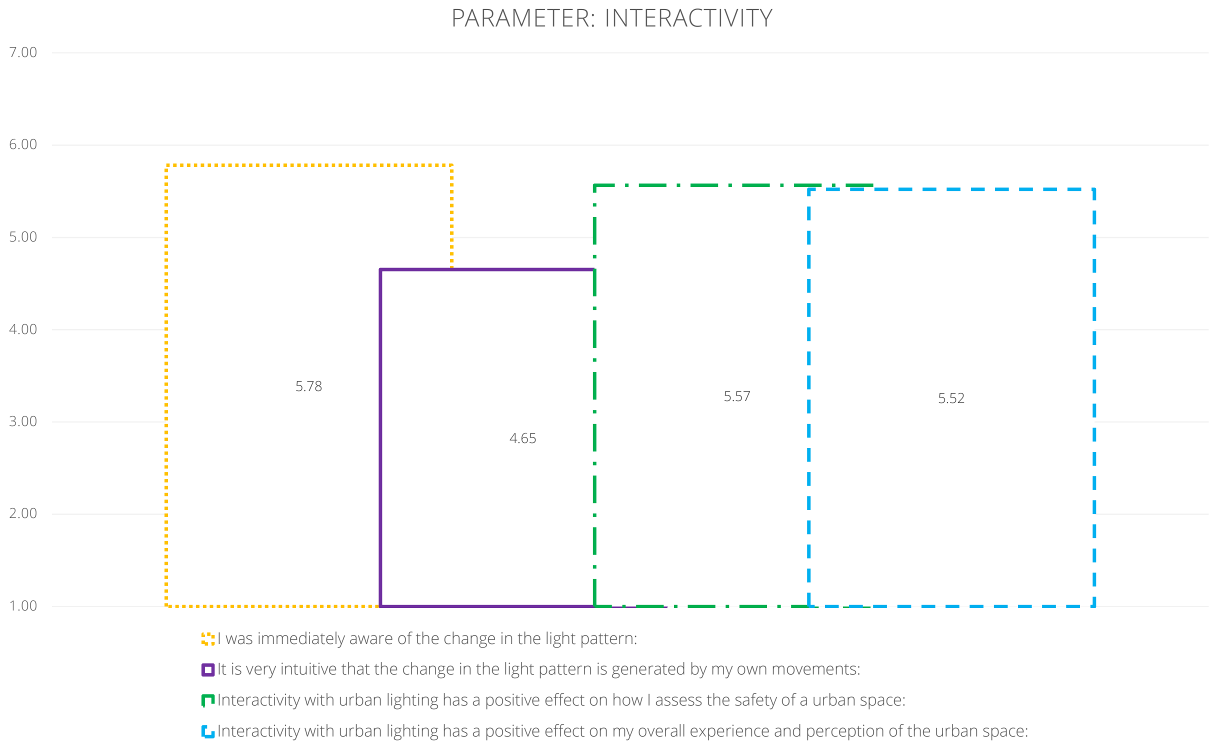


Figure 93. Graph indicating the degree of agreement for each question tested under the "interactivity" parameter.

6.6.5 The influence of the underlying patterns on the rating of perceived atmosphere

For all the tasks involving biophilic patterns, the initial database with 7 selected Processing sketches was used and a biophilic pattern randomly chosen for each participant and between each task. Since some of them are visually so different in nature, a closer look was given to understand if the rating for the same adjectives differ substantially between each pattern. If this is proven to be true, it can mean the perceived atmosphere is influenced by the underlying pattern. However, the results of the parameters "complexity" and "speed of change" clearly show that, regardless of the underlying pattern, the trends are similar. This does not affect those conclusions; however, it can shed some light on which the most preferred pattern was and why.

