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Intentions, Solutions and new Design Principles from a Bicycle Perspective

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Abstract:

This thesis performs an analysis of the current state of street lighting in Copenhagen from a bicycle perspective. The thesis presents results from a case study of selected streets in Copenhagen including an analysis of the photometric performance of current street lighting solutions, and the resulting user experience for cyclists. The current design paradigm for street lighting in Copenhagen is examined through the analysis of current regulation and planning documents. Based on the performed analyses, the thesis proposes seven new design principles aimed at creating better street lighting for cyclists.

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Biking Under Copenhagen's Street Lights

Intentions, Solutions and Design Principles from a Bicycle Perspective

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1 Introduction

This thesis regards street lighting in the city of Copenhagen, focusing on the user experience from a cyclist perspective, and has been written as the final submission for the Lighting Design master programme at Aalborg University Copenhagen, by Christian Ankerstjerne and Anders Dahl.

The thesis researches the context and motivations for Copenhagen's street lighting paradigm and how this paradigm adresses the current urban design strategies of the city. It provides an understanding of different stakeholders in the planning and implementation of the city's street lighting, and includes an analysis of their priorities, roles and interests.

To supplement this overview, the thesis presents a case study data set, which documents ands evaluates Copenhagen's street lighting on 10 locations and discusses them individually and in general.

In this way, the thesis studies the subject of street lighting from several angles, and in dialogue with a more general discourse about the way we design our public spaces through urban design. By performing analyses in different levels of detail, and on different levels of abstraction - from planning and regulations to implemented solutions - we hope to achieve a holistic understanding of the subject and all the factors that influence its design.

The thesis is finalized by proposing a set of design principles for street lighting, that aim to improve the user experience lighting for bicyclists. The agenda of these principles, is to create a discussion about how we can achieve a better experience for all the street's users, by rethinking the way we use light in the public space.

2 Motivation & Hypothesis

2.1 Motivation

As people living in a city, we don't necessarily notice street lighting consciously. It is for the most part experienced as something that is simply there. Rarely we may notice it, when it is broken, or if we happen to experience the moment, where it is turned on. This at least has been our own personal relationship with street lighting, but as we became involved in the academic field of lighting design, we started to notice this technical lighting system present all around us, and we started to discuss its current form, its origin, and the idea behind the way it is shaped. This discussion is very much at the core of our motivation for the work in this thesis.

For the large majority of citizens in Copenhagen, the streets constitute the urban public outdoor spaces, in which we spend most of our everyday life as city dwellers. Most people are heavily dependent on the infrastructure provided by these streets, to move freely in order to work, shop, exercise etc. The street is essentially a space, that we share between us, owned by the public, and as such a democratic space, which should seek to meet the requirements of all its users. Since the 1950s, when modernist urban planning strategies became widely accepted and cars became affordable, cars have dominated the urban planning paradigms in most of the western world. The road has transitioned from being a space shared between horses, trams, pedestrians, bicyclists, playing children and motorized traffic, to being first and foremost an area for motorized traffic. In an international context, Copenhagen is a progressive city, when it comes to controlling the explosion of car-centered urban planning, and in securing good conditions for bicycle traffic and pedestrians. If one looks at the street-scape of Copenhagen in a larger historical context, it is however clear, that while cyclists and pedestrians have a place, the streets are primarily shaped around automotive transportation.

As it is almost evident in the term *street lighting*, the street lighting paradigm is inevitably tied to a conception of what a street is. In the time before motorized traffic was widely implemented, street lighting was primarily a means of creating security and preventing crime, hereby ensuring access, commerce and life in the city after nightfall for all demographic groups of the population. Oil lamps would be placed not to light the street surface, but to cast light on the people in the street. The last of these gas lamps was taken out of use and replaced by electric lights in 1959*. The electrical lights that replaced gas lamps were thus installed at a time, when car traffic was storming forward, and thought to be the way of the future. Around the same time, the roads and the rules of traffic were re-ordered to the model we know today, where cyclists and pedestrians are pushed to the sides of the road profile, to give space to the higher speed car traffic.

Unsurprisingly, most of the street lighting designed and implemented in Copenhagen from the 1960s and forward reflects the conception of the street as an area for motorized traffic. The lighting fixtures are typically mounted centrally in the road profile, above the car lanes, and the light is cast downwards onto the road surface.

In the last few decades, the urban planning paradigm in Copenhagen and many other cities has shifted, and the car-centered understanding of urban life, has been countered by architects, politicians and planners. In a progressive city as Copenhagen, that has already managed to secure a strong infrastructure for cyclists and pedestrians, this means that many streets are now being modified to actively reclaim parts of the streets from cars. This is visible

Ill. 1 & 2. On Nørrebrogade in 1945 (left), cyclists completely dominate the rush hour traffic. On another section of the same street in 1953 (right), cyclists, mopeds, trams and cars all share the street between them.

Ill. 3. Ågade in 1960. As cars increase in numbers, the streets are structured to look like they do today. This means that cyclism is moved to new bike lanes at the side of the road to allow higher speeds for cars on the road. The last oil lamps are replaced with the wire mounted street lighting systems that still dominate today.

