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Abstract:

Based on a vision and an idea that the complexity of dynamic lighting for human needs could be structured and represented as a model to help discover new human potentials in dynamic lighting design, and to help create a holistic understanding of this topic, the currently available dynamic means and their proposed purposes from industry companies and concepts were investigated. These were analysed for possible interrelations, and discussions about interrelations were the foundation for the development of a design model. The design model is divided into three main contexts in which human needs in dynamic lighting design cases exist. The overview of contexts and interrelations in the model, along with a supplementary list of the investigated dynamic lighting potentials, is intended to help a lighting designer discover new dynamic lighting potentials for human needs. The model was tested in a simple experiment, but due to the nature of the test, it could not provide a clear answer to the problem statement. However, the test did provide a subjective indication, that the model helps as intended to some degree.

AALBORG UNIVERSITY COPENHAGEN

DEPARTMENT OF ARCHITECTURE, DESIGN, AND MEDIA TECHNOLOGY

MASTER OF LIGHTING DESIGN

Dynamic Lighting – New Potentials for Holistic Design Meeting Human Needs

A study in the currently available dynamic lighting design means and how to define new human potentials for everyday dynamic lighting design through a design model.

10TH SEMESTER MASTER THESIS

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1 Introduction

This project seeks to investigate how to find new dynamic lighting potentials when designing lighting for human needs. As the multidisciplinarity of the study of lighting design continues to increase the complexity of our understanding of the human needs for light, research and discussions about this complexity and how to work with it holistically, meaning *'dealing with or treating the whole of something or someone and not just a part'* [1], might reveal new insight that can help provide better lighting for human needs in the future. This project seeks to take part in this discussion with the objective to develop a model that can help understand some of the complexity of human needs within a lighting design, and to discover new dynamic lighting potentials.

The broad range of disciplinary research fields that feed into lighting design for human needs has widen the foundation from which inspiration for new research experiments and potentials for new lighting design means arise. We now know that lighting design for human needs can consider knowledge from biology, knowledge about sociology and how light affects social activity, knowledge about the psychological effects, and knowledge from medicine and neuroscience and how light affects hormones, the circadian rhythm and health in general. The purposes of designing with knowledge from these influencing disciplines spans both qualitative values like improving the life of humans, but also more quantitative parameters like productivity, concentration and health issues. Research is also being conducted to understand how dynamism and transition periods affect human behavior and our circadian rhythm. Understanding the transitional interplay between different activities over time, how different disciplines are involved in those, and for which purposes, might be important when defining and choosing dynamic lighting design means for specific cases in a lighting design process. However, acquiring this holistic understanding seems complex due to the complexity of disciplines and purposes involved.

By analyzing the industry's dynamic lighting technologies and means and their intended purposes for meeting human needs, this project seeks to develop a model. The aim is that this model can help discover and define dynamic lighting potentials in the process of a lighting design case analysis by providing a holistic overview of how all these known dynamic lighting means and purposes are related from the perspective of human needs.

1.1 Motivation

We all know that we need light to be able to perform tasks, and a certain amount of light to feel comfortable doing this. In many lighting design cases this need would be a functional task lighting need, and standardizations and the designer's experience would help define a needed illuminance level for the tasks. However, these implemented illuminance levels could be seen as symptomatic treatment to a specific human need, and not be based on an understanding of the holistic reason to this human need and the broader contexts of the human in this situation. This is in typical lighting design practice not a problem, as it clearly helps work efficiency to have predefined suggested values for such typical situations, but as the field of lighting design becomes more and more multidisciplinary, it raises the question whether this approach to defining needs in lighting design is sufficient. This is where the link between lighting design and phenomenology was of inspiration for doing this project. A Phenomenology course of the 8th semester of the Lighting Design Master at Aalborg University Copenhagen, made me think differently about lighting and human needs. When thinking about the many phenomena involved in the general context of humans and light, where we have functional, biological, emotional, aesthetic and other needs, in an unlimited number of situations, activities and tasks and combinations of these, I had the idea that these needs and activity contexts should be easier to grasp holistically – at least for myself. I understood the needs individually, but had difficulties seeing the hierarchy and structure that binds them together to make sense from a holistic human perspective.

> *"Understanding something really deeply has to do with your ability to change perspective."*
> *– Roger Antonsen, logician, University of Oslo [2]*

The reason for doing this project is based on a preliminary idea suggesting that; by investigating and analyzing the reasons and purposes behind what we decide to use of dynamic lighting means and tools in a lighting design case, such as in typical office environments, and by discussing how these reasons and purposes relate to us as human beings and our lives, one might be able to achieve the intended holistic understanding and perspective. Such a holistic understanding might provide a foundation for better design criteria and help find greater meaning in the proposed lighting design. Our analytical perspective would shift to cover all relevant aspects of human life and needs, not just focused on needs related to a given case. If I can succeed in acquiring this holistic understanding, this could be communicated and synthesized into a model that could help other lighting designers better understand dynamic lighting and human needs holistically. An additional intention is that, by having this holistic understanding, one might also discover new needs and how to meet them using dynamic lighting design technology.

Therefore, it is also about protecting and discovering the potentials that exist, but not known, and could add value and quality to the human life.

Because humans are interacting dynamically with space and time, and space and time is dynamic, it could be argued that when designing with light, early in the design process, one should seek potentials in dynamism by understanding the links between humans' experiences in space and time and the possible achievable human values and needs. I consider this being a holistic understanding, because it is open to the whole context of how humans experience space, including all the possible achievable human values and needs, even those we are not aware of currently. My idea is that the holistic understanding could reveal reasons to and relations between our behavior, reactions and needs in a specific context, and by that inspire new dynamic lighting potentials. Böhme describes some of the complexity involved in how we experience space and how it affects us, in the phenomenology of mindful physical presence in space:

> *"We sense expanse or confines, we sense elation or depression, proximity or distance, we sense openness or entrapment, we sense intimations of motion. This outlines some of the basic conditions of mindful physical space such as is accessed by sensation."* [3]

Böhme discusses how we are sensitive to the perceived atmosphere of a space, and he underlines the importance of taking this seriously in situations of for example work and everyday living – not just for special events or occasions.

One might argue that true holistic lighting design should see a given lighting design case as something that exists as one or more periods in the phenomenon and time span of *human life*. Instead of the perspective going outwards from the human in the situation of a task, the situation is seen as a small part of the perspective of a human at a point in a complex life.

The reason why I find this interesting might have to do with my bachelor in Medialogy from Aalborg University Copenhagen, where the focus was on use cases, usability, meeting the needs, and many other topics that are not concerned with the "unexpected" and "invisible" meaning of experiences in time and space, to the same extend I believe phenomenology and designing with light does. The decisions in many designs seem to go from the limited context of a problem or task, towards a solution that seeks to limit its impact on the users, to what is easily justifiable, instead of investigating how to augment and improve the experience and value by seeking additional design ideas that could relate to other needs and parts of our lives. Of course, in lighting design we need to consider biological needs like the circadian rhythm, the functional needs in work task situations, visually aesthetically pleasing arrangements and other obvious needs, but to me these rarely carry meaning that goes beyond our immediate human needs in the given isolated case. And as life is not just about the needs directly related to a task situation, I find it very

interesting to explore and utilize other potentials that can be translated into meaningful lighting design purposes, and media technology gives us most of the tools needed for creating dynamic solutions for these potential purposes.

1.2 Vision

Based on the motivation for this project, the vision is:

> *Imagine if a model could be developed to help lighting designers achieve a holistic understanding of a lighting design case and from that find new dynamic lighting design potentials meeting human needs.*

The model is intended to have the purpose of supporting the lighting designer in the design process, by structuring the complexity of needs, means and contexts involved in lighting design cases that seek to meet human needs. The vision is the basis for the development of a problem statement in the following chapter.

2 Defining the Problem

To understand and define the topics within the vision, these will be investigated and analyzed. The results from the pre-analysis will define and limit a problem statement. The problem statement will then be the basis of an analysis and design that will seek to answer the problem statement, and it will be discussed whether the results can meet the vision.

2.1 Approach

The concept of *human needs* from the vision will be discussed and defined. The vision also mentions *new dynamic lighting potentials,* and therefore understanding currently available dynamic lighting technology and how it is described by the industry is relevant, to make it possible to discuss these potentials. This will be an analysis of what dynamic lighting technology is available from the industry. Additionally, the development of the final problem statement should consider the aspect of the vision that suggests the development of a model. To define the topic *human needs*, and to verify and understand what the current technology is, the following research questions will be investigated in the pre-analysis.

1. What is meant by 'human needs' and 'dynamic lighting'?
    - A discussion and definition of these concept in the scope of this project.
2. Which dynamic lighting technologies are available from the industry, and what are their proposed purposes related to lighting for human needs?
    - An analysis of material from some of the relevant interests in the dynamic lighting industry.

2.2 Pre-analysis

The following chapters investigate the research questions established from the vision and listed in chapter 2.1.

2.2.1 Definition of 'human needs' and 'dynamic lighting'

In this chapter, the terms 'human needs' and 'dynamic lighting' will be defined and discussed, to explain their meanings in the scope of this project.

The term ***human needs*** is meant as a broad term, covering both basic needs, but also values that can improve the quality of life without being necessary. Such qualitative values can be thought of as being needs, because they are needed to achieve the goal of improving the quality of life.

The needs are related to different scientific fields. There are biological needs which relate to our circadian rhythm and health in general. There are psychological needs, highly connected to the biological needs, regarding mood, concentration, relaxation et cetera. There are needs that exist because of expectations from others, for example work efficiency and productivity. There are needs related to social behavior, supporting formal and informal activities and teamwork, and so on.

To illustrate how knowledge from different disciplines are used, through dynamic lighting means and tools, to meet different human needs, two diagrams where developed. Figure 1 shows a typical case focused approach, where knowledge, specifically known to have potentials in lighting design for human needs, is applied through lighting design means to meet needs directly related to the case. The potentials, which is the known combinations of knowledge, technologies and means, are limited to only meet needs directly relevant for the specific case.

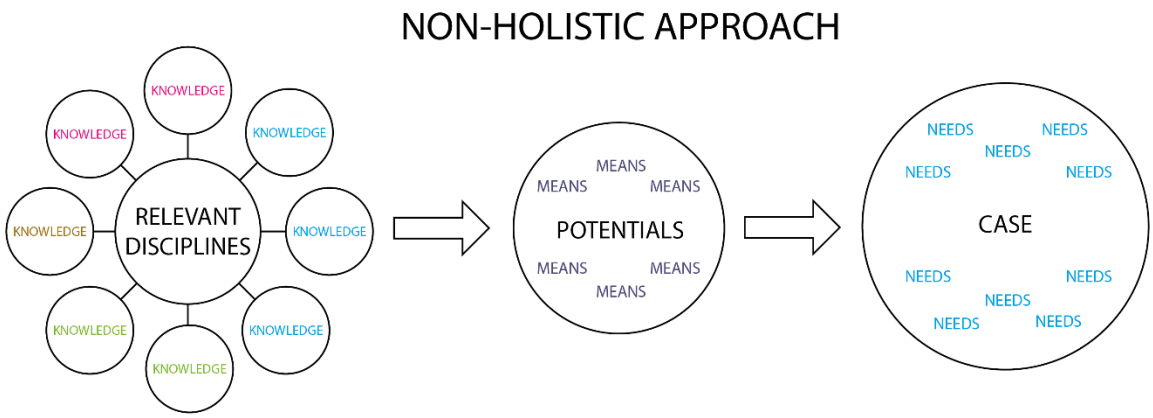

FIGURE 1 - NON-HOLISTIC APPROACH TO HUMAN NEEDS

Example of the relation between knowledge, means and needs in the figure:

Knowledge could represent the result from research, relevant to lighting, for example stating that light with a cool color temperature can energize people and increase performance in a functional task situation. We then have some *means*, in this example the possibility to adjust color temperature for a specific period – the task period. *Potentials* represent all the potentials where knowledge can be combined with means to meet needs. So, to meet a need related to the case, namely increasing performance in the task, knowledge is applied to the case using an available mean – adjustable color temperature.

In a holistic approach, the case is a part of the user's life and should therefore not be isolated. This is illustrated in Figure 2 where the human needs are seen as a whole, resulting in more possible combinations of knowledge, technologies and means - and by that possibly reveal more potentials that can meet more human needs.

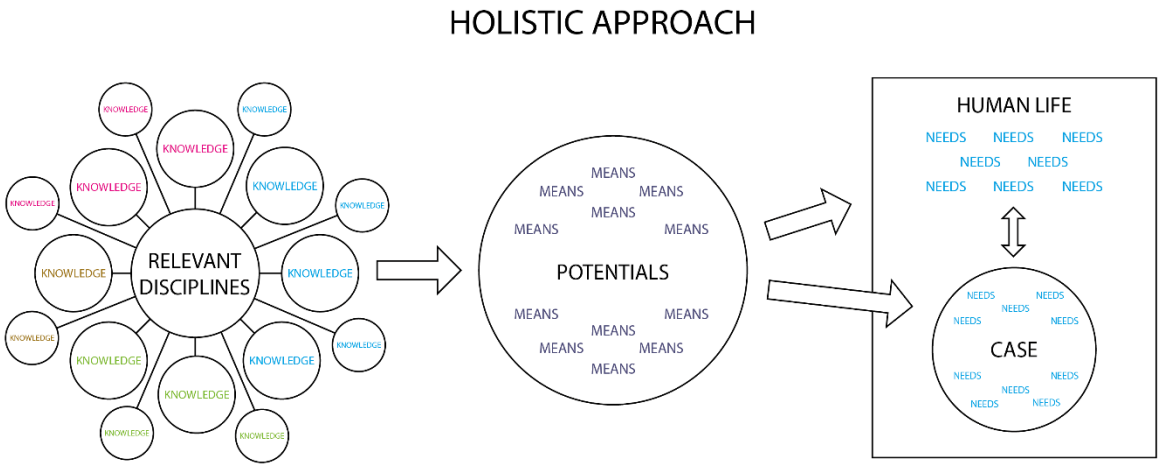

FIGURE 2 - HOLISTIC APPROACH TO HUMAN NEEDS

Because more needs are included, more knowledge, about meeting the additional human needs, is also potentially relevant. The additional relevant knowledge can then be applied using the means, to meet the human needs.