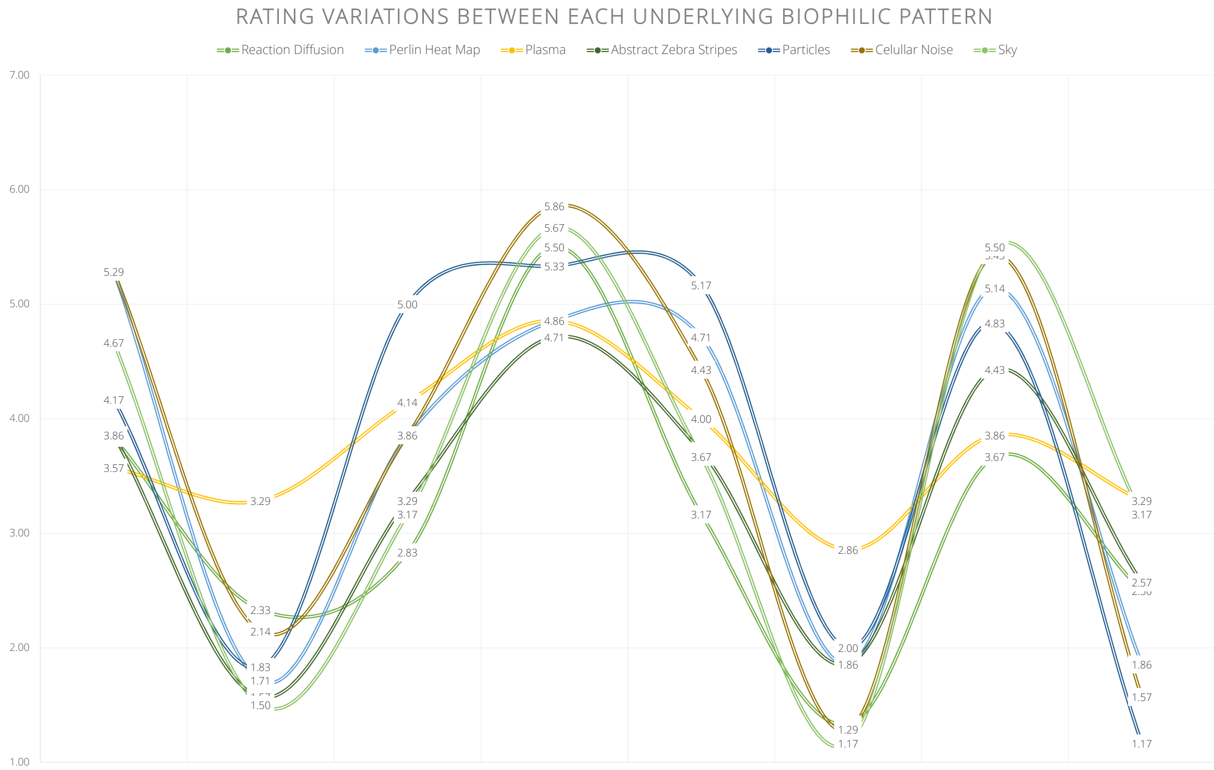


Figure 94. Graph showing the individual rating of each biophilic pattern in its generic state.

We can draw some immediate conclusions by looking at the results' graph above. Overall, the results show a clear pattern in the responses with some natural fluctuations. The rating is of the biophilic patterns in their generic state (low complexity, low speed of change and no interactivity). One-way ANOVA tests were performed for the positive adjectives, in order to assess if there was statistical significance to accept or reject the null hypothesis that:

- There is no effect on the (cosiness or relaxation or pleasantness/hospitability) factor for each individual underlying biophilic pattern.

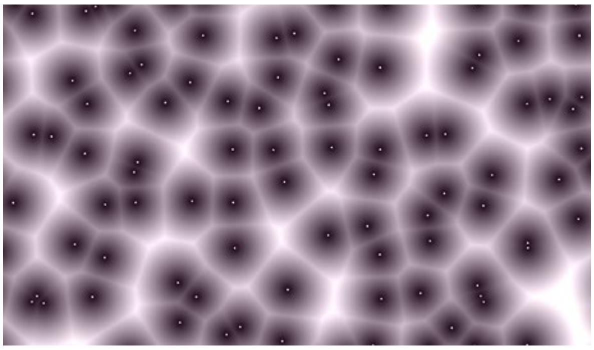
For the adjective "cosy" a p<.0.05 (=0.4344) shows that the null hypothesis can be rejected. What this means is that there is evidence to support that the underlying biophilic pattern is in fact important in the "cosiness" factor of the perceived atmosphere. However, this is not as strong as when looking at the effects of complexity and speed on the perception of atmosphere. For example, the pattern "Plasma" seems to be the most out of context of all, with clearly increased levels of for the adjectives "uncomfortable" and "terrifying". This can be attributed to its colour – a "toxic" green which might not be perceived as natural as the rest.

For the adjective "relaxed" a p>0.05 (=0.578) shows that the null hypothesis can be rejected. However, the evidence is not very strong to support that the relaxing factor does not have a statistically significant effect for each underlying pattern.

For the adjective "pleasant/hospitable" a p<0.5 (=0.024) shows that the null hypothesis cannot be rejected. This again implies that the underlying pattern has an effect from pattern to pattern.

Overall though, these findings were expected. There is more to complexity, speed and interactivity when looking at different patterns. However, of significance to this body of work is that no matter which pattern it is, a high complexity and speed of change are detrimental to fostering positive feelings in the viewers – this can help lighting designers to fine tune the patterns and then only carry a test that assesses the underlying pattern.

On which learnings to draw from this section, the patterns "Celullar Noise" and "Sky" seem to be the overall most liked ones, receiving the highest ratings for the positive adjectives. As to why this happened, it could be because out of all the proposed patterns, these two resembled closely something seen in nature, while the other 6 were abstract, symbolical versions of natural patterns. This does not mean the rest of the patterns hold no value, but might tell us that though statistically insignificant, exact visual replication of nature as opposed to symbolic, abstract representation of it is overall preferred.



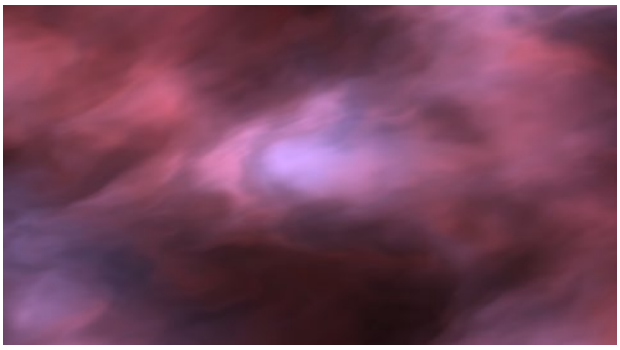


Figure 95. Patterns "Celullar Noise" and "Sky" were the top two most positively rated patterns of all. They were created using shaders from the website TheBookOfShaders.com. Both shown above at "medium complexity".