**Københavns stadsarkiv, artikel om gadebelysning*

in a large number of bicycle and pedestrian friendly initiatives, including widened bike paths, super bicycle highways, traffic regulation prioritizing bicycle speed, restrictions on parking and motorized traffic, discussions about subterranean roads etc. This movement in strategy and philosophy, towards prioritizing bicyclism and pedestrian traffic, and putting the human scale in focus, is today an outspoken goal of *Copenhagen Municipality*.

The advance of LED lighting technology, and the advantages in power consumption, that the technology offers, has revolutionized lighting in the last 5-10 years. This is also true of street lighting. Since 2013, *Copenhagen Municipality* has initiated a large scale replacement and renovation of the street lighting systems throughout Copenhagen. Yet, we have not been able to see the general transition away from car-centered planning, reflected in the street lighting strategy throughout the city. The renovation so far has displayed a clear tendency of retrofitting the existing lighting solutions with new light sources. The placement, the expression, the light distribution, and perhaps most importantly, the underlying logic and understanding of the street as an urban space, appears to remain unaltered. This observation has been the core of our motivation to look into the current paradigm of street lighting in Copenhagen today.

Sparked by this thought, we started making observations around the city at night, in preparation for writing this thesis. We started to ask ourselves some questions. Why does the current street lighting have its current form? What kind of success criteria and evidence lies at the core of the current design? Who has been considered the end user of the lighting design? Unable to answer these essential questions, we developed an interest in researching and understanding the current street lighting requirements and paradigm.

Although Copenhagen is a front-runner and a progressive city in terms of moving away from car-centered urban planning, many other cities across the world are making similar changes to their strategies. There are arguably even cities like Venice, that have never given way to the car-centered planning paradigm in the first place, but who have managed to preserve pedestrian centered urban life up to this day. An area however, in which Copenhagen is truly a unique example, is in the extent of bicycle use as a means of transportation.

Considering this unique characteristic of the city, we wondered why, we could not see anything remarkably different about the street lighting in Copenhagen, compared to other cities. This observation caused us to narrow in our focus on the user experience from a cyclist's point of view. Again, we began to make observations, when bicycling around the city at night, and again, we started asking ourselves a number of questions. What differentiates a cyclist's needs from those of a motorist? Which lighting factors are important to a cyclist? How does the cyclist's designated placement in the street profile relate to the lighting system? To answer these questions, we concluded that we needed to research into how these questions have been treated by others, including those currently responsible for the design and implementation of street lighting in the city. We also decided, that if we could not find satisfying answers to these questions, we would do what we could to answer them ourselves in the course of the thesis.

As explained in the previous chapters, this thesis is inquisitive of nature and driven by curiosity and a set of questions and observations, without a fixed or defined design goal. As such, the primary goal of the thesis is not so much to answer a design problem with a design answer, but to understand and articulate the problem, hereby bringing it into the light for others to see. As the thesis is written within the academic field of lighting design, it is our goal, that the research performed throughout this thesis, is discussed, reflected upon and presented in

Ill. 4 & 5. In the last decade, several large scale bicycle-friendly adaptations to the city's roads have been implemented. Den Grønne Sti (left) provides commuters with a green bike route that connects several city districts. One of the city's busiest bicycle streets, Nørrebrogade has gone through an enlargement of its bike lanes and a restriction on the amount of car traffic - first as a trial (right), then as a permanent solution.

Ill. 6 & 7. In some cases, lighting has played an active role in bicycle-friendly initiatives. Grøn bølge (left) communicates to bicyclists, which speed to maintain, to avoid red lights by use of diodes in the bike lane. On the new bicycle bridge Cykelslangen, integrated lighting in handrails supports the light and playful experience of biking in mid air between tall buildings.

Ill. 8 & 9. In other cases, lighting does not manage to support the goals of bicycle-friendly initiatives. On the section of Den Grønne Sti, that passes through Nørrebroparken (left), the lighting is spotty, insufficient and gloomy. On Sortedam Dossering (right), bike traffic has been moved from the road to a spacious two-lane bike lane. Unfortunately, the street lighting has not been adapted accordingly.

a way, that makes it valuable and usable in the future design of street lighting for cyclists. We will also make our own proposal of how the knowledge generated in this thesis can lead to new design directions and design principles aiming to create better street lighting.

2.2 Hypothesis and Initial Research Questions

Based on the above chapter, we have condensed our interest, questions and presumptions into one hypothesis that will be explored and tested in this thesis:

By performing a critical analysis of the current street lighting in Copenhagen, including registrations of photometric performance, assessment of user experience and discussion of the paradigm behind current planning and legislation, it is possible to develop new principles for the design and implementation of street lighting, resulting in an improved user experience for cyclists in Copenhagen.

The hypothesis unfolds into a number of sub-questions. Below, we have condensed these questions into five initial research questions, that guide and structure the research process of the thesis.