Not only does the holistic approach introduce potential human needs not directly related to the case, it also gives the opportunity to discuss and understand the case from the perspective of a human life.

The term ***dynamic lighting*** refers to the use of changing light over time, such as changing colors, color temperatures and brightness, and movement or change in direction, distribution and uniformity. The topic of dynamic lighting holds more means, tools and parameters than these, and one of the reasons for doing the analysis of available dynamic lighting technology is to get an overview of the means and parameters involved.

The word 'dynamic' is defined by Merriam-Webster as *'marked by usually continuous and productive activity or change'* [4], which carries the reasons to use it in lighting design; to produce something because of change. This production both relates to the actual visible changes in the light qualities, but also the potentials it has for meeting human needs. Dynamism is defined as *"philosophy: a theory that all phenomena (such as matter or motion) can be explained as manifestations of force"* [5], which suggests the potential relevancy of phenomenology. The link between dynamism and "all phenomena" might also support the claim from the motivation chapter 1.1 that *"it could be argued that when designing with light, early in the design process, one should seek potentials in* ***dynamism*** *by understanding the links between humans'* ***experiences*** *in space and time and the possible achievable human values and needs."*.

2.2.2 Which dynamic lighting technologies are available from the industry, and what are their proposed purposes related to lighting for human needs?

This part of the pre-analysis is an investigation into the dynamic lighting technologies and means currently available from the industry, and the proposed purposes of using these means. By investigating these proposed purposes, the intention is to identify the human values and needs that these technologies and means seek to affect, and structure this knowledge to understand how they are interrelated. Understanding the interrelations is necessary for creating the holistic understanding. The analysis of these existing dynamic potentials is important as a reference for later discussions about how to discover new potentials. The survey is done by keyword search for *dynamic lighting* and *lighting for human needs* as well as scanning through brochures and websites for relevant information. Due to the vast amount of information and differences in term definitions from these companies, the observations do not cover everything, but focus on some of the findings relevant to the context of the vision. The analysis does not serve statistical purposes but is instead an overview of the most common dynamic lighting means and their purposes. The focus will be on finding and summarizing means and purposes currently part of dynamic lighting, to provide a state of the art and basis for this investigation.

A matrix of the findings for each of the following companies and organizations is included [Appendix A]. The findings are categorized in terms of dynamic technologies and their intended purposes for meeting human needs.

2.2.2.1 Investigated Lighting Companies

The following sub chapters are investigations of some of the largest and/or relevant companies in the lighting industry.

2.2.2.1.1 PHILIPS LIGHTING

Philips Lighting describes the effects and means of their dynamic lighting technology as the ability to adjust color temperature, full color, brightness levels, as well as temporal functionality and the use of lux sensors,

temperature sensors, human presence sensors and location tracking. Especially their product range Philips Hue [6] serves more experimental functionality related to dynamic lighting, using a smartphone app, which allows for a broad range of internet service-based functionality. Philips Lighting provides several thematic websites and webinars for educational purposes within dynamic lighting [7] and 'Human-Centric Lighting' [8]. From Philips Lighting's description of dynamic lighting:

> *"The system works by changing the color temperature and intensity of light automatically throughout the day. This is achieved by mixing the light output from two different lamps with dedicated optic technology, creating varying balances of cool and warm illumination." [7]*

Philips Lighting's proposed purposes of dynamic Human-Centric Lighting spans themes like to create natural feelings of well-being, adapt to different needs and moods, positively affecting the biological clock, feel alert and refreshed and improve performance. In general, these purposes relate to the circadian rhythm, increasing performance and productivity as well as a focus on *personal* customization for mood adaption. However, it seems that the Philips Hue product range is targeted private consumers and not larger professional lighting design tasks like office environments.

Dynamic factors: Changing color, color temperature and intensity automatically over time.

Proposed purposes: Affect mood, circadian rhythm, and performance. Focus on personal customization.

2.2.2.1.2 USAI LIGHTING

USAI Lighting promotes dynamic lighting technology with a focus on the ability to change full color and color temperature, called for example *Infinite Color+*® and *Warm Glow*®. One of the purposes is the option to set a color that defines one's personal appearance:

> *"How do I want to look? Refreshed, Healthy, Warm tones, Natural, Beautiful, Focused, Organized, Colorful, Professional...", [9]*

Other purposes are the ability to set the color or color temperature according to *"How do I want to feel?"* - mood and circadian related, *"Where am I?"* - the identity or type of space or location, and *"What am I doing?"* - light that fits a given activity.

USAI Lighting provides a thematic website regarding circadian lighting [10], suggesting purposes of wellbeing, mimicking natural daylight, dynamic shift for different situations and activities like teamwork or individual tasks.

> *"Perhaps most importantly, the lighting can be preprogrammed to provide a daily dose of high energy white light in the morning to start the day as daylight would, and dynamically shift to settings more amenable to teamwork and collaboration at the times you choose. Nonvisual effects are what we want and need from our lighting today..." [10]*

Furthermore, USAI Lighting suggests the purpose of personalized light treatment of different medical conditions:

> *"Today, we know how to create lighting prescriptions to eliminate jet lag, improve sleep quality, alleviate symptoms of Alzheimer's disease, ease depression, improve worker satisfaction, and be happier people overall. Many of these ailments have no cure today, but we can provide relief through lighting!" [10]*

Dynamic factors: Changing color, color temperature and intensity automatically over time.

Proposed purposes: Affect mood, circadian rhythm, and performance. Focus on personal customization, with effects like personal appearance and awareness of location. A special mention of the potentials in personal medical treatment through lighting. Change and adapt lighting conditions to support task activities for individuals and teams. Mimicking daylight.

2.2.2.1.3 HUBBELL LIGHTING

Hubbell Lighting has a lighting control system called NX Distributed Intelligence that intends to provide high level of dynamic and intelligent lighting control of standalone fixtures, groups of fixtures and large complex systems. The system provides dynamism in terms of light level change, color tuning, scheduling, relation to present daylight using daylight sensors and energy savings using live data. Their brochure [11] describing the product generally focuses more on energy savings than on dynamism in relation to human needs.

Dynamic factors: Changing color, color temperature and intensity automatically over time and by the use of daylight sensors, occupancy sensors and data.

Proposed purposes: Energy efficiency.

2.2.2.1.4 IGUZZINI

iGuzzini offers luminaires with the dynamic means of adjustable color, color temperature (which they call Tunable White Technology) and intensity. Some of their products are controllable using wireless Bluetooth DALI and provide the purposes of both centralized and personal adjustability. They also have daylight and presence sensors to allow for automated changes to light settings over time [12].

iGuzzini mentions the term Human-Centric Lighting [13], however in a concept catalogue (2018) they introduce the term People Centric Lighting [14, p. 5]. Of proposed purposes they focus on wellbeing and the circadian rhythm.

> *"Light stimuli can have different applications, from the most sophisticated to the simplest, while still retaining its positive character of dynamism. Indoors and outdoors alike, variable artificial light is a natural addition to our psycho-physiological well-being."* [14, p. 5]

In addition, iGuzzini suggests that the purpose of supporting the circadian rhythm serves several potential sub purposes:

> *"The circadian clock affects every moment of our lives, habits, productivity, metabolism and emotions. Everything depends on light."* [14, p. 5]

Dynamic factors: Changing color, color temperature and intensity automatically over time and using daylight sensors and presence sensors. Personal adjustability.

Proposed purposes: Support well-being, circadian rhythm and sub purposes (affect our habits, productivity, biological needs and emotions).

2.2.2.1.5 COELUX

CoeLux is dealing with dynamism in light directionality, not just about directing light to areas/spaces, but also the characteristics of the focus, contrast and angle as experienced, in a way most luminaire technologies do not. CoeLux' mission statement writes:

> *"Our mission is to foster an innovative solution for lighting, architecture and real-estate industries aiming at creating the perception of an extraordinarily wide space, by means of a genuine physical reproduction of optical atmospheric phenomena indoors." [15]*

CoeLux proposes the purpose of creating a perception of a wider space by the means of reproduction of optical atmospheric phenomena, to achieve uplifting mood and well-being and create a better relation between humans and the architecture surrounding them. CoeLux tries to replicate the visual perception of the real phenomena of a sky directed window, aiming at providing the same effects and human values gained from experiencing bright, direct sunlight and a blue sky as seen through a window.

The dynamism itself is however limited to the intensities of the light, not including the directionality of the replicated sunlight. One could guess that more dynamic functionality is in development, or will be, and will be included in near future.

CoeLux product demonstration. [16]

Dynamic factors: Changing light intensity automatically over time, with a relation to the natural daylight.

Proposed purposes: Affect mood, well-being, relation to the outside, replicate the positively weighted phenomenon of direct sunlight and blue sky.

2.2.2.1.6 LIGHTEN - "PILCS"

Lighten *PILCS* [17] is a patent pending *Personalized Intelligent Lighting Control System*, a product that helps achieving highly personalized lighting control. Through hardware lighting controllers, software and smartphone applications, the system integrates personal user profiles with biological information such as age, gender and chronotype - individual circadian rhythm patterns - and synchronizes this profile to a cloud service for analysis of usage data and optimized lighting control.

> *"Generically we are all equipped with different lengths of the endogenous clocks, meaning some people have an internal rhythm being slightly shorter than 24 hour and some slightly longer. In modern terms this phenomenon is defined by our chronotype, most commonly divided into two types - morning and night persons (also often referred to as Morning Larks and Night Owls).", [18]*

The website also suggests additional personal parameters, for example a medical profile that can support personal lighting needs for treatment of, in example, dementia. The targeted user segments are nursing homes, seniors in general, businesses and offices, education and schools and healthcare for better well-being and faster recovery.

Lighten suggests that *Human-Centric Lighting 2.0* is one of the foundations of their concept, however they also state *"But the lighting industry does not find consensus in the definition of HCL. It is LIGHTEN's mission to contribute to the definition of HCL and become a first mover in developing intelligent and personal solutions in an evolving market."* [19].

The proposed purposes of Lightens product are centered around their definition of *Human-Centric Lighting*, and includes topics like improved circadian rhythm, enhanced drug efficacy and other medical purposes, general health improvements and well-being, better task light, higher staff productivity, increased concentration and energy, increased motivation, biorhythm adjustment for night shift workers, energy savings, improved learning and individual light for special tasks. Of dynamism, the system suggests controlling of light levels, color and color temperature, scheduling and having personal profile and data affect the lighting dynamically. Lighten has a general strong focus on human needs.

Dynamic factors: Dynamism through software and personal lighting profiles. Controlling light intensity, color and color temperature over time and in relation to individual needs.

Proposed purposes: Affect mood, well-being, medical treatment, personal biological adaptation, improved performance and concentration, specialized task lighting and health improvement.

2.2.2.1.7 ZUMTOBEL

Zumtobel offers a wide range of fixtures that are controllable, with a focus on dynamic light levels and color temperature [20]. Additionally, Zumtobel have a website dedicated to the meaning of dynamic lighting for human needs, which they call *Active Light* [21]. *Active Light* is divided in three levels of light qualities and four dimensions of the dynamic lighting. The light qualities are the visual, emotional and biological needs. The dynamic dimensions are intensity, direction, color and time. However, the *Active Light* does not cover functional task lighting.

> *"Visual, emotional and biological needs are fully supported by a blend of Active Light and additional workplace-oriented lighting for work during the day and the night.", [21]*

Zumtobel suggests that holistic lighting enhances wellbeing in office spaces, and of other purposes they mention supporting the circadian rhythm, visual comfort, promoting creativity, personalization to focus on the individual, encourage social activity and improve productivity.

> *"Wellbeing in office spaces is enhanced by holistic lighting ecosystems. Active Light is linked to daylight dynamics, actively supporting the natural bio rhythm and seamlessly ensuring maximum visual comfort for tasks. Such human centric lighting solutions bring people together and promote creativity, as they are effortlessly personalized, with the individual always at heart.", [21]*

Zumtobel also refers to the term Human Centric Lighting. Their interest in using dynamic lighting with personalization is expressed with the following:

> *"The aim is to create a world of experiences linked to various types of personalities that activate our senses and guide our perception, drawing people to what stimulates them and crafting a lighting environment for every kind of individual." [21]*

Dynamic factors: Dynamic light intensity, color, timing, direction, sensor technology and personalization.

Proposed purposes: Affect mood, increase well-being, support circadian rhythm, provide creative inspiration, increase productivity and visual comfort. Encourage social activity.

2.2.2.1.8 FAGERHULT

Fagerhult discuss the topic of *Light for humans* and how dynamism helps controlling our dynamic clocks, or circadian rhythm. Fagerhult seem to focus intensely on mimicking the natural daylight throughout the day.