6.7 Discussion & test conclusions

As presented in the beginning of chapter 6 – "Test", the intention behind this test was to fine tune the proposed parameters to meet the intended goal of this thesis. The results of this test are presented as guidelines/framework for the interested party to be able to apply them into spaces with similar properties to our proposed context. As already discussed and recommended, further analysis of the selected space is necessary for obvious reasons: e.g. spatial placement of the patterns, choice of underlying pattern, user behaviour, cultural background, client needs, etc. This is a natural step of the design process and should not be neglected. However, the purpose of this thesis and subsequent test was not on providing a proof of concept, but rather on establishing valuable knowledge into how biophilic dynamic light projections can be used to attract more public life into socially-inactive urban spaces.

The results of the test provided valuable knowledge into what values for the parameters "complexity" and "speed of change" are considered as able to create atmospheres that are overall more positive. What we can conclude is that a low degree of complexity is overall rated as generating a more pleasant, hospitable, cosy and relaxing atmosphere. Of interest here is that the same results also show that a medium level of complexity does not have significant negative effects on the perceived atmosphere (see Figure 96 on the next page). This means there is a clear liberty for using both low and medium complexity, as well as values in-between. A possible future exploration is thus looking at the values in-between "low" and "medium", in a similar approach as with the experiment assessing which is the ideal D value of statistical fractals. It can also be hypothesized that upon selecting the location, the complexity can be balanced between low and medium as to provide visual harmony with the rest of the space. The concepts of "visual hierarchy" and "light zones" could be areas of interest in such a case.

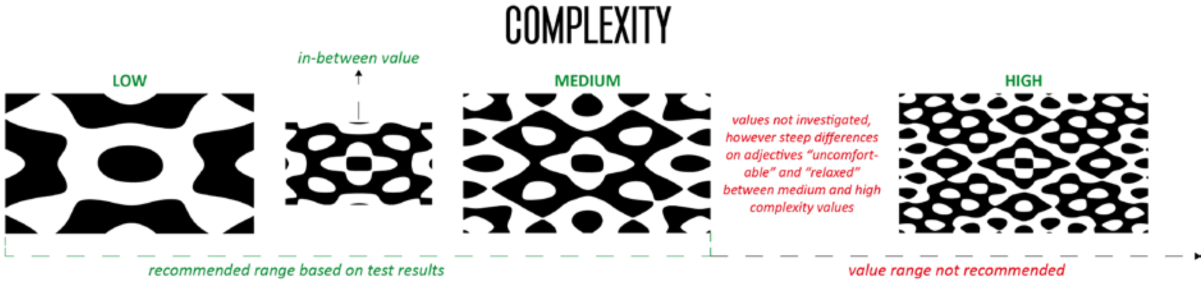


Figure 96. Summary of the recommended values for the parameter "complexity".

On the parameter “speed of change”, we see a clear indication that a low speed of change is overall responsible for keeping the perceived atmosphere on the positive end of the scale (see Figure 97). The statistical analysis shows that there are significant negative repercussions on the perception of atmosphere for a medium speed of change and more-so for a high speed of change. Also, of importance is that the speed of change was assessed in combination with a low complexity level. This means that even with low visual complexity, a low speed of change is still ideal and anything above that has a significant influence on how people perceive the atmosphere and space. With this realization comes another: that even though the parameters were assessed in isolation from one another, putting them together would have likely yielded similar results. Therefore, on the robustness of the test, I consider that it has successfully met its intended purpose.

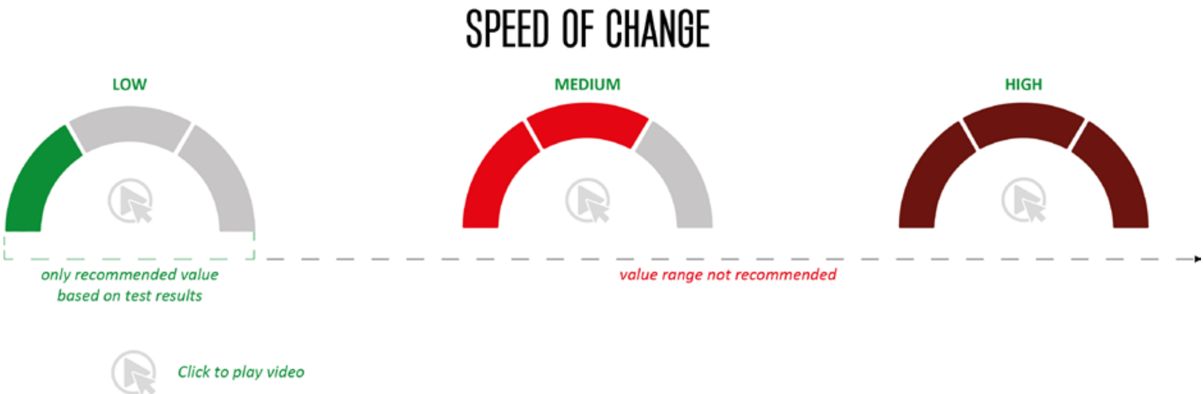


Figure 97. Summary of the recommended values for the parameter "speed of change".