How does the current street lighting perform for different user groups?

Since our hypothesis aims to improve upon the current conditions, an essential task consists of analyzing and understanding these conditions. This includes an assessment of how street lighting functions and performs in Copenhagen today, with an analytical focus of distinguishing the way it performs for different user groups, including cyclists.

How is the street lighting in Copenhagen experienced from a cyclist's point of view, and what are the user needs of cyclists?

If our hypothesis aims to improve the experience for cyclists, we need to know more about this experience. This requires an analysis of how the current conditions are experienced from a cyclists' point of view, as well as a more thorough look at cyclists' needs, and how they are influenced by street lighting.

How is street lighting in Copenhagen currently planned and designed? Who does it and with what intentions and priorities?

Before proposing any changes to the current conditions in Copenhagen, it is important to us to understand why they have their current form. To achieve this, we need to examine the thoughts behind the way street lighting is planned, designed and implemented. This in turn necessitates a mapping of the stakeholders involved in this process, allowing us to identify the different interest that these stakeholders represent. Our hypothesis is openly aimed towards understanding and improving conditions for a selected user group. Therefore, we wish to understand, how different user groups are considered and prioritized in current planning. Furthermore, we wish to understand the planning process, in order to assess, where new design principles should be applied and fed into a larger planning and design process.

What are the regulations and requirements in regard to street lighting, and why are they shaped as they are?

Street lighting is a part of an infrastructural network and has some very important safety functions. Therefore, there are strict requirements and regulations on a national level, that any street lighting scheme must respect. These regulations play an important part as a framework in shaping what street lighting is and what it can be. To determine, what can be done within this framework, we need to understand the relevant requirements, and in order to be able to discuss the requirements critically with our hypothesis' design intent in mind, it is necessary to analyze the intentions, success criteria and argumentations behind the requirements.

What are the current urban planning tendencies in Copenhagen?

Street lighting is never experienced as an isolated element. It is intertwined with a number of other elements, that together shape the perception and experience of the street in the dark hours. It is therefore evident that to create the best possible user experience, street lighting must be designed in dialogue with the other design disciplines influencing the street, including urban planning, traffic planning and landscape architecture, and that street lighting must be fitted to the user types and usage patterns of the street that it serves to light. These different factors constitute a design context, that is continuously evolving. To understand the current state of this context and where it is headed, and whether street lighting is currently planned and designed in connection and dialogue with this design context, we need to take a closer look at the current urban planning tendencies dominating in Copenhagen, and how they are influencing the street as a urban space in form and function.

3 Method & Approach

3.1 Academic Approach

The thesis is rooted in our backgrounds as landscape architect and urban design bachelors, in combination with our education as lighting designers. These two backgrounds represent different mindsets and methods, which we want to combine in order to achieve the most thorough analysis and design parameters.

The competences we have from landscape architecture and urban design include experience from working with complex contexts, with many design parameters and influencing factors. Rooted in this background, we are used to working in different scales and levels of the design, from overall strategy to fine detail, and we recognize the necessity of moving between them.

Our position between two academic fields, puts us in a good position to look at the subject of street lighting from an urban planning and landscape architectural perspective. It is natural for us to see outdoor lighting in an urban context not as a restricted discipline, but as one of many factors influencing the urban spaces and urban life. We have sought to make this holistic approach to lighting a cornerstone of this thesis, in our analyses, choice of literature and registrations.

We believe that this way of approaching street lighting constitutes an alternative to the way, this subject has been treated traditionally within the academic field of lighting engineering, which has been dominated by evidence based research, often working with isolated design parameters, recreated in an experimental context.

The scientific position, we would like to take regarding the scientific aspects of this thesis, is that we will use ourselves to build an understanding of the problems in the real context, on site. We believe, that this approach, actively using ourselves to observe the sum of all factors influencing the final user experience, will yield results and knowledge, that is not possible to recreate within a laboratory or a virtual simulation tool. There are obvious problems in terms of scientifically validating some of the knowledge, that this approach produces. By using ourselves as lenses through which, we observe, we introduce a number of biases. Likewise, by always observing the sum of factors influencing the user experience, it is difficult to make conclusions about isolated factors influencing the experience.

We think however, that this approach is the most relevant for us to choose, considering our backgrounds, the subject at hand, and our goal of producing knowledge aimed towards a design discussion. Implicit in this, is that we identify as designers rather than scientists, and that the work we are doing in this thesis is design research, meaning research performed with a design intent and a design discussion in mind.

Lastly we think that it is necessary to say a few words about street lighting as a design object in regard to our academic approach. As mentioned above, we consider this thesis to be a work of design research - in other words research performed with a design intent in mind. We have also earlier mentioned, that our thesis is driven by questions, rather than a fixed and defined design goal. These two statements can perhaps sound contradictory, but are in fact not. The street lighting of a city as a whole, as a design object, is an enormous one, consisting of great network of systems, inarguably tied to a vast diversity of urban spaces and context. Therefore, the design of street lighting is an ongoing and ever changing design process. As long as the urban spaces and the use of the city is evolving, and the technology at hand is evolving, the design of the street lighting, will be changing as well. As such, when looking at street lighting for a city, it is hard to identify a finished design product, and the design process is therefore not comparable to the design process of for example a fixture. In this light, we think the best way to channel our research towards a design intent, is to generate knowledge that can affect the ongoing design discussion, that defines how we design street lighting, and we think this approach very much qualifies our work as belonging in the realm of design research.