> *"The fact that blue light activates and warm light calms, in increasing substantiated, it is all about imitating the natural light and its variation that has controlled our biological clock since the origin of life. With dynamic light we can see that the biological clock keeps time, especially during the dark months, or in rooms with limited access to natural light.", [22]*

Fagerhult also suggest the use of light showers that provides cold light in short periods for increasing activity levels in for example school environments. While they mostly describe the manual adjustability of their products, to support different activities like teamwork or relaxation, they also have a technology called *e-Sense Tune* [23] advertised as being *"a true human-centric lighting solution, giving users the opportunity to work in a lighting environment that supports alertness and wellbeing."*. e-Sense Tune provides a decentralized solution for personalized lighting that follows the users and controls the lighting dynamically when one enters a room.

For dynamism in open plan offices Fagerhult suggest the hypothesis that *"Open plan offices cannot be controlled to reflect each individual's personal preferences since the room is lit for a group of people."* [24], a limitation not found discussed in the material of the other companies in the analysis.

In their material, Fagerhult distinguish between subjective and objective well-being, without further explanation.

Dynamic factors: Dynamic light intensity, color temperature, timing, sensor technology and automated personalization of fixtures in some situations. So-called *light showers*.

Proposed purposes: Improve subjective and objective well-being, increase activity, support the circadian rhythm, support types of activities, increase alertness and strengthen the sense of natural daylight.

2.2.2.1.9 OSRAM

OSRAM evolve their description of dynamic lighting for human needs around Human-Centric Lighting as have been seen in several other evaluated manufacturers. Of dynamic parameters, OSRAM states

> *"Dynamic lighting solutions are especially noticeable with high impact, i.e. white or coloured light that modifies its colour, direction or intensity.", [25]*

Regarding purposes of using dynamic lighting, OSRAM mention "*visual comfort, biological effect and emotional perception to support people in their architectural-functional surroundings."* [26], and they suggest that *"natural light is the best light"*, which is the reason why they seek to achieve the most natural-like light as possible by using an intelligent combination of artificial and natural light, in their own words.

Additional purposes are effects of relaxation, activation, concentration, attention and alertness, and considerations about circadian rhythm and the chronotypes of individuals.

Dynamic factors: Dynamic light intensity, color, timing and sensor technology.

Proposed purposes: Visual comfort, biological effects like supporting the circadian rhythm, emotional perception, a relation to the architectural-functional surroundings, imitate natural light, relaxation, performance, concentration and activation. Support different chronotypes.

2.2.2.1.10 HELVAR

Helvar states that Human-Centric Lighting consists of changing color and intensity of white light in relation to the needs of the users [27]. The focus is the circadian rhythm, however Helvar also suggests tuning light during the day to support temporary needs, like calming warm light to reduce stress or cooler light for energizing. In a white paper by Helvar about Human Centric Lighting, Helvar introduces more medical oriented purposes.

> *"In healthcare, patients can experience enhanced medicated efficacy, reduced therapy periods and capacity requirements and stimulation by light despite outdoor conditions.", [28]*

Helvar mention increased concentration and decreased fatigue in education, improved performance and employee satisfaction in work places, adjustment for night shift workers and lower error rate of repetitive work steps.

Dynamic factors: Light intensity and colored white light.

Proposed purposes: Support the circadian rhythm, support temporary needs, reduce stress, enhanced medical efficacy, reduced therapy periods, increase performance and concentration, decrease fatigue, support needs of night shift workers.

2.2.2.2 Investigated Lighting Concepts

The following sub chapters are investigations of some of the relevant lighting concepts related to dynamic lighting for human needs.

2.2.2.2.1 LIGHTING FOR PEOPLE

Lighting for People is a project that facilitates open innovation, creating collaborations between knowledge institutes, companies, customers, municipalities, schools and other interests. Lighting for People provides a website with a large collection of material about lighting for human needs with a focus on the term Human-Centric Lighting. Beyond the typically proposed purposes of dynamic lighting for human needs, like supporting the circadian rhythm, increasing alertness et cetera, Lighting for People provides the report *"Lighting for health and well-being in education, work places, nursing homes, domestic applications, and smart cities"* [29] from 2014, which describes in detail many of the means and purposes of lighting for non-visual human needs. The report mentions the relevancy and effects of transitions between lighting conditions.

> *"Not only the absolute light level, but also the relative light level in comparison to prior light exposure and/or the concurrent ambient light determine the extent of non-visual effects. A person coming from dimmer light may be expected to show stronger responses to subsequent light exposure than a person that had a brighter preceding light exposure.", [29, p. 5]*

In such situations, the perceived lighting conditions are dynamic - shifting from one state to another, whether it is due to the user moving between different spaces, or simply a change in lighting within one space. Specifically, for education the report recommends dynamic means like possibility for personalization, support different types of activities and automated adaption to the outdoor natural light [29, p. 12]. For workplaces, the report notes that individuals have substantial variations in preferred light settings, again suggesting the importance of considering possibility for personalization [29, p. 21].

Dynamic factors: Dynamic light intensity, color temperature, duration of exposure, effect of transition, personalization.

Proposed purposes: Support circadian rhythm, increase alertness, concentration, performance. Increase general health and wellbeing. Reduce aggressive behavior and agitation in education.

2.2.2.2.2 DOUBLE DYNAMIC LIGHTING

Tridonic, iGuzzini, Fagerhult and Zumtobel have partnered with Aalborg University in Copenhagen in an ongoing research project investigating the concept *Double Dynamic Lighting*, which is based on the dynamic potentials that exist in the interplay and relation between the indoor electrical lighting and the natural light. In this case, the dynamic means are the combination of other means like dynamic color temperature, intensity and the dynamism of the natural light coming from the outside.

> *"Double Dynamic Lighting is the name of this study carried out by PhD fellow Sofie Linnebjerg under the direction of Prof. Dr. Ellen Kathrine Hansen, Aalborg University Copenhagen. The study will investigate the spatial properties of a dynamic lighting environment and the influence on users' wellbeing. The lighting is approached as a tool for the everyday user of a workplace to stimulate different activities over time." [30]*

In the article *Architecture for the Senses*, lighting designer and artist Christina Augustesen discussed the concept of Double Dynamic Lighting and how she used this in a lighting design for the Novo Nordisk Headquarter in Bagsværd, Denmark.

> *"The shape of the atrium's apertures and the building control system makes it possible to combine and regulate the resources of the daylight and the artificial lighting alike. Thus, it is possible to work with [what] can be called a 'double dynamic' setup, which combines the natural dynamic of the skylight and daylight – as well as the dynamics that occur when the intensity and colour temperature of the artificial lighting are changed over time." [31]*

In the study "The Luminaire Window" by Hansen and Horóczi, such double dynamic potentials were investigated. In the qualitative experiment where LED's with adjustable color temperature and intensity were installed in the frame of a window, to support and create interplay with the natural daylight, they found:

> *"The findings from this pilot experiment, concerning the design and testing the concept of a luminaire window, illustrate that dynamic LED light integrated into the top of a window has potentials to meet human needs for light supporting circadian rhythm, enhancing the contact to nature, and at the same*

> *time creating an even and natural light distribution in the interior space, boosting the daylight without limiting the intake.", [32]*

While the proposed purposes include typical purposes like supporting the circadian rhythm, supporting different activities over time, improve wellbeing and enhancing the contact to nature, the Double Dynamic Lighting research project continuously and more holistically explores the purposes which could arise from designing and utilizing a spatial interplay between the dynamic electrical lighting and the incoming dynamic natural light.

Dynamic factors: Dynamic light intensity, color temperature, and their spatial interplay with incoming dynamic natural light.

Proposed purposes: Support circadian rhythm, improve wellbeing, support different activities dynamically and enhance the contact to nature (possibly related to biophilia). Additional, but under ongoing exploration: Potential purposes created because of the spatial interplay between dynamic electronic lighting and dynamic natural light.

2.2.2.2.3 HUMAN CENTRIC LIGHTING SOCIETY

Human Centric Lighting Society is a commercial interest group run by a committee of researchers, contractors, lighting designers, customers and others. This is particularly relevant, as several of the investigated dynamic lighting industry interests use the term Human Centric Lighting to describe the purposes of their technology that seeks to meet human needs.

> *"We are in the process of formulating an evidence based qualification guideline to provide 'Human Centric Lighting' certification service. The purpose of forming a new standard is to bridge the gap between academic research & mainstream project applications.", [33]*

Above is part of the mission statement by the interest group. To understand the purposes behind their mission to introduce Human Centric Lighting in mainstream project applications, they refer to an article about Human Centric Lighting by Stan Walerczyk. He describes how the human lighting needs have evolved with Earth's natural lighting cycle and the intensities and color temperatures related to this, suggesting that *"Without regular and direct exposure to such dynamic lighting, the circadian rhythm can be disrupted, which could lead to health issues."* [34, p. 20]. The purpose of using dynamic lighting to prevent health issues is consistent with the proposals by most of the investigated industry interests. Stan Walerczyk lists the benefits of this:

"During the day, with a natural circadian rhythm, appropriate amounts of dopamine are secreted for pleasure, alertness and muscle coordination; serotonin for impulse control and carbohydrate cravings; and cortisol for stress response. During the night, melatonin allows for sleep, and refreshes our body." [34, p. 20].

Light's effect on carbohydrate cravings has not been suggested as an effect or purpose in the earlier investigations. Human Centric Lighting Society also discusses *biophilia*. The *biophilia hypothesis* is, according to Encyclopædia Britannica, an *"idea that humans possess an innate tendency to seek connections with nature and other forms of life.* [35]. By designing with an understanding of our physiological relation to nature as a mean, Human Centric Lighting Society proposes purposes like increased performance and stronger social bonds.

However, the industry's use of the term Human Centric Lighting is receiving criticism. In an article by Tom Zind from 2018, he writes *"But as fast as HCL has become trendy, there's anything but consensus around it —*

on what it really is, how to actually design it, and even whether the lighting industry should be promoting its deployment." [36, p. 1]. These claims are backed by Deborah Bernett, a lighting designer and researcher, as Zind quotes:

> *"Burnett, part of a cadre of researchers studying links between light and human health, says there's a risk that some solutions marketed as HCL may reflect only a surface understanding of the complex light-brain/body connection. The danger, she says, is that many may latch on to the HCL buzzword and promote lighting solutions whose purported value may be difficult to measure, limited in scope, and possibly even counteracted by unforeseen negative consequences.", [36, p. 2]*

The debate surrounding the term Human Centric Lighting is ongoing, and due to the criticism and apparent lack of consensus, this term will be used with caution.

Dynamic factors: Dynamic light intensity, color temperature and duration of exposure. A relation to nature.

Proposed purposes: Support the circadian rhythm, pleasure, increased muscle coordination and productivity, some effect on carbohydrate cravings, general well-being and health. Satisfy potential biophilia.

2.2.3 Findings

To understand which main dynamic lighting means and purposes are currently widespread in the industry and practice of dynamic lighting for human needs as found in the prior material collection, these will be summarized and categorized.

2.2.3.1 Dynamic lighting technologies for human needs

In the prior chapters material has been collected to discuss the research question "Which dynamic lighting technologies are available from the industry, and what are their proposed purposes related to lighting for human needs?". This chapter discusses the dynamic lighting technologies.

From the collected material, the most commonly found dynamic lighting means were changing light intensity and color temperature over time. The temporal aspect is approached with different technologies based on preprogrammed task related scheduling, preprogrammed scheduling related to the circadian rhythm, manually activated scene presets for spaces or individual adjustability of fixtures, and automation based on sensors. Common sensor types are daylight sensors and occupancy sensors. Additionally, several companies use data to define and drive the dynamic changes, and the data is derived from both extensive internet sources, especially for the Philips Hue product, but also data from personalized user profiles used by several of the companies in different ways. Several companies mention dynamic direction without discussing how this is achieved.

Of more noticeable dynamic means, the effect of transitions is mentioned by Lighting for People, in the sense that *"the relative light level in comparison to prior light exposure and/or the concurrent ambient light determine the extent of non-visual effects"* [chapter 2.2.2.2.1]. This is particularly relevant to understand the human needs holistically, as it binds together all the different sequential activities or tasks one is designing for in a lighting design case. Lighting for People also discusses how the duration of light exposure has different effects for different purposes, with Fagerhult providing an example of this using the term "light showers", which are brief exposures to specific light settings for different purposes. The concept Double

Dynamic Lighting introduces the dynamic mean existing as a combination of means used in indoor electrical lighting and the dynamism of the outside natural light.

Several companies suggest the use of a relation to nature as a mean with different purposes, linked by Human Centric Lighting Society to the *biophilia hypothesis*.

Summary of dynamic lighting means found in the material from the companies and concepts:

- Changing light intensity over time
- Changing color temperature over time
- Changing color over time (color temperature + full color)
- Dynamic daylight
- Changing light distribution over time; distribution, direction and uniformity
- Preprogrammed scheduling for tasks
- Preprogrammed scheduling for the circadian rhythm
- Manually activated scene presets
- Individual adjustability of light intensity and color temperature of fixtures
- Automation based on sensor; daylight sensors and occupancy sensors
- Data as a basis for dynamic changes; internet services and personalized user profiles
- Relative differences in lighting between spaces (transition effect)
- Durations of exposure (for example "light showers")
- Dynamic effect of combining electrical lighting and outside natural light (double dynamic lighting)

2.2.3.2 Dynamic lighting purposes for human needs

The most commonly found proposed purpose of dynamic lighting for human needs was to support our circadian rhythm. Supporting the circadian rhythm, divided into the support of individual chronotypes by some companies, holds several sub purposes, as suggested by iGuzzini [14, p. 6]. These sub purposes include improved health and general well-being by providing healthier and more natural sleep patterns, which then result in possibly improved case related effects like task performance, productivity, concentration, alertness, mood, activity level and reduced stress and fatigue. The mentioned case related effects are also proposed by several of the companies as separate purposes which can be achieved individually using different dynamic lighting means not related to the circadian rhythm.