Same applies to the last part of the test, which assessed the usability and applicability of the interaction model. It is clear from the results that interactive light can aid in the perception of safety and atmosphere of a space. However, more work is needed to fine tune the interactivity model in a similar manner used for the other two parameters investigated. Already some recommendations can be drawn by referring to a similar study that focused on the interaction model. From it we can mention that people preferred when the light changed in front of them, thus helping with the anticipation of danger (Jackson et al., 2015).

On the limitations of the test, it is important to mention the experimental room. Given the possibility to replicate it, it could be in the interest of strengthening the knowledge to use an actual socially-inactive urban space. The nature of the space and the visual complexity of the urban environment might have an influence on the results. However, the difficulty of controlling all the factors of such a space for all participants might suggest a controlled indoor environment is overall more reliable.

One last point of discussion is the effect of the underlying pattern on the perception of atmosphere. Although the findings were largely expected, it is safe to conclude based on the results of “complexity” and “speed of change” that regardless of the underlying pattern, the preferences show similar trends. Still, the pattern named “Plasma” showed the importance of other parameters in the perception of atmosphere. I believe that in the case of this example, its colour was the biggest contributor for the pattern being rated the least positive of all. With "colour" being such a vast field of investigation in lighting design, it is worth underlying its value as an additional parameter for fine tuning the biophilic patterns. Also, on the abstract level of the underlying pattern, the examples with the highest level of similarity to actual natural patterns were the most positively rated ones. However, the differences are insignificant and the studies of Stephen R. Kellert, as well as others in the field (please refer back to the "Analysis" section), clearly indicate that abstract representation of nature yields similar positive results.

Chapter 7

Final Design

This body of work is supplemented with a “video database” of all the created biophilic light projections which constitutes the final design – a controllable library of effects to use and the knowledge to implement and fine tune the patterns to generate positive effects on the users. To access this overall database, *please click here.* It includes all patterns created in Processing with low-medium-high speed values, as well as videos of the effects created with the gobo projector. For instructions on how to use this video database, please check "Appendix I". For visuals of the complexity parameter, please check "Appendix III".

On meeting the design criteria, we can conclude the following:

For criterion “Form” – all proposed patterns are, either in a direct or symbolical, abstract interpretation inspired by nature. They are organic and fluid in the way they behave. Though limited, the experimentation with the gobo projector also resulted in patterns whose movement, colour and aspect are reminiscent of nature (e.g. flames, water).

For criterion “Variability” – each pattern individually presents a great deal of variability, behaving dynamically. This implies a constantly moving and evolving behaviour, which is proven to be inherently more attractive. Furthermore, on a general scale, the proposed design also proves there are various ways such patterns can look, proving that biophilic dynamic light projections can be modified in a multitude of ways to generate visual variability.

For criterion “Interactivity” – the patterns can be interactive and change their behaviour in response to the user/s. This was proven through the optical flow code created as part of the design process and implemented on several of the proposed biophilic patterns.

7.1. Suggestions for spatial implementation

Before concluding on the overall results of this thesis, I would like to draw attention to some possible suggestions for implementation of biophilic dynamic light projections in socially-inactive urban spaces. This section only proposes some possibilities of how the patterns can be placed spatially and should be treated as a concept. Six alternatives were drawn using the editing software Photoshop and a quick sketching technique for illustrating light. The departure point is a photograph of a street near Nyhavn, Copenhagen taken by the author. However, the actual cultural particularities of the place are irrelevant. Rather what is important is that the place is really only a communication way between the areas around Nyhavn, quite isolated but with beautiful architecture and proximity to a lot of public life.

Proposal I: Projection on the façade.

The benefit of vertical illuminance is that it provides better visibility of the surrounding space. In this case, it also draws attention to the façade's architecture, which is otherwise left completely dark throughout the night. The patterns should be mapped with regards to the openings so that they do not create glare. Furthermore, the illustrations only show the patterns on a portion of the façade. This is only an exercise, however projecting at an appropriate level (up to 3-4m) should be considered to avoid illuminating unnecessarily. Three approaches are presented in the illustrations below (please check caption for details):

Figure 98. Homogenous pattern projection: creates an immersive experience.

Figure 99. Vertically-split pattern projection: creates "pockets" of light and hierarchy.

Figure 100. Masked-projection (the actual biophilic pattern is shown inside natural/organic shapes): adds playfulness.

Figure 101. Masked-projection (the actual biophilic pattern is shown inside natural/organic shapes): adds playfulness.

Proposal II: Projection on the ground

The alternative to façade projections is ground projection. This provides illumination on the horizontal plane, but needs additional functional light to support the need for visual awareness and safety. Two suggestions are shown in the illustrations below (plese check caption for details):

Figure 102. Homogenous ground projection: as with its façade projection counterpart, it creates an immersive experience.