3.2 Methodical Approach

We have created a flowchart, that functions as a graphic representation of the process and methodical approach of the thesis, and it contributes with an overview of each step taken through the different stages. See illustration 9. Motivation and background has already been covered in chapter 1 and 2 and in the following sub-chapters the remaining stages are explained in detail.

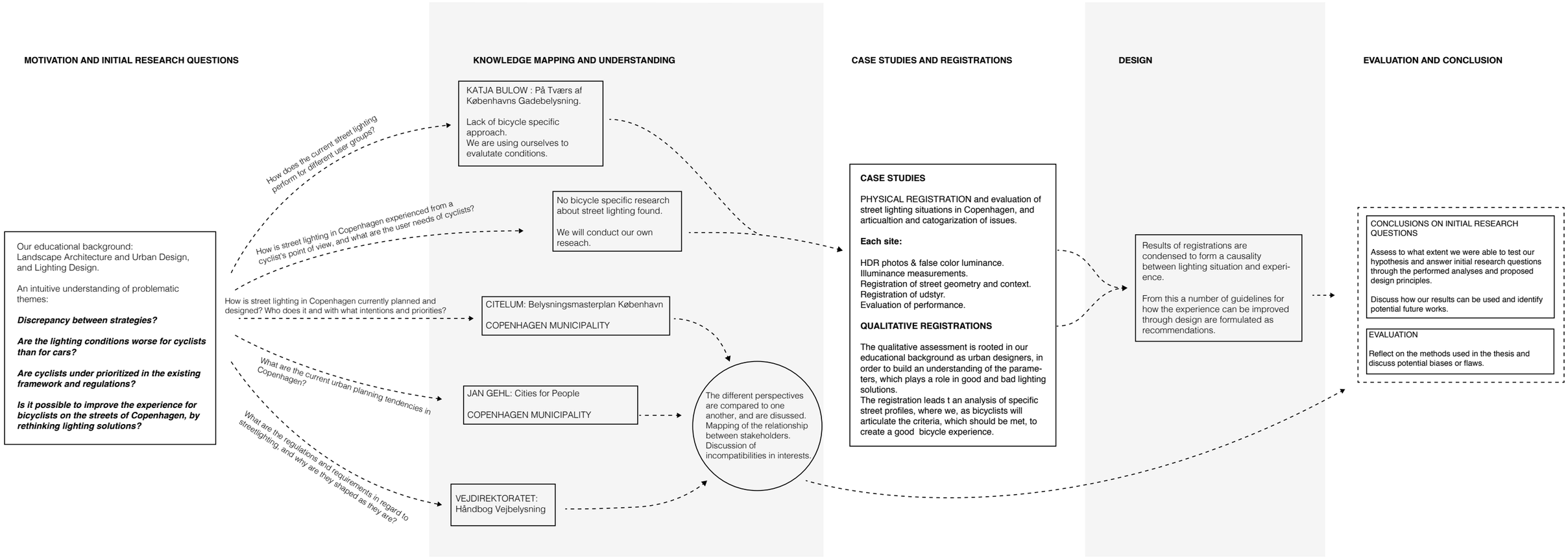
3.2.1 Knowledge Mapping & Understanding

In order to move forward from our motivation and hypothesis, we set out to identify and seek out a selection of relevant knowledge and information, that would help us gain a holistic understanding of the subject at hand, and ultimately answer our questions. We have used our initial research questions to define a number of *research threads*, that have led us to a number of different sources.

In order to find the most relevant sources of information and to ensure that we did not overlook essential information, we took contact to several people, that could help us to more effectively identify the most relevant lighting requirements to become acquainted with, the most relevant publications and litterature to analyse, and the most important persons to talk to. In addition, we have also actively selected theory and litterature from other academic fields that we have found relevant to our subject.

One of our contacts was *Bjørn Halberg Nielsen*, who is employed by *Supercykelstisekretariatet*, which is a secretariate devoted to advancing and developing a system of super cycle highways connecting Copenhagen to a number of surrounding suburbs and cities. Although the super cycle highway project is a trans-municipal project, Bjørn works from within *Copenhagen Municipality*'s offices, and works together with many different people and departments in the municipality, and was able to help us get an overview of the different stakeholders within the municipality involved with aspects of street lighting and bicyclism. Bjørn was a helpful source of knowledge regarding ongoing intitatives and projects aimed at advancing cyclism in Copenhagen. Furthermore, Bjørn was also able to help us establish contact to several people in the municipality, of which some proved useful to our research.