The investigated companies, including those using the term Human Centric Lighting, rarely reference the scientific background for their proposed purposes and effects on human needs, however research is continuously done within the effects those. Some of these effects will be discussed in a scientific context in the following.

The proposed purpose of increasing concentration and performance using lighting is supported by a German study from 2012 by Sleegers et al, concluding:

> *"First, the results of our field studies offer support for the positive influence of classroom lighting conditions on concentration. Although all pupils performed better at the concentration test at the consecutive measurement points, it appeared that the performance of the pupils in the experimental groups improved more than the performance of their peers in the control groups." [37, p. 171]*

The study by Sleegers et al was in 2016 referenced in a related study by K. Choi and H. Suk with more focus on dynamism, concluding:

> *"The purpose of this study was to identify the effects of different lighting CCTs on elementary students' performance, which can be applied as the basis for developing a dynamic lighting system in learning environments. Although the results from the laboratory experiment were not meaningful enough, the preliminary study and the field experiment fully supported a positive effect of 6500 K lighting on academic performance, and 3500 K lighting on encouraging recess activities." [38, p. 10]*

Regarding possible effects on mood, the study *Effects of dynamic ambient lighting on female permanent morning shift workers* by Canazei et al from 2012 suggests:

> *"Anxiety/Depression ratings were reduced before the start of the morning shift if subjects had been exposed to a dynamic lighting scenario for 4 weeks. Surprisingly, this effect was found in winter and summer", [39, p. 152]*

Their findings relate to both the effects on mood and the importance of considering seasonal differences, suggesting *"To our knowledge, we are the first to report mood enhancing effects of a blue-enriched bright light on healthy subjects during summer."* [39, p. 152], and regarding the purposes of increasing productivity and reducing stress and a correlation with season:

> *"In winter the dynamic lighting scenario additionally improved productivity-related measures (mean relative handling time) and reduced a physiological stress indicator (very low power frequency HRV) during shift work." [39, p. 151]*

Several companies propose the purposes of supporting multiple types of activities and special tasks, both individual and in groups. Helvar uses night shift workers as an example of a general special task type which can benefit from dynamic lighting. Other related purposes are the support and encouragement of social activity. These proposed activity purposes can be seen as different contexts that represents different sets of purposes and human needs. For night shift workers, the needs could be focused around supporting the circadian rhythm, wellbeing and performance, while social activity in some cases could focus on how to affect mood and create a cozy atmosphere, or in other cases aim to increase team work and productivity.

Regarding purposes related to architecture, spatiality and the environment outside, several companies propose the intention to strengthen the sense of natural daylight and positive effects of this, and CoeLux goes a step further by providing technology that seeks to replicate the phenomenon of direct sunlight and blue sky. The potential dynamics in electrical versus natural light also includes the concept Double Dynamic Lighting as discussed by Christina Augustesen and the ongoing research project from Aalborg University in Copenhagen and partner companies.

Human Centric Lighting Society suggests the purpose of satisfying potential biophilia and by that provide a positive sense of the outdoor nature indoors. OSRAM and USAI propose the purpose of creating a relation to the architectural-functional surroundings and create awareness of the location.

Several companies discuss the medical possibilities of dynamic lighting. Purposes are actual medical treatment using dynamic light, but also effects like reduced therapy periods, enhanced medical efficacy, and Human Centric Lighting Society suggests increased muscle coordination and an effect on carbohydrate cravings. What the *effect on carbohydrate cravings* is was not clear in the collected material, however investigating this led to the study *Timing and Intensity of Light Correlate with Body Weight in Adults* by Reid et al, concluding

> *"In conclusion, the findings of this study indicate that the temporal pattern of light exposure during the daytime can influence body weight independent of sleep timing and duration. Further studies are needed to understand the causal relationship and mechanisms linking biologically appropriate and inappropriate light timing with weight. Nevertheless, light is a powerful biological signal and*

> *appropriate timing, intensity and duration of exposure may represent a potentially modifiable risk factor for the prevention and management of obesity in modern societies." [40, p. 10].*

This may suggest a possible purpose of affecting the user's body weight with the use of *temporal pattern of light exposure*, which is dynamic lighting. This may be related to how light affects the quality of sleep and wakefulness, and the production of serotonin, which is known to affect carbohydrate cravings [41]. There is no indication that this is directly linked to the *effect on carbohydrate craving* proposed by Human Centric Lighting Society, but due to the relevancy of the proposed purpose in the conclusion of the study, it is included in these findings.

In relation to education, several companies propose the purpose of increasing learning and social activity in schools, and Lighting for People suggests the purpose of reducing aggressive behavior and agitation in education.

Another important aspect mentioned by many of the companies is the purpose of approaching some of above mentioned purposes on a personal level, allowing for individual personalized utilization of dynamic lighting means to meet the personal human needs which depends on age, chronotype, illnesses, visual needs, personal visual and mood preferences et cetera.

Visual comfort and acuity is also a common purpose of dynamic lighting, as well as the environmental and economic benefits of using dynamic lighting wisely to reduce energy consumption.

Summary of purposes proposed by the companies and concepts:

- Support the circadian rhythm, chronotypes and quality of sleep
- Support general wellbeing (including reducing stress and fatigue)
- Support general health
- Improve performance in functional tasks (including performance, concentration, alertness and level of activity)
- Affect mood for different situations
- Support effects of seasonal changes
- Support multiple types of activities and special tasks dynamically throughout a case and in the day cycle (different contexts, including, but not limited to, individual work, team work and increasing learning in education)
- Support social activity
- Support the connection with nature (including biophilia)
- Support the spatial relation to the architecture
- Support medical treatment, therapy
- Provide medical lighting therapy
- Support individual acute adjustability
- Support personal needs for circadian rhythm, health, therapy and mood (including influencing parameters like age, chronotype, illnesses)
- Support visual comfort and acuity

2.3 Problem Statement

The findings from the pre-analysis serve as a foundation and reference for a problem statement that will seek to investigate the problem related to the vision. After the collection of knowledge related to the vision, the problem statement and following analysis will reflect the vision's quest to develop a holistic understanding of the complexity of available dynamic lighting design means and particularly their

proposed purposes. This should be done through the development of a model which, in extend to help achieve a holistic understanding, also could help discover new dynamic potentials for lighting design cases working with human needs. The problem statement therefore is as follows:

- How can dynamic lighting design be represented in a model to help discover new human potentials for everyday dynamic lighting design?

2.3.1 Context and Limitations

The following analysis should be seen in the context of typical "everyday lighting" unless other contexts are stated. Everyday lighting refers to lighting in different types of typical work environments, offices, education and homes. These will not be specified in detail as the discussions are often abstractions and more general ideas that would fit some or many purposes, each of which would require individual in-depth considerations per context, and that lies beyond the scope of this project. However, the intention of solving the problem and the final design are not limited to this context, as the vision is open for a wider range of possible contexts and cases.

3 Analysis

The following analysis will seek to understand and find answers to the problem statement.

3.1 Approach

To develop the basis for the design of the model that should help solve the problem, the findings from the pre-analysis will be analyzed and discussed in the context of the problem statement. By evaluating and discussing the interrelations between the means and purposes found to be part of dynamic lighting for human needs, the analysis will try to find answers that can help the development of a model, that provides a holistic understanding of human needs in a lighting design case and reveal new dynamic lighting design potentials.

3.2 The dynamisms of the available lighting means

This will be an analysis of the dynamic lighting means found in the collected material of the pre-analysis. As the means are understood as being dynamic, this involves different parameters that change in time and space in different ways for different contexts, and to develop an overview and holistic understanding, these parameters and contexts will be discussed. The contexts are to be understood from the perspective of one individual and the related human needs. As the dynamism happens in space and time, the dimensions related to the means will also be discussed. The summary from the Findings will be the basis for this analysis, however they will be grouped into means that share relatively similar parameters.

3.2.1 Changing basic light qualities over time

This includes changing light intensity, color temperature and color over time. These represent the main light quality parameters in a fixture, which can be changed dynamically through wireless or wired control (Bluetooth, WiFi, DALI and more), or through inbuilt sensors, user interface with buttons and alike, or scheduling. The dimension in which these parameters are changing is time. The light quality parameters can be set differently within areas of a space but doing this for dynamic lighting purposes is more related to the light distribution than the basic light qualities. The light quality parameters are essential to dynamic lighting and therefore part of most, if not all, dynamic lighting contexts, however these are not defined by the parameters themselves.

Changing light qualities (intensity, color temperature, color) is the main parameter. This mean relates to time explicitly, and the contexts in which it can be used is not defined.

3.2.2 Changing light distribution, direction and uniformity over time

Distribution, direction and uniformity imply dynamic changes in the light quality parameters from one or more fixtures, or from the dynamic daylight, or a combination of both (double dynamic lighting), in areas of a space. The division of a space into different areas is a parameter that enables dynamic changes in distribution, direction and uniformity. Uniformity is regarded as a form of distribution quality or type. Direction relates to the angle of the light and can be seen as a parameter on its' own. The distribution parameter and division of a space suggest the existence of different potential contexts which differ in relation to the area and location the user is experiencing the light from. This context will be called the individual location context.

Distribution (division of space) and direction is the main parameters. This happens in both time and space. The context is based on the location of the individual.

3.2.3 Dynamic daylight

Using or "harvesting" the dynamic daylight automatically includes the changing light qualities of the sunlight and skylight, as well as the spatial distribution, direction and the impact on uniformity. Both the light quality parameters and the distribution parameters of the daylight are uncontrollable to some degree. The light output of the sun and sky cannot be changed, but its use in a space and over time is automatically dynamic and ever changing and can be used dynamically using architectural means like window shades, light wells, filters, reflectors, shutters and the basic location and design of the space. Daylight changes dynamically throughout the day, but also throughout the seasons and the year, depending on the context of geographical location and weather. Therefore, the dimension of time should be understood in contexts of time *ranges* and how they relate to lighting and human needs. How the daylight affects the needs of the individual depends on the individual's location in the space, and by that implying a relation to the individual location context. The daylight also depends on the time of day and year and latitude, and its impact will differ significantly between day shift workers and night shift workers, suggesting the importance of considering period contexts. The period contexts will not be called individual, as a period is the same for all individuals in the given period. Time ranges are not considered to be period contexts, as the time ranges are predefined (day, season, year etc.).

The main parameters are daylight light qualities (partly controllable), daylight distribution, daylight direction (angle of sunlight), weather (uncontrollable) and the concept of time ranges (day, season, year etc.). Dynamic daylight relates to both space and time. The context is based on the location of the individual, a period context and the geographical context.

3.2.4 Preprogrammed scheduling

Preprogrammed scheduling is a mean that seeks to relate and use other means in space and time. It generates changes in for example the basic light qualities and distribution over time, and possibly in relation to the expected daylight conditions. From the collected material, it was found that scheduling was also mentioned in the contexts of functional tasks and the circadian rhythm. As tasks are activities that happen over periods of different undefined or predefined durations, they will be called activity contexts. The term activity is used instead of the term task, to include all types of potential activities, not only tasks. Circadian rhythm can be understood in the context of a day cycle, called a circadian cycle, but it also holds the personal parameter of chronotype, involving individual distorted circadian cycles, sleep patterns and needs. The need for a personal parameter as an addition to other non-personal parameters also introduces a possible discussion about different layers of needs to consider in dynamic lighting design. A discussion about layers of needs will be done in the analysis of the found proposed purposes of dynamic lighting.

Preprogrammed scheduling relates to both space and time. It is relevant for the activity context, and circadian cycle context – possibly based on individual chronotypes.

3.2.5 Manual control

Manual control includes both individual and non-individual possibility to manually adjust the lighting settings of a space, with the purpose of creating dynamic lighting. From the findings, an example of non-individual manual control was "scene presets" that can change the lighting in larger spaces like open office environments with more than one individual. Individual manual control is the possibility to change the

lighting from specific fixtures relevant for the individual, in a single user space or in spaces with more users. The difference between single user spaces and spaces with more users introduces the existence of social context, which describes the number of users and possibly other relevant social conditions. If the lighting in a space with more users is controlled as a whole, not on the individual level, the chosen lighting settings could be the result of a social compromise of the users' individual preferences, introducing the parameter of social preferences.

The possibility of individually adjustable lighting parameters introduces the parameter of individual adjustability, which relates to personal needs and preferences. Individual adjustability is not to be confused with personal needs. Individual adjustability is understood as the possibility within a lighting system or in a fixture to change the lighting for meeting personal needs and preferences.

As the reason to allow for manual control is to allow for different lighting settings at different times and possibly in different areas, this involves the dimensions of time and space.

Interesting parameters are social preferences and individual preferences. Manual control relates to both space and time, and an interesting context to consider is the social context and number of users in a space.

3.2.6 Sensor based automation

This includes daylight sensors and occupancy sensors. More types of sensors exist, however only daylight and occupancy sensors were found discussed in relation to human needs in the collected material. Daylight and occupancy sensors are used as means to dynamically control light quality parameters, distribution et cetera. Daylight sensors can measure the light quality parameters of daylight (intensity and color temperature), at a specific point, or in an area if more sensors are used. Occupancy sensors, also called presence, activity or motion sensors, are often used for lowering energy consumption by reducing light intensity when a space is not in used. However, occupancy sensors can also be used to trigger dynamic lighting and transitions with purposes related to human needs for different activity contexts.