Figure 103. Gobo-type projection: creates “pockets” of light and light hierarchy.

Chapter 8

Conclusion

"Study nature, love nature, stay close to nature. It will never fail you." – Frank L. Wright

This thesis was initiated from a passion for nature and a desire to create knowledge into a fairly untapped niche of lighting design. A niche situated at the edge between light, technology and what is nowadays, an extremely popular and valuable topic – "biophilia". With the belief that, much like my personal admiration for nature and its capacity for inspiring us to better our lives, everyone could benefit from investigating the potentials of these fields combined, as a mean of improving spaces in our urban environments that are otherwise unappealing and unpopular.

The proposed research question for which I strived to bring forward a structured, problem-based argumentation is:

How can the use of dynamic light projections based on biophilic design principles attract more public life into socially-inactive urban spaces?

To answer this, a three-fold approach was engaged:

An academic, in-depth evaluation of relevant literature and case studies to bring knowledge on the use of biophilia, on the creation of biophilic designs and its benefits, the use and emotional implications of dynamic light on space use and human perception and finally a generalized understanding of designing for urban spaces and the role of light in their revitalization were discussed and analysed. They have all shed light on equally important aspects, concluding on the realization that nature, combined with lighting technology in urban spaces can address important issues that go beyond functionality and can tackle aspects of aesthetics and social behaviour in a successful and more-importantly accessible manner. As a result of these realizations, the foundation for the framework was set.

The second approach – a practical design experimentation, explored various methods and technologies for creating and projecting biophilic patterns. The result, a fully-controllable database of biophilic effects created using the coding software Processing and the gobo projectors from Martin Professional, succeeded at answering the "how can" of the research question from the practical perspective – providing motivated solutions and alternatives for replication, implementation and future improvements. The software Processing coupled with video projectors was argued as the more flexible solution for creating and experimenting with biophilic visuals and the gobo projectors as the more financially-feasible, long-time perspective solution for implementation in an urban space - however, with short-comings on the creativity and variability side.

The last approach, one which supplemented on the robustness of the thesis was the scientific test in which selected parameters were investigated for fine tuning the biophilic patterns to match what people inherently perceive as more pleasant. The scope was to answer the "how-to" from an empirical and human-centred perspective. With valuable knowledge built on the notions of "visual complexity" and "preferred speed of light" in the context of socially-inactive urban spaces, as well as on the value-add of interactive light projections, the test successfully tackled and answered the issue of "attractiveness" of urban spaces. The conclusion was that low and medium complexity levels and low, natural speed of change are overall the preferred values for positive spatial atmosphere perception.

Each of these three approaches thus form the framework for understanding how to create and work with biophilic dynamic light projections in socially-inactive urban spaces or other spaces with similar properties as to those addressed in this thesis. The importance of these findings is valuable in streamlining the process of understanding, developing, calibrating (fine tuning) and implementing these types of light projections in the proposed spatial context to achieve positive results.

From a personal perspective, what this thesis manages to bring forward is a starting pillar in what I hope will remain of interest in the years to come. We are much too worried, though not undermining the importance of it, in what urban lighting design can do to tackle energy costs and consumption but forget the importance of us, humans, in the process of shaping the night-time urban atmosphere. This should not be achieved through generic, standard outdoor lighting but through what we genetically and almost universally perceived as pleasant and that has positive effects on us from multiple points of view. Having successfully proven how to create, work and implement biophilic dynamic light projections as a framework is, I believe a valuable contribution to the field of outdoor lighting design and future explorations.

In conclusion, the recommendations from each of the three approaches engaged, holistically answered the "how to" question-type raised in this thesis. It is a framework of creation, calibration and implementation but also one of argumentation of concept robustness. The assumption brought forward is that the findings can be applied to urban spaces with similar characteristics to those described as "socially-inactive" with the important mention that as with all lighting designs, precise analysis of the actual spatial properties, user behaviour, cultural background and client needs of the selected space are needed for complete success.

Chapter 9

Future Work

With the findings of this thesis and conclusions some interesting opportunities arose. They could be further explored to strengthen the findings outlined in these pages.

The proposed points for future work are:

I. An investigation into additional relevant parameters that are known to affect atmosphere perception. Such parameters can be, but are not limited to colour, light intensity and further fine tuning of the interactivity model.

II. Once this is done by looking at these additional parameters in isolation, it would be beneficial to put them in combination with the already investigated ones. This might provide knowledge into the relevance of some values when combined with for example, different colours. E.g.: *Could the preference for complexity change when the colour of the pattern is red?*

III. Of utmost importance is to take the findings of this thesis and provide a proof of concept. While in a theoretical place (the experimental room), we were able to identify ideal values to generate positive improvements on the perception of atmosphere, it is necessary to observe and investigate their applicability in an actual socially-inactive urban space. However, it is also important to stress that similar types of projects (please see section 4.4) were successful at revitalizing otherwise undesirable urban spaces.

IV. Last but not least, since this is a framework/guideline for creating and fine tuning biophilic dynamic light projections, when using them for implementation, the design criterion "Spatial Properties" should be considered. This criterion can entail various aspects, such as cultural background of space, architectural elements, regulations, user behaviour, client and community needs, etc.