We also contacted *Kenneth Munck* and *Marianne Hornuff*, who are both lighting engineers employed in *ÅF lighting* with great experience working with street lighting. *Kenneth Munck* has been involved with developing a road classification system for *Copenhagen Municipality*, and *Marianne Hornuff* has been involved in the development of the new Street lighting



Ill. 10. A flowchart that graphically represents our methodical apprach and the steps taken in our process.

hand book *Håndbog Vejbelysning*, which is the legally binding document nationally regarding street lighting. In addition to this very important source, Kenneth notified us of *Copenhagen Municipality*'s close work with the french company *Citelum*, and led us to the other important source, which is *Citelum*'s *Belysningsmasterplan København*, developed for *Copenhagen Municipality*.

Thirdly, we received guidance from our supervisor *Jakob Markvart* and our study leader, *Ellen Kathrine Hansen*, who amongst other sources, helped us identify the Ph.D. publication *På tværs af Københavns Gadebelysning 2014*, which documents the current street lighting of Copenhagen, and the way it is changing.

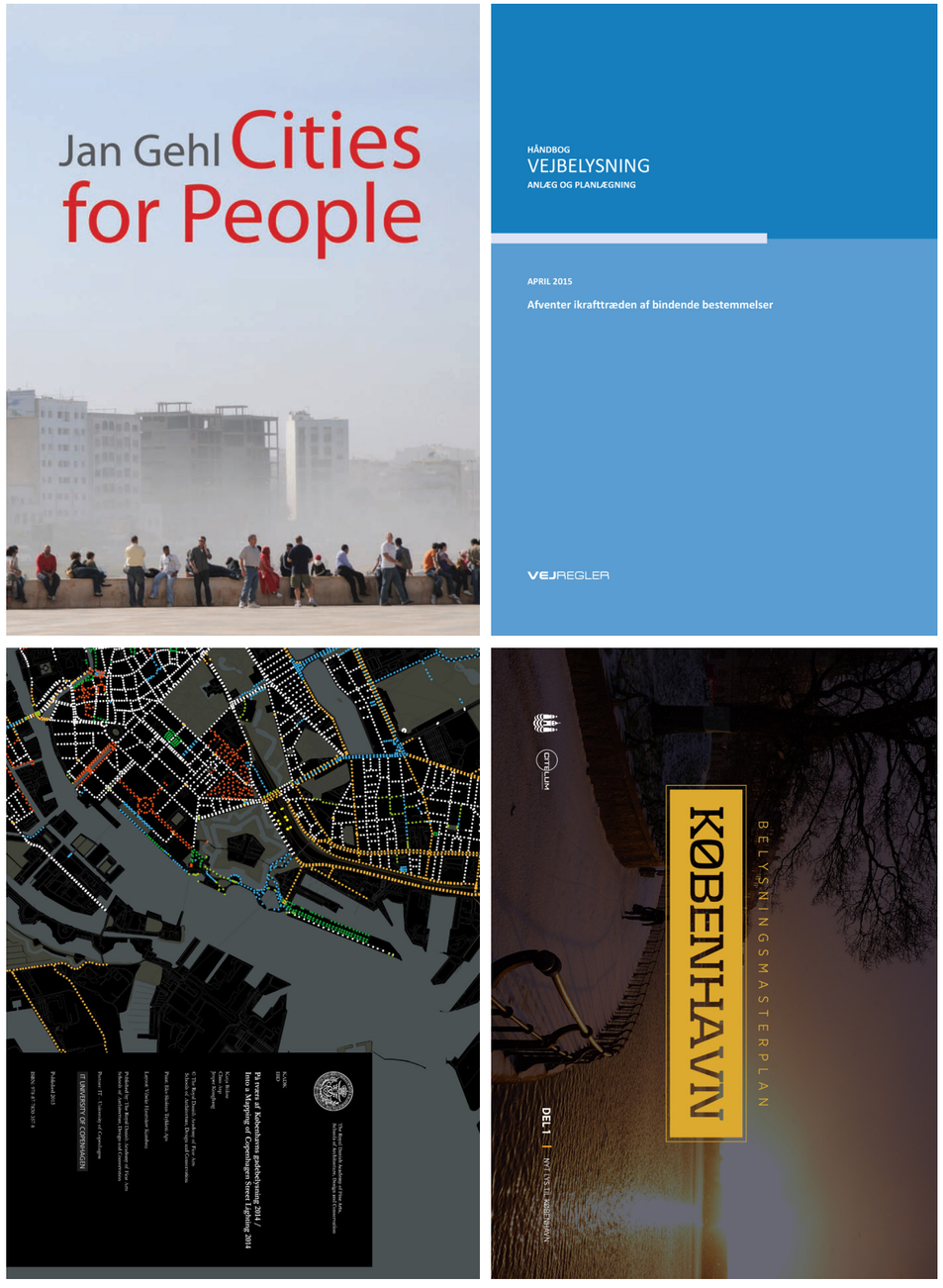
On our own initiative, we have included theories from renowned danish architect *Jan Gehl*, that we wish to include in the thesis as a lens and a counterpoint, to use in discussions. These theories are not specific to the academic field of lighting design, but are highly relevant to the subject of urban planning and as such to the holistic approach that we wish to apply to the subject.