A main parameter is daylight light qualities (intensity, color temperature), as well as level of human activity. The use of sensors relates to both time and space and would often depend on activity context.

3.2.7 Data based automation

The companies and concepts use data in different ways for controlling dynamic lighting. This includes general internet-based data with information about weather, time, season, events and so on, as well as personalized user profiles holding data that is specific to the individual and his or her specific needs and preferences. Data is not necessarily related to time or space, but the dynamic changes would happen over time, and possibly with spatial dynamic changes as well. General data and personal data could hold practically an unlimited number of different parameters, but as these are not predefined, they will just be referred to as the parameters general data and personal data. The use of personal data as a dynamic mean introduces a personal context. This context includes a personal layer of needs: age, chronotype, illnesses, cultural background and all other relevant personal conditions influencing the human needs for lighting.

The main parameters are general data and personal data. These could affect and be influenced by both time and space. The use of data relates to activity contexts and personal context.

3.2.8 Transitions

Transitions and their use in dynamic lighting relates to achieving an effect from the relative difference in experienced lighting when the user moves between two locations or just between two points in time. Transitions are happening every time the lighting changes dynamically or a user moves between different lighting conditions. And no matter if these transitions affect the users intentionally or unintentionally, they are important when trying to understand dynamic lighting and its' effect on human needs holistically. In terms of dimension, transitions are something that exist between all activity contexts that could possibly have different lighting settings over time and space.

The main parameter is transition – the effect of relation between experienced light between two points in time. It relates to both time and space, because the user can experience transition when moving in or between spaces. The purpose of transition relates to activity contexts.

3.2.9 Duration

This includes the effect of duration of light exposure and "light showers". Using different durations of light exposure for different purposes is a simple mean holding a parameter that defines the duration of a period. The context is not predefined.

The main parameter is duration of exposure, which happens over time, and without a predefined context.

3.2.10 Double Dynamic Lighting

The mean Double Dynamic Lighting suggests the existence of a parameter which is a result of intentionally combining electrical lighting and the natural daylight. This parameter will be called double dynamism. The ongoing research project about Double Dynamic Lighting mentioned in the pre-analysis might reveal more or clearer parameters related to using this mean.

The double dynamism happens both over time and in the space. The contexts of use are difficult to define and could potentially include all contexts that are affected by the natural daylight. The ongoing research project could also provide further knowledge about which contexts double dynamism can add value to dynamic lighting design, but for now the contexts will be undefined.

Double dynamism (the use of Double Dynamic Lighting as a mean) is seen as a parameter itself. It relates to both space and time, and the context is not predefined.

3.2.11Summary

By analyzing the dynamism and dynamic factors involved in the means found in the collected material, several contexts related to human needs were found. Later, together with the following analysis of proposed purposes, these contexts, and how they are interrelated and can be structured to provide a holistic understanding, will be analyzed. The listed parameters of dynamic lighting means are the result of breaking down the proposed dynamic lighting means into more basic parameters, which can be used in different ways to achieve dynamic lighting purposes and meet human needs. The list can also serve as a reference of available parameters when discussing new dynamic lighting design potentials. The importance of some of the individual parameters and their role in the needs of the different contexts will also be discussed in the following chapters. In example, the time range parameter and personal chronotype relates to the circadian cycle, social preferences relate to social and activity context and daylight qualities relate to the period context and the needs of night- versus day-shift workers.

Contexts related to the dynamic lighting means:

- Circadian cycle context
- Geographical context
- Period context
- Activity context
- Social context
- Personal context (including the individual location context)

Parameters of the dynamic lighting means:

- Light qualities (intensity, color temperature, color)
- Distribution
- Direction
- Transition
- Duration (of exposure)
- Time range (day, season, year etc.)
- Daylight light qualities (including distribution and direction)
- Weather
- Social preferences
- Individual preferences
- Personal chronotypes
- Personal data
- General data
- Double dynamism (the use of Double Dynamic Lighting as a mean)

3.3 The contexts of the proposed purposes

This will be an analysis of the dynamic lighting purposes found in the collected material of the pre-analysis. The purposes will be discussed in terms of what type of contexts they relate to. Contexts are to be understood as the frames or boundaries of circumstances within a situation or scope. A context includes the human needs that exist because of the circumstances, for example circumstances like the time of day, geographical location, the needs for functional tasks if these are part of the circumstances, and the physical space, which also includes the available or planned dynamic lighting means and technology – and all other circumstances that can influence the needs and decisions for dynamic lighting design. The layering of needs and contexts will be discussed as suggested in the previous chapter. The summary from the Findings will be the basis for this analysis, however they will be grouped into purposes that can share relatively similar contexts.

3.3.1 General context

Some of the found purposes can be seen as being general, in the sense that they exist independent on context. They represent some of the common human needs that are important to consider under possibly all circumstances. They can vary from person to person, yet still represent general purposes for humans. Whether the biophilia hypothesis is true or not, it has been included as a general purpose because the contact with nature has been a purpose discussed by several of the investigated companies and concepts, but without specifying special contexts for its relevancy. Furthermore, the biophilia hypothesis has not

been found to suggest that it only applies under certain circumstances, but this could be investigated further if necessary.

The following purposes are considered to be aimed at meeting general human needs.

3.3.1.1 Support the circadian rhythm

The circadian rhythm is seen as a general purpose because it relates to human needs that exist because of our biological needs for keeping a healthy daily routine and sleep quality – needs which all humans have in common. Supporting the circadian rhythm was in the collected material found to be a widespread argument for using dynamic lighting. It is closely related to the time range of a day cycle, because the time frame of a circadian cycle is almost one 24-hour period but varying depending on differences in personal chronotypes. This time range was called the circadian cycle context in the previous chapter. The effect of personal chronotypes relate to the personal context. How the circadian rhythm should be supported can also depend on the time of an activity. Night shift workers can have other needs than day shift workers because night activities do not follow our natural circadian rhythm. This suggests the influence on activity context.

3.3.1.2 Support general wellbeing and health

Like for the circadian rhythm, supporting general wellbeing and health are purposes that are relevant to consider in all situations. While we have individual preferences and needs for wellbeing and health, we also share general human needs. Wellbeing and health relates both to a general context and a personal context.

3.3.1.3 Support effects of seasonal changes

Different seasons provide different natural daylight conditions, also dependent on the geographical location. This means that it also affects how a lighting designer can support the circadian rhythm. As the effect of seasonal change is uncontrollable and is not affected by activity or personal context, it is seen as a general purpose. However, it affects how to design for activity contexts, because activity contexts differ in geographical context and therefore have different seasonal changes.

3.3.1.4 Support the connection with nature

As discussed, if the biophilia hypothesis is true, we have a general human need to connect with nature. One could argue, that if a given activity context already provides enough connection with nature, the need for supporting this with light is less important, and vice versa – in places with very little or none connection with nature, this need is more relevant. This suggests the influence on activity context. It was not investigated whether biophilia differs from person to person, but if it does, this is a matter of personal context.

3.3.1.5 Summary of the purposes related to general context

From the purposes that are seen as being of general context, two other contexts were found to be relevant; activity context and personal context. The general context influences the activity context because of how the circadian cycle relates to for example night and day shift workers, and because of the effect of seasons and light conditions based on the geographical location of the activity context, as well as differences in the natural environment and need for considering biophilia. The personal context influences the basis of the general context, because personal chronotype, wellbeing and health needs represents variations of the general human needs of the general context. These interrelations are visualized below.

General → Activity

General ← Personal

The activity context and personal context and purposes related to these will be discussed in the following.

3.3.2 Activity context

Several of the purposes found in the pre-analysis directly suggests the relevancy of activity context. Furthermore, the purposes considered to be of general context also suggest the existence of activity context. The basis for the activity context is that some of the purposes and the needs they seek to meet depends on the type of activity and circumstances surrounding it.

The following purposes are considered to be related to needs that depends on the activity context.

3.3.2.1 Improve performance in functional tasks

The purpose of improving the performance in functional tasks is directly related to the character and needs for a specific activity context. To simplify, the term performance is considered to also cover similar terms like concentration, alertness and level of activity. It is assumed that the dynamic daylight and general health and wellbeing of the users performing the tasks also influence the performance, hence suggesting that the general context influences this purpose and activity context. Additionally, as the users can have individual needs and therefore different preconditions for performance, for example the age and vision of the user, the personal context also influences the performance in an activity context.

3.3.2.2 Support multiple types of activities

Several of the investigated companies and concepts propose the purpose of dynamically supporting multiple types of activities over a period. This means that when discussing lighting design for a case, the case can consist of sub activities, and therefore sub activity contexts. Therefore, the case context is introduced. The case context can be seen as the total period and sum of all activities which the lighting designer is design lighting for. The case context the consist of one or more activity contexts. The purpose of supporting multiple types of activities includes other purposes like affecting the mood in different situations, supporting social or individual activity in different ways, and allowing for individual adjustability to support individual needs for different activities.

3.3.2.3 Support social activity

The need for social activity depends on the activity context. In some situation the lighting could support team work, or informal and social lunch breaks, and sometimes individuals are intended to work alone. Because it has been established that the lighting could support multiple types of activities within a case context, the need for supporting social activities relates to the individual activities and not necessarily the whole case context. One could also argue that humans have a general need for social activity, but that is covered in the general human needs discussed in the general context.

3.3.2.4 Support the spatial relation to the architecture

Different lighting design cases involve different architecture. Even at the level of sub activities of a case, architecture can play different roles. Therefore, the purpose of supporting the relation to the architecture is considered to be part of the activity contexts – and by that also the case context. The architectural aspect is influenced by the general context (geographical location, daylight conditions et cetera).

3.3.2.5 Support individual adjustability

The purpose of supporting individual adjustability relates to preferences and needs of the user in a given activity. The need for this individual adjustability only exist in relation to an activity, and not because of general personal needs. This implies that the activity contexts include the aspect of individual context. The individual context of an activity context is not to be confused with the personal context. This is because the personal context holds the personal needs, which exist independent on the activity. The individual context holds the need for individual adjustability arising from the relation between personal needs and the activity conditions.

3.3.2.6 Support visual comfort and acuity

The purpose of supporting visual comfort and acuity depends on the task, or activity context. Visual comfort and acuity depend on both general human needs and the personal age, wellbeing and vision of the user.

3.3.2.7 Summary of the purposes related to activity context

Several purposes are directly related to specific types of activity contexts. It was suggested that, because of the need to design for multiple types of activities, activity contexts exist under the umbrella of a case context. The case context and underlying activity contexts are influenced by the general context because general human needs are relevant to for example the purpose of improving performance and visual comfort tasks. The relation between the personal context, the activity context and the purpose of individual adjustability suggested that activity contexts hold the aspect of individual context. The interrelations between the discussed contexts are visualized below, including the general context.

General → Case (→Activities←Individual) ← Personal

3.3.3 Personal context

The personal context holds all the personal human needs that differ from the general human needs. It includes the purposes of considering age, culture, chronotype, illnesses, supporting medical treatment, personal light therapy, affect personal mood, personal preferences and possibly many other personal aspects.

The purposes, found in the collected material, that are related to the personal context are:

3.3.3.1 Support medical treatment

This includes purposes like increasing drug efficiency and decreasing the time in bed while under medical treatment. As the needs for personal medical treatment does not disappear while doing a case activity, this personal medical context can have influence on the case and activity contexts, possibly implying a need for individual adjustability.

3.3.3.2 Provide light therapy

Light therapy was proposed to provide purposes like reducing stress, energizing and the support of other temporary or chronic needs that are personal and not necessarily related to a case or activity context. These

needs are not general human needs relevant for everyone. However, the needs can exist in case and activity contexts and therefore this supports that the personal context influences the activity contexts. Also, the seasonal changes and influence of different geographical locations on the circadian rhythm can result in the condition SAD (Seasonal Affective Disorder) [42] which can provide symptoms like stress and fatigue, suggesting that the general context of a case can have influence on the personal context and needs for light therapy.

3.3.3.3 Support personal needs for circadian rhythm, health and wellbeing

The general personal needs of supporting the circadian rhythm based on chronotype, specific health conditions, age, visual needs and illnesses, as well as mood, was mentioned by several of the investigated companies and concepts. These needs represent minor or significant personal modifications to the general human needs of the general context, and therefore they influence the activity contexts, resulting in the individual context of activity contexts.

3.3.3.4 Summary of the purposes related to personal context

The purposes related to the personal context influence the activity contexts. This is because personal conditions like age and illnesses have influence on activity related things like need for visual acuity for performance. The general context influences the personal context because seasonal changes in natural daylight can result in illnesses such as SAD, and such illnesses and their symptoms have been proposed to be treated with for example light therapy. The interrelations between the personal context and the general context and activity contexts are visualized below.

Case (→Activities←Individual)	←	Personal
General	← →	Personal

3.3.4 Interrelations between the proposed contexts

From the analysis of the contexts, the different purposes relate to, several relations between these contexts were found. In the quest to understand the purposes of dynamic lighting design holistically, these interrelations between contexts are combined and visualized below.

General	→ Case (→Activities←Individual) ←	Personal
General	← →	Personal

3.4 How the dynamic lighting parameters relate to the contexts

Understanding how the different contexts relate to the found dynamic lighting parameters could be of importance for creating a holistic understanding of dynamic lighting design for human needs. The dynamic lighting parameters will be discussed in relation to each of the contexts found in the previous chapter.