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tectural+lighting:+designing+with+light+and+space&ots=1BKR9eXj_P&sig=3ZUSow0KsqYZiqRcBzFcEL-2qg4U&redir_esc=y#v=onepage&q=Architectural%252520lighting%25253A%252520designing%2525

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Appendices

Appendix I: Navigating the effect database

This Appendix briefly presents how to navigate the "database" that supplements this thesis. This database can be found at the following link: *goo.gl/bNC52a*

It includes the following folders:

1. Biophilic patterns_video database: includes video demonstrations of all the biophilic patterns and is structured as follows:

- *Gobo effects:* includes videos of all the create gobo visuals

- *Interactivity model_sketches:* includes video demonstrations of how the interactivity model works

- *Pattern_X_Name of Pattern:* 1xfolder per each of the 13 biophilic patterns created using the software Processing. Each folder includes links to videos of the pattern under its different "speed" values and generic complexity. For the 7 biophilic patterns used in the "Test", an additional video showing all iterations side-by-side is included.

2. Processing_Source_Codes: includes .pde files (Processing format) of each pattern created using the software. To run the sketches / check the code, you need to have the Processing software installed on your computer. This can be downloaded from here: *https://processing.org/download/.*

3. Additional deliverables: includes a poster presenting a summary of the thesis - see Appendix II and a video presenting the thesis.

Appendix II: Thesis Poster

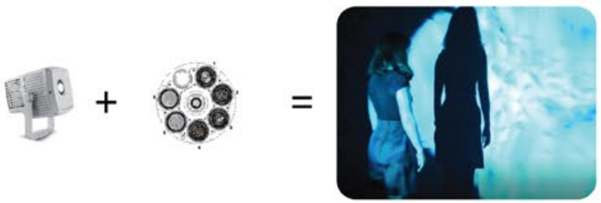
The poster on the following page presents a summary of the thesis. To see it in high-quality, *please click here.*

BIOPHILIC DYNAMIC LIGHT PROJECTIONS

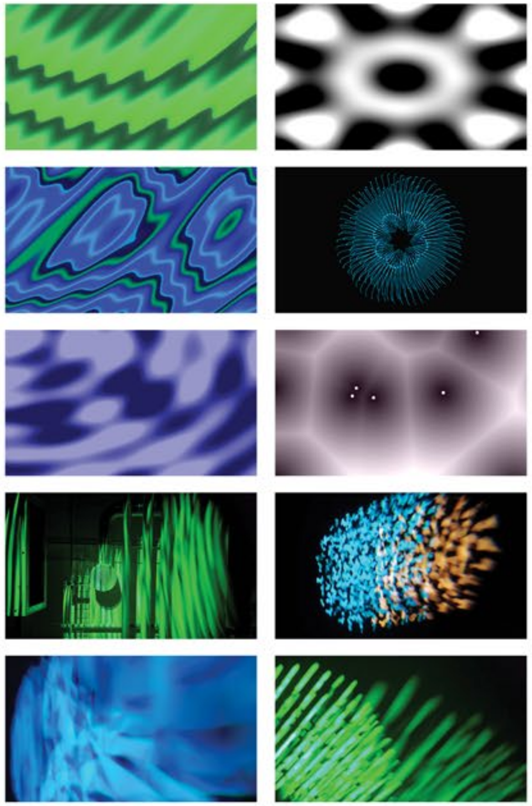
Imagine if...

we can explore our innate attraction to nature to create biophilic dynamic light projections for application in socially-inactive urban spaces with the goal of transforming them into more attractive, pleasant environments.