It has not been possible for us to locate relevant research or documents that in depth describes cyclists' needs and user experience in a context comparable to Copenhagen. This makes sense, as the bicycle culture in Copenhagen, just by its scale of implementation in its infrastructure, can only be compared to few cities around the world. Neither have we found any relevant research or documents, that in depth describes the relationship between street lighting and the bicycle experience. Therefore, these themes will not be explored through literature, but through our own observations and registrations.

The contents of the above described literature, that we have identified with the help of our contacts, will be treated in depth in chapter 4. In this methodical chapter, it is relevant to mention, that there are two overall objectives of including the different sources in our thesis.

The first objective is to gather knowledge and understanding, and become acquainted with the current state of the art within the field of street lighting. We had very limited knowledge in this field upon starting our work, and by looking into these different sources, we are been able to gather a broad understanding of how street lighting is planned, regulated and implemented today.

The second objective was to map the different perspectives, motivations and success criteria that currently affect and dictate the current street lighting paradigm. By juxtaposing the perspectives, motivations and success criteria from one source with those from another, we are able to create a discussion between entities that do not usually have any dialogue. It is the hope that this discussion reveals overlaps and differences and yields a nuanced and critical perspective on the the success criteria and motivation behind street lighting in a contemporary and future context. We think, this nuanced perspective is essential to our overall goal of exploring the possibilities of designing street lighting in new ways.



Ill. 11. Four of the most essential written sources used in our process of knowledge mapping and understanding.

3.2.2 Registrations & Case Studies

In addition to the study of literature and sources, a substantial part of the work in this thesis has gone into creating a set of case studies, documenting and registering the performance of the current street lighting solutions on a number of sites around the city of Copenhagen.

We were driven to perform this set of case study, primarily due to a lack of access to comparable data. We did not find any existing registration of the current street lighting, that offered measurements, enabling comparison between different sites, and we did not find any data documenting the street lighting performance from a cyclists or pedestrian point of view. Another reason for performing the case studies, was to gain an intuitive understanding of the different factors at play. Due to our previous lack of knowledge regarding street lighting, the case studies were an effective way for us to develop a frame of reference in regard to the measurable factors, such as light levels, types of fixtures used, distributions and mounting systems. In addition, the case studies were perhaps even more important to develop a frame of reference in regard to the more qualitative factors, such as perceived darkness, ability to read the spaces, comfort, security, etc.

By documenting the registrations performed, in the form of measurements, photographs, sections and descriptions, we have created a pool of data to analyse, compare and draw conclusions from. We have also created a way of cross referencing and checking the performance of the implemented street lighting solutions with the goals and values described in plans and requirements.

The specifics and methods of the registrations performed, will be described in detail in chapter 5.2., but in short, we have chosen to document a set of measurable data, for each case, including road geometry, lighting equipment, vertical and horizontal illuminances, and HDR photographs.

The registrations include a qualitative assessment of the user experience for each site as well. These assessments were made, based on observations on foot and on bike, and discussions had on site.

3.2.3 Results & Design Approach

From the literature studies, a resume of findings will be presented. A collection of general observations and conclusions based on the case studies, will also be presented. This knowledge will provide the basis for proposing how the experience can be improved through design.

To exemplify, how this can be done, we will propose seven design principles condensed from our findings. The aim of these principles, are to transform our generated knowledge into a tool set for ourselves and others others interested in designing street lighting.
The principles are accompanied by graphics, meant to help communicate their meaning in the best way possible.

3.2.4 Evaluation & Conclusion

Based on the amassed knowledge throughout the thesis, gained through analysis of literature, mapping of stakeholders' interests and case studies, we will attempt to answer our initial research questions and evaluate, if our studies have enabled us to confirm our hypothesis.

There will be a discussion about how our results can be used by others, and we will propose relevant future works.

Finally there will be a critical assessment of the methods used in the thesis, a reflection on what could have been done differently and an evaluation of howour choice of methods may have affected our results in the form of introduced biases.

4 Knowledge Mapping & Understanding

4.1 Introduction of Sources

In this section we present the literature, that we have found to be most relevant for our work. Each title will be presented in brief, along with an explanation of the title's relevance for our thesis and problem statement and why they have been chosen to represent a given stakeholder in Copenhagen road lighting. The main points and the stance of the chosen literature, will be described and statements will be supported by quotes.

To represent the legislative framework, we have chosen the publication created by The Danish Road Directorate, *Håndbog Vejbelysning*, which is combination of several previously separate legislative documents, as well as recommendations. This document therefore constitutes the current regulation, that all street lighting must live up to, as well as offering a selection of recommendations and explanations.

Knowledge about general urban planning is mainly extracted from the works of *Jan Gehl*'s publication *Cities for People*. The theories he represents can be observed in many initiatives and projects carried out in Copenhagens urban spaces, and provide the basis for new urban strategies in cities from New York to Melbourne. They serve to ensure human scale qualities, and distance themselves from a modernistic, car-centered way of planning our urban spaces.