3.4.1 Dynamic lighting parameters in the general context

In the general context, the parameters of daylight qualities (intensity, color temperature, distribution, direction et cetera) are always existing. The parameter of time range is relevant, as the basic human need for circadian rhythm is related to the time range of a day, and the seasonal changes affects this as well. The parameter of double dynamism could be relevant, as it is influenced by the daylight, however double dynamism is not possible without the electrical light in a case context. The general data parameter can hold information that is related to the general context, for example information about different lighting needs for different chronotypes. The transition parameter is relevant because transitions in the daylight are happening constantly. These daylight transitions could potentially be used for different specific lighting purposes for meeting human needs. Weather is an uncontrollable parameter in the general context. Duration of exposure could also be relevant and utilized in the general context.

The general context does not imply the use of electrical lighting, as this is related to a case context, and the electrical light quality parameters (intensity, color temperature, distribution, direction et cetera) are therefore not relevant or required in the general context. The social preferences and individual preferences are considered to depend on the case context and not the general context. Personal chronotype and personal data is related to the personal context.

Dynamic lighting parameters in the general context: Daylight qualities (intensity, color temperature, distribution, direction et cetera). Time ranges. Weather. Transitions. Duration of exposure. General data.

3.4.2 Dynamic lighting parameters in the case, activity and individual context

The case context, with underlying activity contexts and their individual context, the parameters of daylight qualities are present. Electrical light qualities are the basis of the lighting design in the activity contexts. Time range is relevant because the time of a given activity context influence the daylight quality parameters. The most relevant time range is a day cycle, or circadian cycle, because most people have a daily rhythm where the activities of a case happen during typical school or working hours from morning till afternoon, or another period in the day for non-day shift workers. The importance of a day cycle or circadian cycle for a case context should be considered in the design. Transitions are important, for example between the activities in a case context. This however also suggest that there exists a relation between before the first activity and after the last activity of a case. From a circadian cycle perspective, this could for example be the night and morning before working hours, and the evening and sleep after the working hours. These before and after periods should also be considered in the design. Social preferences and individual preferences, personal chronotype and personal data exist as parameters in different activity contexts, because activity implies the involvement of one or more people. Duration of exposure is relevant, as the exposure could relate to and happen during the activities of a case. Double dynamism is highly relevant for the activity contexts, as the combination of daylight and electrical light would be experienced in relation to the activity context. General data can hold information about the lighting needed for specific activities and is therefore relevant.

Dynamic lighting parameters in the case context: Light qualities (intensity, color temperature, distribution, direction et cetera). Daylight qualities (intensity, color temperature, distribution, direction et cetera). Time range. Transitions. Duration of exposure. General data. Double dynamism. Social preferences. Individual preferences. Personal chronotype and personal data.

Additional criteria for the design:

- Use the day cycle or circadian cycle as the main time range of a case.
- Include the periods before and after a case context.

3.4.3 Dynamic lighting parameters in the personal context

The dynamic lighting parameters existing in the personal context are personal chronotype and personal data, covering all the personal needs and preferences. The individual context of an activity depends on the person, but also the activity context. These exist independently of the general context and case context. All the other dynamic lighting parameters exist independently of the personal context.

Dynamic lighting parameters in the general context: Personal chronotype. Personal data (needs).

3.5 Design criteria

From the analysis of the dynamic lighting means, several dynamic lighting parameters were suggested. How the means, parameters and proposed purposes relate to each other from a human perspective revealed different groups of contexts and how they relate to each other. These contexts and interrelations should be a critical basis for the design of a model, as they intend to cover how all the found dynamic lighting purposes relate to human needs and therefore represent a holistic overview of these. The contexts and interrelations are as follows.

General → Case (→Activities←Individual) ← Personal

General ← → Personal

Additionally, it was suggested that the designed model should use a day cycle or circadian cycle as the main time range of a case, meaning that the model should represent the beginning to the end of a day cycle. The relation between transitions and a case context also revealed the requirement to include the periods before and after a case, to provide a holistic understanding of how transitions and activities interact.

Some of the dynamic lighting parameters were found to be existing or a requirement in different contexts. To develop a model that can help discover human potentials for everyday dynamic lighting design, understanding how the dynamic lighting means, parameters and purposes relate to the contexts of the human needs seem important. Therefore, these should be provided in or as a supplement to the developed model. How the means, parameters and purposes relate to the contexts are described in the different chapters of the analysis.

4 Design and/or Experiment

Based on the results of the analysis and design criteria, the design of a model that seeks to solve the stated problem will be developed.

The analysis resulted in a description and interrelations of the main contexts that are relevant in the structuring of human needs in dynamic lighting design. The division into these contexts is based on the different types of purposes of dynamic lighting means found in the collected material. Some purposes are of a general human nature, like the circadian rhythm. Some purposes are directly related to an activity (or task) of a case, like improving performance, and some purposes are directly related to a personal context, for example the need for medical lighting therapy or support for personal chronotypes.

4.1 The axes of the model

The design criteria suggest that a day cycle, based on the circadian cycle, is the main time axis of the model. The circadian cycle differs from person to person, so this will be based on a 24-hour day cycle. The different contexts involved in dynamic lighting design for human needs also relates to time, in the sense that the general context relates to daylight and our general human needs for circadian rhythm. The case context exists within a day cycle, and all these contexts are affected by specific personal needs of the personal contexts. The second axis is there for decided to be represented as layers of contextual needs.

4.2 The layers of contextual needs

In this chapter, the design of the different layers of contextual needs will be developed.

4.2.1 The layer of general context

The general context consists of needs and conditions that are the basis for all cases, and therefore it is the first layer of needs. In the context of working with cases in day cycles, the general layer spans the entire time axis. It should be noted that the general context also is affected by higher time ranges like the seasonal impact on needs for circadian rhythm support. This will be included as a note for this layer. This layer can be seen in the two axes in Figure 3.

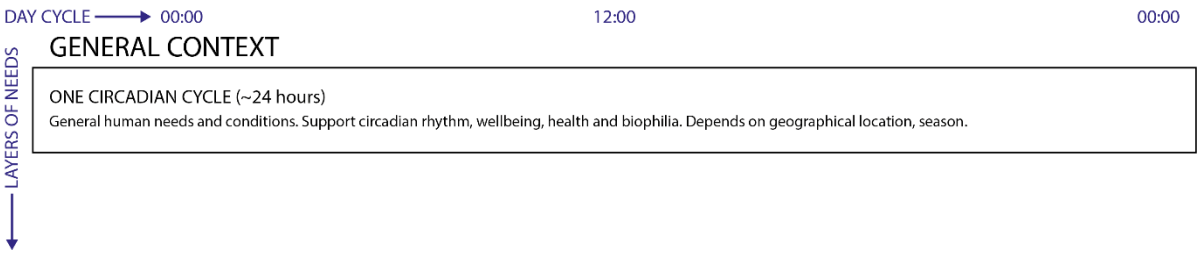

FIGURE 3 - LAYER OF THE GENERAL CONTEXT

4.2.2 The layer of case context

The case context itself holds needs and conditions that exist because of the type of case and activities. No matter what person is experiencing it, it can have some general case needs that are modifications or a higher layer on top of the general needs, and therefore this layer is decided to come after the general context. The case context was found to consist of several sub contexts, namely the activity contexts and individual context of these. This layer can therefore be divided into sub layers. The first sub layer holds the

general needs existing in the overall case context. This is for example affected by the geographical location, cultural conditions and type of case. The second sub layer holds the activities that happen within the case. And the third layer represents the individual context of the different activities.

The case context relates to the time axis in the sense, that it will typically be a period within a day cycle. A criterion is also, that the case context requires the representation of the periods before and after the case. As most people work from morning to afternoon, the case context is positioned in this period, however this will always depend on the individual case. For example, this would be positioned differently when working with lighting for night shift workers. The case context layer and sub layers in relation to the aces are represented in Figure 4. From the analysis and design criteria, it was found that the general context influences the needs of the case context, and this influence is represented with flow arrows. Flow arrows are also added to represent how the sub layers of the case context influence each other.

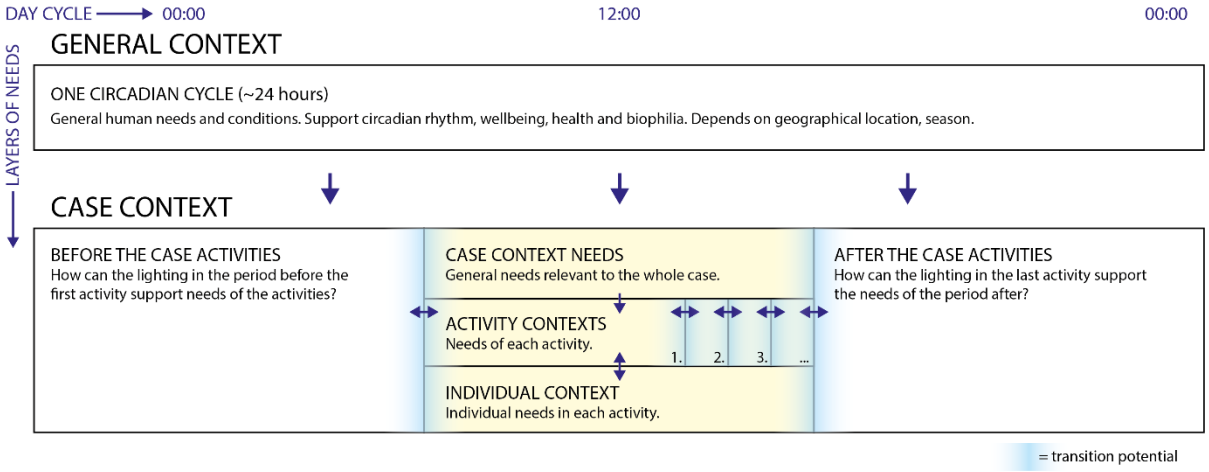

FIGURE 4 - LAYER OF THE CASE CONTEXT

4.3 The layer of personal context

The personal context holds all the personal needs that can be met with dynamic lighting. These needs are changing dynamically throughout our lives, because of age and non-chronic illnesses, and this layer is therefore relevant at any given time. The personal needs are seen as modifications or a layer above the general needs of the case context and is therefore positioned after this. Flow arrows are added to represent how the personal context is interrelated with the other layers. The layer of personal context and the relation to the axes is represented in Figure 5.

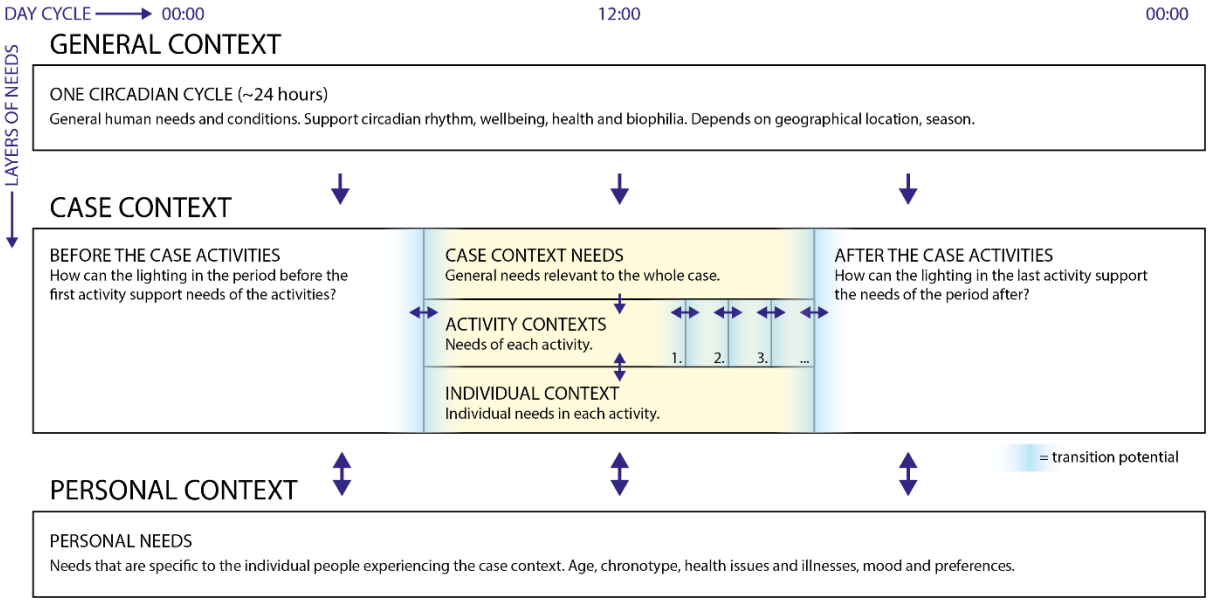

FIGURE 5 - LAYER OF THE PERSONAL CONTEXT

4.4 The design model of holistic dynamic lighting design for human needs

The findings from the pre-analysis and the results of the analysis have been synthesized into a design model that includes the contexts of needs and how they are interrelated. The contexts act as layers of needs, in the order of which they are relevant in a lighting design case. First, the general context represents needs that are general. These general needs affect the basis for the needs of the case context and activity contexts. After understanding the general needs of the case and activity contexts, these can be related to personal needs from the personal context. All the dynamic lighting purposes found in the collected material relates to one or more of the represented contexts, resulting in a design model that seeks to provide a holistic overview of how human needs relate to dynamic lighting design cases.