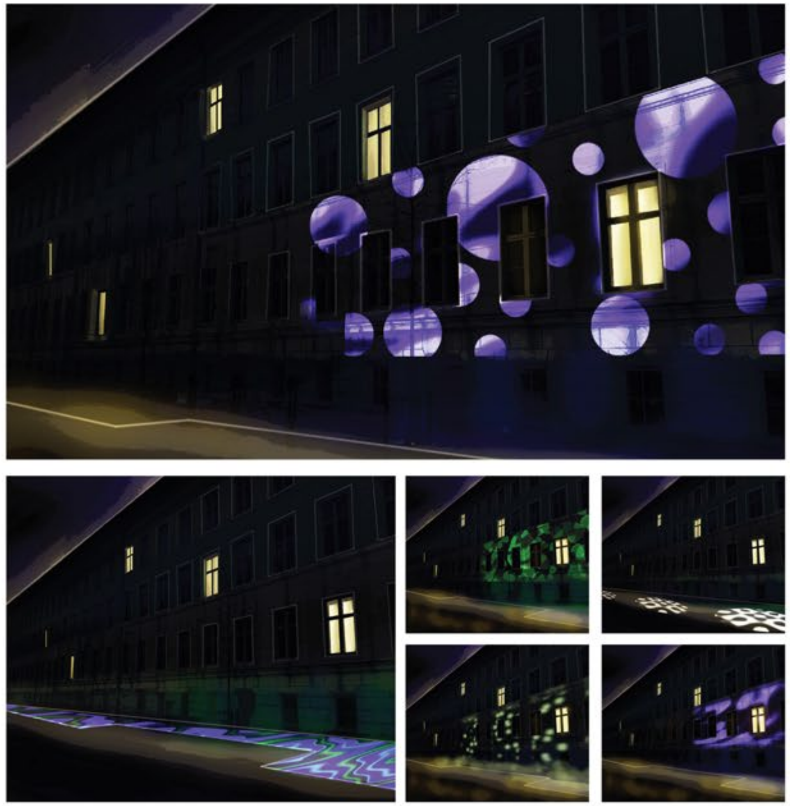
Creation



Effect database



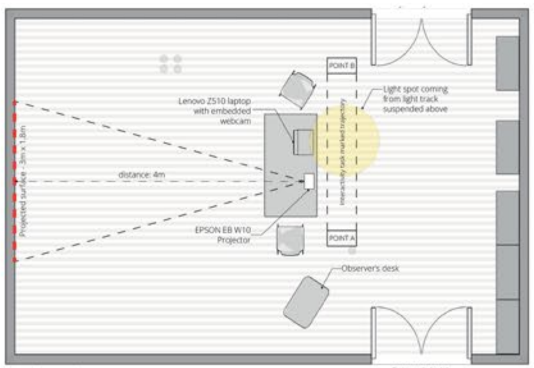
Spatial implementation proposals



Test

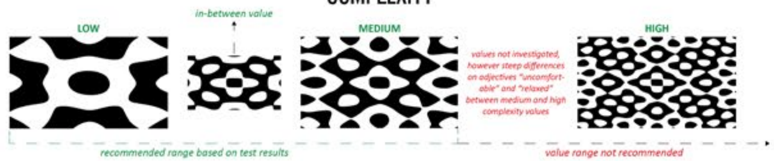
An atmosphere perception test was performed to identify the ideal values for the visual complexity of the pattern and the speed of change.

This test was necessary to create the design framework for using biophilic dynamic light projections in spaces with a low level of attractiveness. It is intended to provide some valuable knowledge on fine tuning the proposed parameters to what people perceive as more pleasant. The findings are then expected to work as the foundation for any interested party to apply them on their given space.