Street lighting in Copenhagen is currently maintained and installed by the french company, *Citelum*. *Citelum* is also responsible for a massive replacement project, initiated in 2013, that will replace 20.000 of the city's 44.000 street lamps with new LED light sources. In collaboration with *Copenhagen Municipality*, they have produced a lighting master plan for the city. The strategies presented in this, will form our understanding of how lighting is currently maintained and planned by the company taking care of it. Furthermore the information extracted from the masterplan is supplemented by an interview with *Maja Hyveled Jakobsen*, who is responsible for maintenance and operation of street lighting in *Copenhagen Municipality*. Maja works together with *Citelum* and various other departments of *Copenhagen Municipality* in regard to street lighting.

Katja Bülow published a part of her work as a ph.d. Scholar at the *The Royal Danish Academy of Fine Arts*, under the name *På tværs af Københavns gadebelysning 2014*. The publication is a research and registration project of Copenhagen's street lighting, performed during a time where traditional light sources were being replaced with LED panels, in order to achieve a more energy efficient lighting system. Her work has an architectural angle, and has a strong focus on the aesthetic appearance of different light sources, and the way street lighting affects the visual identity of the city. It also provides an extensive mapping and photo-documentation of the street lighting around Copenhagen.

In the following chapters, each source will be treated more in depth. Each source will be presented in a way that summarizes the content, that we have found most relevant and important to the thesis. In addition, where we have found it relevant, we will include figures, quotes or data from the sources accompanied by our comments, analyses and interpretations.

4.2 Cities for People, Jan Gehl

Jan Gehl is a renowned danish architect who has specialized in urban design. His focus is on improving urban life by rethinking urban design - often from a pedestrian- and bicyclist perspective. *Cities for People*'s most prominent concept is a design paradigm dictated by the human scale, which represents a drastic shift from decades of urban planning dominated by motorized vehicles. The concept is to understand the city based on a bottom-up methodology, starting with the human scale, and letting this create the guidelines of design. In this case the human scale is represented by the experiences and impressions obtained, while commuting or staying in urban spaces as a pedestrian or bicyclist. The reason why these two user groups are especially important, in the theories presented in *Cities for People*, is because *Jan Gehl* views them as the only user groups which actually generate city life. A high quality city and the presence of city life is, from his perspective, generated from the urban environment's attention to detail and adjustment to the speeds that create city life.

The relevance of this book lies in the strategies *Jan Gehl* represents, since the outspoken ambition of *Copenhagen Municipality* is to create an urban environment, which is of high quality and supports city life. The concepts introduced in Gehl's theories permeate Copenhagen's urban planning paradigm. An example is included below, from *Handlingsplan for Københavns Byrum*:

"Udgangspunktet for alle byrumsprojekter er at fremme bylivet og livskvaliteten, uanset om det primære formål er ophold, handel, rekreation eller trafik." Page 27, Handlingsplan for københavns byrum, Københavns Kommune

Furthermore, Gehl is one of the most prominent ambassadors of this school of thought, and has been using Copenhagen as a case study to exemplify specific urban design solutions for decades, while coining many of the phrases and terms popularized by urban designers today. In this way he has become a well known figure within the field of urban design and the paradigm in function, when cities are redesigned to accommodate its citizens from a human perspective.

In this thesis, lighting is treated as design element on level with all the other elements, which make up our urban spaces: Facades, horizontal surfaces, vegetation, curbs, urban furniture, etc. This premise makes lighting just as important a factor, for improving quality and increasing city life, whether it is to add detail in itself or to emphasize details that are already present. By using *Jan Gehl*'s approach as a tool to think about lighting, we hope to bring new contributions to the field of lighting design and the discipline of street lighting, but also to create new knowledge about the role of lighting in city life, that can be fed back into the field of urban planning.

The points made by Gehl are often rooted in the contrast between the urban planning tradition of modernism, and the principles that have existed before cars dominated the city scape:

"In old cities almost all traffic was by foot. Walking was the way to get around, the way to experience society and people on a daily basis. City space was meeting place, market place and movement space between the various functions of the city." page 115, Cities for People, Jan Gehl

"For decades the human dimension has been an overlooked and haphazardly addressed

urban planning topic, while many other issues, such as accommodating the rocketing rise in car traffic, have come more strongly into focus. In addition, dominant planning ideologies - modernism in particular - have specifically put a low priority on public spaces, pedestrianism and the role of city space as a meeting place for urban dwellers." page 3, Cities for People, Jan Gehl

Gehl argues that there has been a neglect of the human's role in urban development, in the years where modernism dominated the urban planning paradigm. In the lighting strategy implemented in Copenhagen, there are still traces leading back to modernism, which are especially apparent in road lighting, since many renewal projects are taking measures to ensure the comfort of pedestrians and cyclists on ground level, while the lighting appears to be solved in the same manners. Furthermore, modifications and updates of the system, does not question the placement relative to the road surface, but remain in the same point in space, which is usually right above the car lanes.