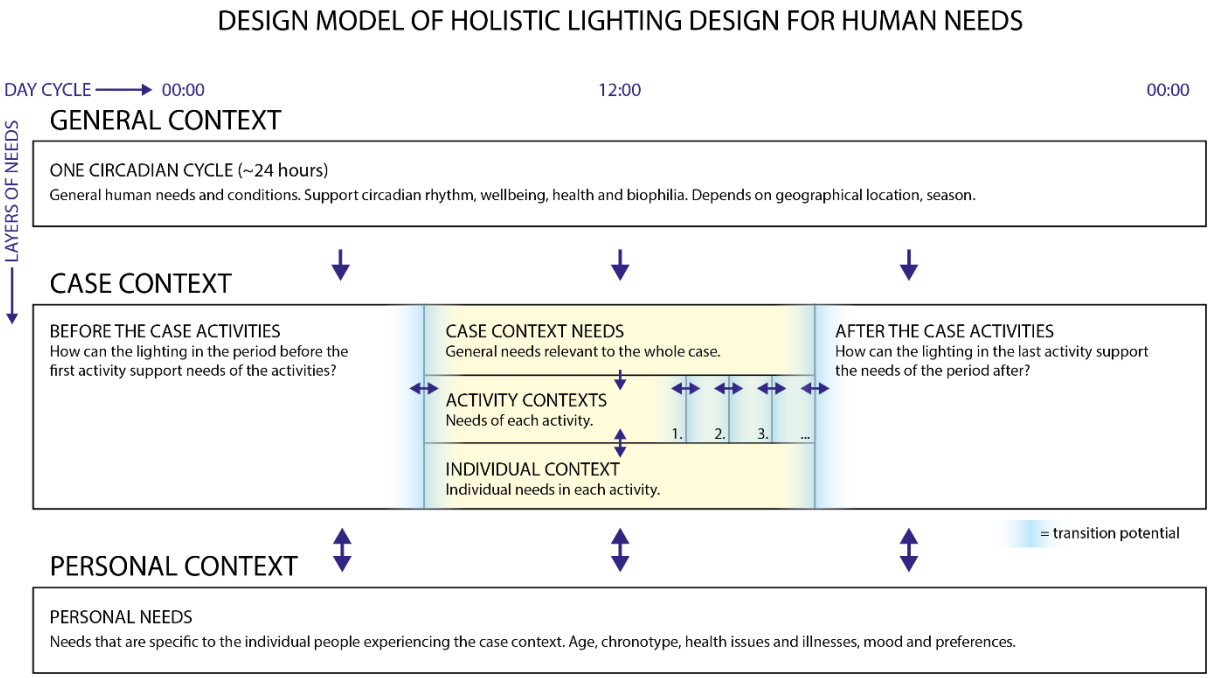

FIGURE 6 – DESIGN MODEL OF HOLISTIC LIGHTING DESIGN FOR HUMAN NEEDS

The purpose of the model, in addition to providing a holistic understanding, is to help discover new human potentials in dynamic lighting, as stated in the problem statement. The idea is that by relating a lighting design case to the different contexts in the model and discussing how and why they are interrelated for the given case, one could discover more human needs that can be met with the use of dynamic lighting means. To help understand the potentials in each context, a supplementary list of the found proposed purposes and the contexts they relate to is included, and a list of the found dynamic lighting parameters that are used to implement these potentials.

General context potentials

- Support the circadian rhythm
- Support general wellbeing and health
- Support effects of seasonal changes
- Support the connection with nature (biophilia)

Case context potentials (activity contexts and their individual context)

- Improve performance in functional tasks
- Support multiple types of activities
- Support social activity
- Support the spatial relation to the architecture
- Support visual comfort and acuity
- Support individual adjustability

Personal context potentials

- Support medical treatment and provide light therapy

- Support personal chronotype, health and wellbeing
- Support personal preferences

Dynamic lighting parameters used for implementing the available potentials

- Light qualities (intensity, color temperature, color)
- Distribution
- Direction
- Transition
- Duration (of exposure)
- Time range (day, season, year etc.)
- Daylight light qualities (including distribution and direction)
- Weather
- Social preferences
- Individual preferences
- Personal chronotypes
- Personal data
- General data
- Double dynamism (the use of Double Dynamic Lighting as a mean)

The design model might work for different purposes. The following three purposes are considered to be of interest.

Using the model as a reference for discovering new human potentials in dynamic lighting cases

- The purpose is to see if the model can work as a reference for considerations and discovery of dynamic lighting potentials for a specific case. The different contexts of the case are discussed, and from that a lighting designer can look at the potentials related to the contexts and decide what is relevant. After finding the dynamic lighting potentials for the different contexts, the lighting designer could investigate which dynamic lighting means and parameters are needed to exploit the potentials, and this would also reveal requirements for the fixtures and technology needed for the implementation.

Using the model to discuss new lighting research in a holistic context

- The purpose is to test if new potentials and purposes can be discovered by relating the lighting related findings of scientific research to the holistic overview of the different contexts. This might help discover new contexts in which the findings are relevant or interesting for future research projects. Ultimately, if the findings directly suggest new potential dynamic lighting purposes, these could be added to the supplementary provided with the model.

Using the model to analyze a dynamic lighting solution

- The purpose is to see if the model can be used to analyze existing lighting design solutions and understand how these might potentially meet more human needs by the use of the dynamic lighting technology already available in the solution, or by the addition of new technology and means. If the analysis reveals that the solution lacks considerations about relevant contexts, this could be an argument that the solution is not a holistic dynamic lighting design solution for human needs.

In the following chapter, the design model will be tested for its proposed purpose of helping discover new human potentials in a dynamic lighting design case.

5 Testing the model in a case

In this chapter, the design model will be used in an example cases to see if it can help discover new potentials in dynamic lighting for human needs.

It is important to note, that this test cannot directly verify if the design model helps discover *new* human potentials for everyday dynamic lighting design. Such verification would require comparisons between using and not using the developed model, and that is not possible in the scope and resources of this project. The test should therefore be seen as an experiment providing discussions and arguments that can be of interest in the evaluation of the developed model and whether it could solve the problem statement.

5.1.1.1 Using the model as a reference

This test will be based on a simple fictive dynamic lighting design case, where a lighting designer should develop dynamic lighting design for a typical office environment with multiple users in the hours from morning till afternoon. The purpose is to see if the model can work as a reference for considerations and discovery of dynamic lighting potentials for a specific case.

5.1.1.1.1 THE FICTIVE CASE:

A client has hired a lighting designer to design lighting for a new office building in Copenhagen, Denmark. The main space, and example for this case, is an open office environment with > 10 people. The employees work from 09:00 to around 17:00, or longer for some individuals. In the morning, the employees meet for different team work activities, followed by individual paperwork and computer tasks. Around noon they go to the canteen to have lunch break. After the break, the individual work continues. The ages of the employees range from 25 to 70 years old. One end of the office space is facing south, with a canal of water in front, the other facing north with another office building on the other side of the road.

5.1.1.1.2 THE CASE AND THE MODEL

The case will now be discussed in relation to the model and the different contexts to see if the model helps discover dynamic lighting potentials.

From the case, we know the geographical location, and how the daylight changes throughout the seasons. This helps define the basis for understanding the general needs in this general context. When these fundamental needs and potentials have been defined, the case context can be analyzed. The potentials are found in the supplementary list of potentials provided with the design model, however the lighting designer analyzing the case is encouraged to think of other potentials as well. The general potentials are:

- General context potentials
    - Potentials: Support the circadian rhythm, general wellbeing and health, effects of seasonal changes, connection with nature (biophilia).

From the model we see that we need to consider the different types of activities happening in the case period. We know that the activities in the space roughly is as follows, in order of occurrence; team work activities, individual tasks with individual needs, lunch break, individual tasks. We can also see from the model, that potentials exist in the transitions between the different activities, and in the transition from the period before the case, to the case, and after the case. In total, the model reveals the following activity contexts and transitions that dynamic lighting can be considered for, in running order from the morning hours.

- Transition from the morning hours and arrival to the first activity, team work
- Lighting for team work
- Transition from team work to individual tasks
- Lighting for individual tasks
- Transition from individual tasks to a social lunch break
- Lighting for lunch break
- Transition from lunch break to individual tasks
- Lighting for individual tasks
- Transition from individual tasks the period after the case – the evening

The lighting designer have already defined the fundamental needs and potentials from the general context, so now the dynamic lighting potentials in the activity contexts can be discussed. The following is in the order of occurrence, beginning from the morning hours.

- Transition from the morning hours and arrival to the first activity, team work
    - Potentials: Prepare for team work and energize for improved performance but respect the needs of the circadian rhythm in the morning hours.
- Lighting for team work
    - Potentials: Improve performance, support social activity, support special activity (team work), visual comfort and acuity. Support the spatial relation to the architecture.
- Transition from team work to individual tasks
    - Potential: At the end of the team work, provide lighting that prepares for individual work.
- Lighting for individual tasks
    - Potentials: Improve performance, support special activity (paperwork, computer tasks), visual comfort and acuity, individual adjustability. Support the spatial relation to the architecture.
- Transition from individual tasks to a social lunch break
    - Potentials: Prepare the individuals for social activity and mood suited for lunch break.
- Lighting for lunch break
    - Potentials: Support social activity.
- Transition from lunch break to individual tasks
    - Potential: Prepare the individuals for improved performance.
- Lighting for team work
    - Potentials: Improve performance, support social activity, support special activity (team work), visual comfort and acuity. Support the spatial relation to the architecture.
- Transition from individual tasks the period after the case – the evening
    - Potentials: Prepare the individuals for optimal evening relaxation if wanted and support circadian rhythm.

Additionally, the lighting designer should consider and decide which personal needs the dynamic lighting solutions should be able to meet. These potentials also define additional requirements for the lighting in the activity contexts.

- Personal lighting potentials
    - Provide acute light therapy to reduce stress and fatigue at individual office desks.
    - Provide light treatment for employees with SAD [42].

After defining the dynamic lighting potentials which the lighting designer wants to exploit, he or she could begin investigating how to achieve those, if it is not already known by experience. After finding what dynamic lighting means and parameters are needed to exploit the potentials, these will also define the

requirements for fixtures and technology needed for the implementation. The model or supplement do not provide exact suggestions about what lighting means are necessary to exploit the potentials however these relations are discussed throughout the analysis and could be developed into an additional supplementary reference list in future works.

5.1.1.1.3 RESULT

By using the design model for the fictive case, it was possible to discover a range of potentials that could be exploited to support the different contexts of the case. First, the basic general needs where established based on the circumstances of the general context. By relating the case and knowledge of the activities to the different contexts proposed by the model, as well as the interrelations between these contexts, human needs and potentials were considered for every activity context of the case, and every transition between these activities. By reading the list of proposed context potentials, the supplement to the model, and considering the activity contexts and transitions in the test case, ideas emerged that I am not sure I, as the conductor of the test case, would have thought of without the model, and if the model had not helped seeing the interrelations of the contexts holistically. However, due to the nature of the test, there is no data for comparison of the experimental variable of discovering new potentials, and therefore the results only serve the purpose of subjective opinion.

6 Discussion

The purpose of the test was to see if the design model, developed based on the analysis, could help discover new human potentials for dynamic lighting design. The result was, from the subjective experience of conducting the test, that there were indications that the model can be of help in the process of discovering potentials. Instead of focusing on individual activities or tasks of the test case to begin with, the general context was broken down into several contexts that are understood in relation to each other and therefore, if the design model works as intended, provided a foundation for holistic lighting design that meets the human needs of this test case.

Whether the result would have been the same or not without the use of the model is not possible to conclude from this test. As stated in the results of the test, the test did not provide data for comparison of the experimental variable of discovering new potentials, meaning that the indications from the test results are subjective to the author of this paper. It was considered, before designing the experiment, to also analyze the fictive test case without the use of the model, to have a comparison, but because I had already developed the model, I would not be able to avoid its' influence on the test results. Therefore, the test was conducted only using the model, with the purpose of evaluating it subjectively.

A suggestion for a future test could be a qualitative test where lighting design students or lighting designers with different levels of experience could try using the model on real cases followed by qualitative interviews. Qualitative tests are suggested due to the complexity of the topic of dynamic lighting for human needs, and interviews could reveal potential specific problems to be corrected before seeking quantitative feedback. However, to get indications, it could also include quantitative evaluation with questions regarding to which degree the model helps discover new human potentials in dynamic lighting and provides a holistic understanding.

It should also be noted, that this project's approach to the topic and definition of holistic dynamic lighting design is up for discussion. There was not found a clear existing definition of this, which also was one of the objectives of doing this project – to see if it was possible to contribute with a take on how to understand the complexity dynamic lighting design for human needs with a holistic overview.

7 Conclusion

Based on the vision [chapter 1.2], the pre-analysis was an investigation into the dynamic lighting technologies and means that are currently available from the industry, and the proposed purposes of these means in relation to dynamic lighting for meeting human needs. The collected material was the reference for the analysis of the problem statement [chapter 2.3]. In the analysis, the dynamic lighting means and their proposed purposes found in the collected material, were discussed in terms of human needs and which contexts they relate to in a lighting design case. This analysis helped the development of three main contexts, and their interrelations, to consider when designing holistic dynamic lighting for human needs, namely the general context, the case context and the personal context. The case context holds several sub contexts (activity contexts and individual context). The importance of considering transitions between activities was also suggested. The result of the analysis was the definition of design criteria, which were the foundation for the development of a design model that seeks to answer the problem statement. The objective of the design model was to help lighting designers discover new human potentials for everyday dynamic lighting design. A long with the design model, a list of the dynamic potentials for each context found in the analysis was supplied. To test if the design model could solve the problem, an experiment was conducted. In a fictive lighting design case, the model was used for the analysis and discovery of dynamic lighting potentials for human needs. Due to the nature of the test, there is no clear conclusion whether the design model solves the problem, however a subjective indication was that the model was of help in the discovery of new dynamic light potentials. It was suggested that future tests should involve more participants without prior knowledge of the model. It is also suggested that the model is tested for its ability to provide a holistic understanding of the complexity involved in dynamic lighting design for human needs.