experimental room

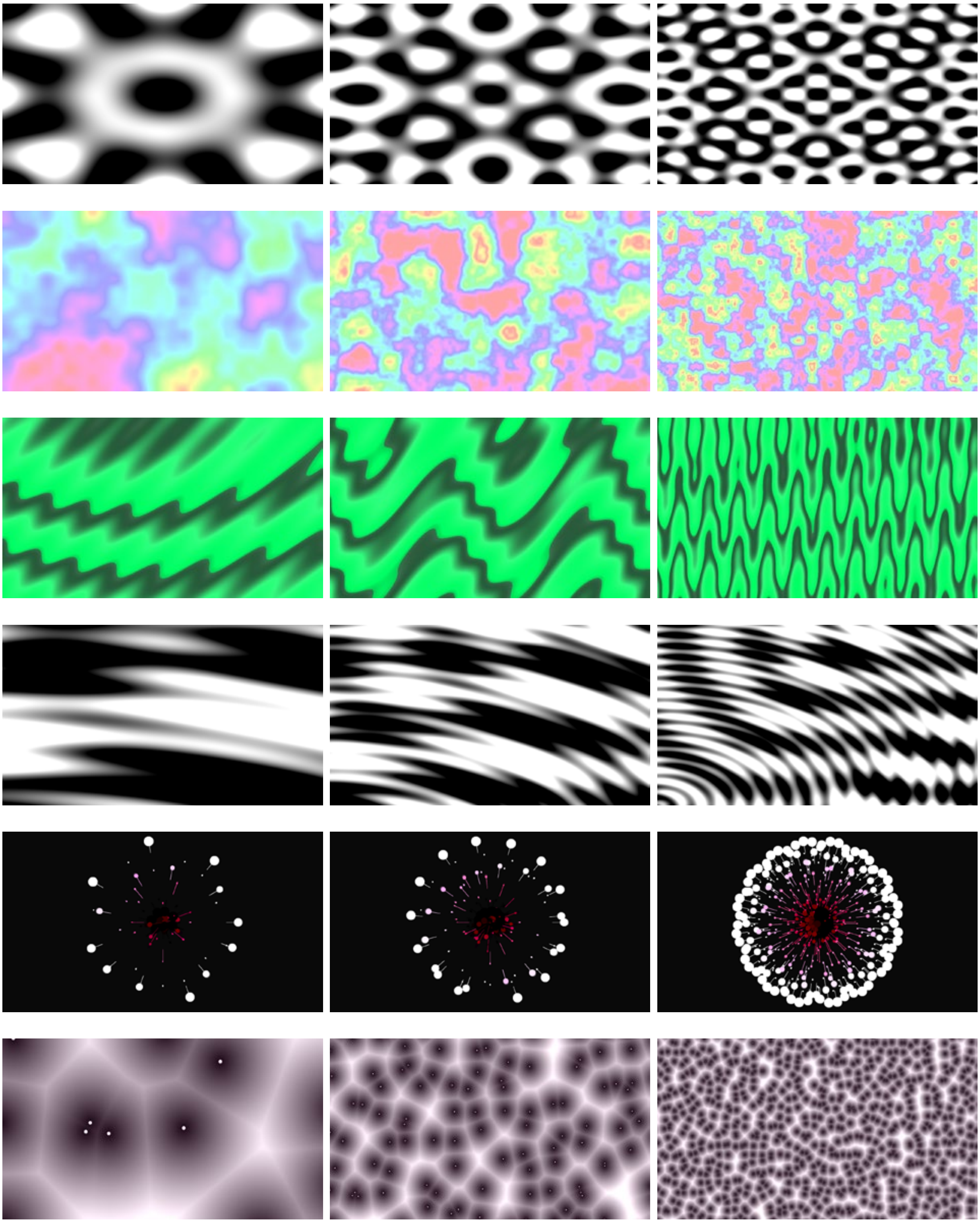
Results

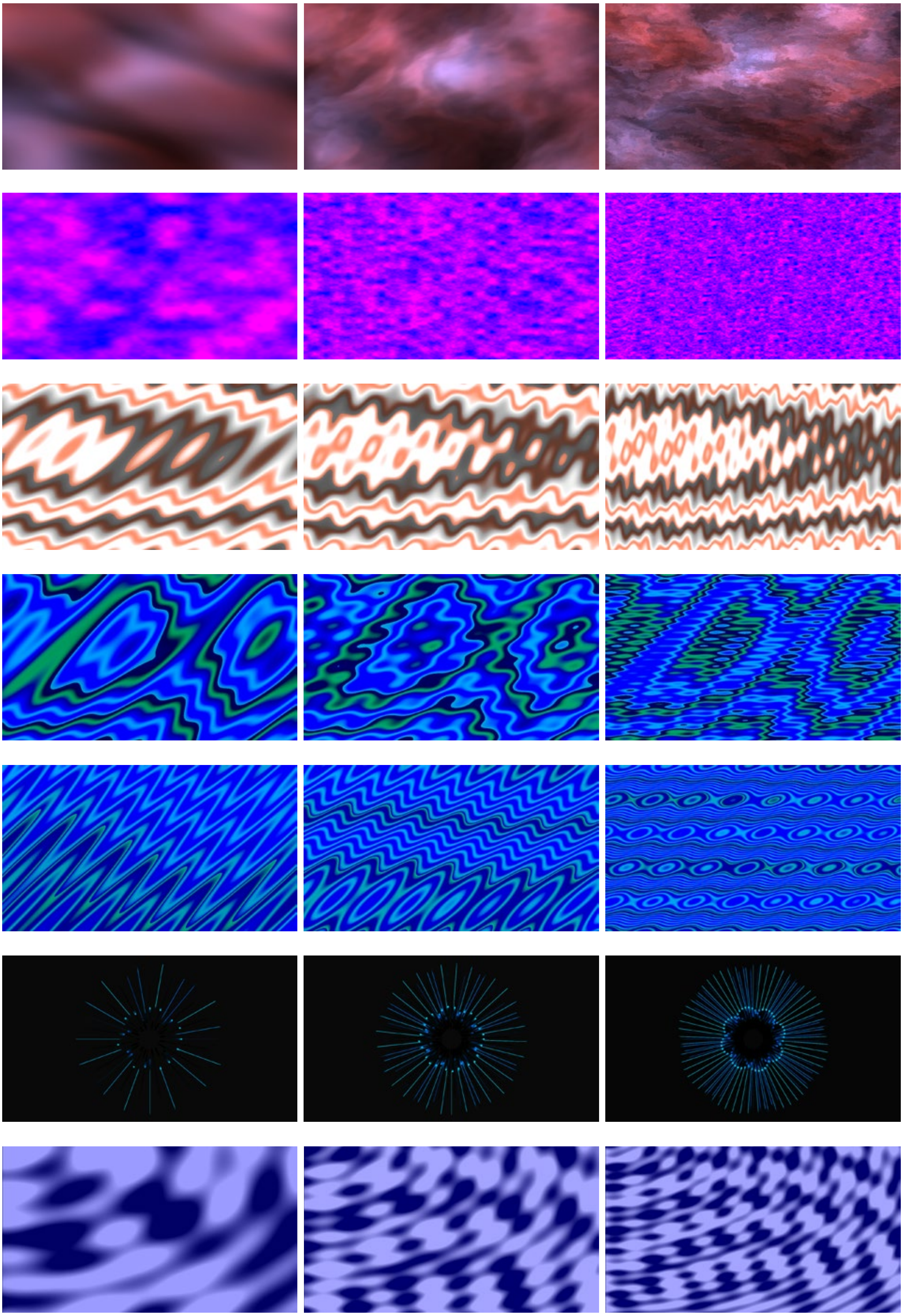


Ioana Fartadi-Scurtu | *May 2018*

Appendix III: Visuals of patterns under low-medium-high complexity

To supplement the videos of the change in speed from the video database, this appendix includes visuals of the complexity values "low", "medium" and "high" for all the Processing patterns.





d

Biophilic Dynamic Light Projections
A proposal for the revitalization of socially-inactive urban spaces

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