8 Future works

While the process and development of this project has been of great inspiration for me, more work is needed to conclude whether the model is useful for the intended purpose. Most importantly, a more resourceful and better designed test should be conducted, to learn whether the model is helpful for two things; help discover new human potentials in dynamic lighting design and provide a holistic understanding of the complexity involved in dynamic lighting design for human needs.

As additions to the purpose of the design model, it was suggested that the model might be useful when considering how new lighting design related knowledge, from various disciplines, can provide dynamic lighting potentials in the different contexts in the model. It was also suggested that the design model can be used for analyzing whether existing lighting designs could meet more needs using dynamic lighting technology already implemented in the space.

The design model was supplemented by a list of the potentials found relevant for each context in the model. It is suggested that this list is continuously developed and updated to reflect new knowledge, research findings and new proposed purposes of dynamic lighting means.

9 Figures

10

11 Bibliography

[1] "Cambridge Dictionary - Meaning of “holistic” in the English Dictionary," [Online]. Available: https://dictionary.cambridge.org/dictionary/english/holistic. [Accessed May 2018].

[2] R. Antonsen, "Math is the hidden secret to understanding the world | Roger Antonsen," TED Talks, Oslo, 2016.

[3] G. Böhme, "Atmosphere as Mindful Physical Presence in Space," *Journal for Architecture,* vol. Building Atmosphere, no. #91, 2013.

[4] "Definition of Dynamic by Merriam-Webster," [Online]. Available: https://www.merriam-webster.com/dictionary/dynamic#h1. [Accessed March 2018].

[5] "Definition of Dynamism by Merriam-Webster," [Online]. Available: https://www.merriam-webster.com/dictionary/dynamism. [Accessed March 2018].

[6] "Philips Hue Bulbs | Wireless Light Philips Lighting," [Online]. Available: https://www.philips.co.in/c-m-li/hue. [Accessed February 2018].

[7] "Dynamic Lighting - Philips Lighting," [Online]. Available: http://www.lighting.philips.com/main/systems/themes/dynamic-lighting. [Accessed February 2018].

[8] "Human Centric Lighting - Philips Lighting," [Online]. Available: http://www.lighting.philips.com/main/education/lighting-university/lighting-university-browser/webinar/human-centric-lighting. [Accessed February 2018].

[9] "Personalized Lighting® as Defined by USAI Lighting," [Online]. Available: http://www.usailighting.com/stuff/contentmgr/files/0/58ad5e919608154c7a94bbd1afb5b1b0/files/personalized_lighting.pdf. [Accessed March 2018].

[10] "Circadian Lighting, Lighting's Impact On Circadian Rhythm | USAI," [Online]. Available: http://www.usailighting.com/circadian-rhythm-lighting. [Accessed March 2018].

[11] "Hubbell NX Distributed Intelligence - The Next Generation of Lighting Control," [Online]. Available: https://hubbellcdn.com/brochure/HCS_NX_Brochure.pdf. [Accessed April 2018].

[12] "iGuzzini - Light management systems," [Online]. Available: https://www.iguzzini.com/indoor-light-management-systems/. [Accessed 9 June 2018].

[13] iGuzzini, "iGuzzini Lighting," [Online]. Available: https://www.iguzzini.com/indoor-lighting/. [Accessed 9 June 2018].

[14] "iGuzzini - Topics&Tools - First Half 2018," [Online]. Available: file:///C:/Users/joknj/Downloads/Topics-Tools-01-2018-iGuzzini-EN-pdf..pdf. [Accessed 9 June 2018].

[15] "CoeLux - About Us," [Online]. Available: http://www.coelux.com/en/about-us/index . [Accessed April 2018].

[16] "New CoeLux® 45 SQUARE for wall applications," [Online]. Available: http://www.coelux.com/en/news/new-coelux-45-square-for-wall-applications-174. [Accessed April 2018].

[17] "Lighten P I L C S - Personalised Intelligent Lighting Control System," [Online]. Available: http://lighten.dk/. [Accessed April 2018].

[18] "Human Circadian System — LIGHTEN.DK," [Online]. Available: http://lighten.dk/human-circadian-system/. [Accessed April 2018].

[19] "Human-Centric Lighting 2.0 — LIGHTEN.DK," [Online]. Available: http://lighten.dk/human-centric-lighting-20/. [Accessed April 2018].

[20] "These products ensure that you get the best light - Zumtobel," [Online]. Available: http://www.zumtobel.com/com-en/products.html. [Accessed April 2018].

[21] "Active Light - Zumtobel," [Online]. Available: http://www.zumtobel.com/com-en/active-light.html. [Accessed April 2018].

[22] "Light for humans - Fagerhult (International)," [Online]. Available: https://www.fagerhult.com/Tunable-White/Personal-Light/Light-for-humans/. [Accessed March 2018].

[23] "e-Sense Tune is wireless light control with your phone - Fagerhult (International)," [Online]. Available: https://www.fagerhult.com/Campaigns/e-Sense-Tune/. [Accessed March 2018].

[24] "Applications with Tuneable-white - Fagerhult (International)," [Online]. Available: https://www.fagerhult.com/Tunable-White/Personal-Light/Applikationer/. [Accessed March 2018].

[25] "Human Centric Lighting: Dynamic Light | Lighting Solutions," [Online]. Available: https://www.osram.com/ls/light-for/office/human-centric-lighting/dynamic-light/index.jsp. [Accessed April 2018].

[26] "Human Centric Lighting: Effect of Light | Verlichtingsoplossingen," [Online]. Available: https://www.osram.nl/nl/ls/light-for/office/human-centric-lighting/hcl-effect/index.jsp. [Accessed April 2018].

[27] "Human Centric Lighting – Helvar," [Online]. Available: https://www.helvar.com/en/lighting-now/human-centric-lighting/. [Accessed April 2018].

[28] "Helvar - Whitepaper - HUMAN CENTRIC LIGHTING," [Online]. Available: https://www.helvar.com/media/filer_public/39/1c/391c77f6-f2dd-446b-a014-ac808afe816c/hcl_whitepaper.pdf. [Accessed April 2018].

[29] "Lighting for People - LIGHTING FOR HEALTH AND WELL-BEING IN EDUCATION, WORK PLACES, NURSING HOMES, DOMESTIC APPLICATIONS, AND SMART CITIES," 2014. [Online]. Available: http://lightingforpeople.eu/2016/wp-content/uploads/2016/03/SSLerate-3.2-3.4-v4.pdf.

[30] "Double Dynamic Lighting - Light as a tool for creating dynamic work environments," [Online]. Available: https://www.tridonic.com/com/en/pr-2018-double-dynamic-lighting.asp. [Accessed May 2018].

[31] C. Augustesen, "Architecture for the Senses - VELUX," 2015. [Online]. Available: http://iva.velux.com/competitions/international-velux-award-2018/posts/architecture-for-the-senses.

[32] E. H. Ellen Kathrine Hansen, "The Luminaire Window," *ARCH17 3RD INTERNATIONAL CONFERENCE ON ARCHITECTURE, RESEARCH, CARE AND HEALTH CONFERENCE PROCEEDINGS,* 2017.

[33] "Human Centric Lighting | HCL Mission," [Online]. Available: http://humancentriclighting.org/hlc-mission/. [Accessed April 2018].

[34] C. L. P. L. W. Stan Walerczyk, "Human Centric Lighting," Architectural SSL Magazine, June 2012. [Online]. Available: http://humancentriclighting.com/wp-content/uploads/2012/07/Stan-Article-SSL1.pdf.

[35] "Biophilia hypothesis | Britannica.com," [Online]. Available: https://www.britannica.com/science/biophilia-hypothesis. [Accessed May 2018].

[36] T. .. E. &. M. :. E. C. a. M. Zind and O. Park, "The Human-Centric Lighting Debate," Apr 17, 2018.

[37] N. M. P. M. G. P. A. P. P. B. S. P. a. B. v. d. Z. P. PJC Sleegers PhD, "Lighting affects students' concentration positively: Findings from three Dutch studies," *Lighting Res. Technol. 2013; 45: 159–175,* 2013.

[38] K. C. a. H.-J. Suk, "Dynamic lighting system for the learning environment: performance of elementary students," 2016.

[39] M. ,. P. D. D.-I. S. S. a. W. P. M. M Canazei Dipl-Ing MMag, "Effects of dynamic ambient lighting on female permanent morning shift workers," *Lighting Res. Technol. 2014; Vol. 46: 140–156,* 2013.

[40] S. G. B. K. W. J. K. J. e. a. Reid KJ, "Timing and Intensity of Light Correlate with Body Weight in Adults," *PLoS ONE 9(4): e92251.,* 2014.

[41] J. J. W. Richard J. Wurtman, "Brain Serotonin, Carbohydrate-Craving, Obesity and Depression," *OBESITY RESEARCH Vol. 3 Suppl. 4 Nov. 1995 477s,* 1995.

[42] R. N. Golden, B. N. Gaynes, R. D. Ekstrom, R. M. Hamer and e. al, "The Efficacy of Light Therapy In the Treatment of Mood Disorders: A Review and Meta-Analysis of the Evidence," *The American Journal of Psychiatry,* Vols. 162, 4, no. April, 2005.

[43] "Definition of Phenomenology by Merriam-Webster," [Online]. Available: https://www.merriam-webster.com/dictionary/phenomenology. [Accessed May 2018].

[44] "Definition of Phenomenon by Merriam-Webster," [Online]. Available: https://www.merriam-webster.com/dictionary/phenomenon. [Accessed May 2018].

[45] "Phenomenology (Stanford Encyclopedia of Philosophy)," [Online]. Available: https://plato.stanford.edu/entries/phenomenology/. [Accessed May 2018].

12 Appendix

Appendix A – Table of collected material from the industry, regarding dynamic lighting means and their proposed purposes

Company/Concept	Dynamic Lighting Means	Proposed Purposes
Philips Lighting [6] [7] [8]	Changing color, color temperature and intensity automatically over time	Affect mood, circadian rhythm, and performance. Focus on personal customization.
USAI Lighting [9] [10]	Changing color, color temperature and intensity automatically over time.	Affect mood, circadian rhythm, and performance. Focus on personal customization, with effects like personal appearance and awareness of location. A special mention of the potentials in personal medical treatment through lighting. Change and adapt lighting conditions to support task activities for individuals and teams. Mimicking daylight.
Hubbel Lighting [11]	Changing color, color temperature and intensity automatically over time and using daylight sensors, occupancy sensors and data.	Energy efficiency.
iGuzzini [12] [13] [14]	Changing color, color temperature and intensity automatically over time and using daylight sensors and presence sensors. Personal adjustability.	Support well-being, circadian rhythm and sub purposes (affect our habits, productivity, biological needs and emotions).
CoeLux [15] [16]	Changing light intensity automatically over time, with a relation to the natural daylight.	Affect mood, well-being, relation to the outside, replicate the positively weighted phenomenon of direct sunlight and blue sky.
Lighten – "PILCS" [17] [18] [19]	Dynamism through software and personal lighting profiles. Controlling light intensity, color and color temperature over time and in relation to individual needs.	Affect mood, well-being, medical treatment, personal biological adaptation, improved performance and concentration, specialized task lighting and health improvement.
Zumtobel [20] [21]	Dynamic light intensity, color, timing, direction, sensor technology and personalization.	Affect mood, increase well-being, support circadian rhythm, provide creative inspiration, increase productivity and visual comfort. Encourage social activity.
Fagerhult [22] [23] [24]	Dynamic light intensity, color temperature, timing, sensor technology and automated personalization of fixtures in some situations. So-called *light showers*.	Improve subjective and objective well-being, increase activity, support the circadian rhythm, support types of activities, increase alertness and strengthen the sense of natural daylight.
OSRAM [25] [26]	Dynamic light intensity, color, timing and sensor technology.	Visual comfort, biological effects like supporting the circadian rhythm, emotional perception, a relation to the architectural-functional surroundings, imitate natural light, relaxation, performance, concentration and activation. Support different chronotypes.
Helvar [27] [28]	Light intensity and colored white light.	Support the circadian rhythm, support temporary needs, reduce stress, enhanced medical efficacy, reduced

		therapy periods, increase performance and concentration, decrease fatigue, support needs of night shift workers.
Lighting for People [29]	Dynamic light intensity, color temperature, duration of exposure, effect of transition, personalization.	Support circadian rhythm, increase alertness, concentration, performance. Increase general health and wellbeing. Reduce aggressive behavior and agitation in education.
Double Dynamic Lighting [30] [31] [32]	Dynamic light intensity, color temperature, and their spatial interplay with incoming dynamic natural light.	Support circadian rhythm, improve wellbeing, support different activities dynamically and enhance the contact to nature (possibly related to biophilia). Additional, but under ongoing exploration: Potential purposes created because of the spatial interplay between dynamic electronic lighting and dynamic natural light.
Human Centric Lighting Society [33] [34] [35] [36]	Dynamic light intensity, color temperature and duration of exposure. A relation to nature.	Support the circadian rhythm, pleasure, increased muscle coordination and productivity, some effect on carbohydrate cravings, general well-being and health. Satisfy potential biophilia.