"After many years of pruning back pedestrian areas, Copenhagen was one of the first cities in Europe to grasp the nettle in the early 1960s and begin reducing car traffic and parking in the city center in order to create once again better space for city life." page 3, Cities for People, Jan Gehl

Gehl often uses Copenhagen as a good example, and emphasizes that Copenhagen has been a frontrunner when it comes to human scale urban development, and prioritizing pedestrians and cyclists. Yet, we would like to point out, that this position is maintained by the circumstance that roads and urban spaces fulfill human scale values of accessibility, comfort and recreation during daytime. If the actual initiatives initiated are not available or of lesser quality during hours without sunlight, a huge part of its potential is lost.

In *Cities for People*, the key to prioritizing certain types of traffic lies in the term *invitation*, which is defined by the idea that the capacity and facilities provided for a each type of traffic, is the main factor in determining which kind of transportation becomes dominant. For instance, better conditions for car traffic equals more cars, better conditions for bicyclists equals more bicyclists etc. Good conditions are seen as an *invitation*, while bad conditions are seen as the opposite. Gehl elaborates on the idea that if a certain form of transportation is preferable over another in a practical sense, it will also become the dominant one. He takes example in cars:

"The connection between invitations and behavior came to a head for cities in the 20th century. In the efforts to cope with the rising tide of car traffic, all available city space was simply filled with moving and parked vehicles. Every city got as precisely as much traffic as space would allow." page 9, Cities for People, Jan Gehl

Using Copenhagen as an example, he shows, that this cause and effect is interchangeable with other user groups as well:

"In short a whole-hearted invitation has been extended to cyclists, and the results are reflected clearly in patterns of use. Bicycle traffic doubled in the period from 1995 to 2005, and in 2008 statistics showed that 37 % of personal transport to and from work and educational institutions was by bicycle. The goal is to increase this percentage considerably in the years to come." page 11, Cities for People, Jan Gehl

The statistics presented by Gehl, are available in a newer version, in the form of a statistical

Ill. 12. Den Grønne Sti is a successful bike route, connecting several of Copenhagen's districts, allowing cyclists to make their daily travels largely separate from the noise and traffic on the roads. The route is characterized by surroundings consisting of green recreational open spaces.

Ill. 13. The same section of Den Grønne Sti at night. The lighting on the bike lane is spotty, the surroundings are hard to read, and in spite of an effort with decorative use of fluorescent tubes, the overall experience is dark and lacking many of the qualities that make the route attractive in the daytime.

analysis made by *Copenhagen Municipality* from 2014, to form a more current overview of the percentage of people commuting by bike. Some key numbers are included below:

"45 % af alle, der arbejder eller studerer i København, tager cyklen til job og uddannelse. Tallet dækker både over københavnere og folk fra andre kommuner, der arbejder eller tager uddannelse i København. Ser man udelukkende på personer med bopæl i Københavns Kommune, som arbejder eller studerer i byen, har cyklen en markedsandel på 63%. I 2012 var andelen 52%." Page 5, København Cyklernes By - Cykelregnskabet 2014, Copenhagen municipality

From the perspective of this thesis, the term *invitation* is relevant as we see lighting as an an important part of extending an *invitation* towards cyclists, since the perception of urban design features and comfort of users are jeopardized if the lighting design is not in compliance with other urban design elements.

Invitation also goes beyond the intention of comfort for commuters on foot or bike. According to Gehl, it also helps create a lively city. A lively city is an ideal in *Cities for People*, and pedestrianism and bicyclism are presented as an essential part in achieving this, which is one reason the strategies presented by *Jan Gehl*, heavily prioritize these kinds of traffic.

"The potential for a lively city is strengthened when more people are invited to walk, bike and stay in city space." Page 6, Cities for People, Jan Gehl

"A whole-hearted invitation to walk and bike as a natural and integrated element of daily routines must be a nonnegotiable part of a unified health policy." page 7, Cities for People, Jan Gehl

An essential element in Gehl's approach is the acknowledgement of the importance of our senses and our viewpoint from which we experience the world around us. Gehl characterizes the human as a linear, frontal, horizontal mammal walking at max 5km/h. This observation can seem banal in it's simplicity, but to Gehl it is crucial to understanding the way different users experience their surroundings, and thus to understanding the end user, when designing our cities. Gehl explores a number of very interesting phenomena. He identifies a number of distance thresholds, that allow us to read different things about people, using different senses to extract different information at different distances. He also explores the correlation between the speed at which a person is moving, and the amount of detail possible to read out of the surroundings, and how this depends further on the scale of these details.

We think these thoughts are important, in the context of our thesis. By adopting this attention to the user's senses, a street becomes a very complex space, facilitating users with different fields of view, different speeds, different abilities to extract information, and different needs for information from their surroundings. We will construct an example: A motorist may not have any need to extract information about a crack in the road, or whether a bicyclist is texting while biking on the bike lane, but might need to know that lanes will merge a hundred meters ahead. For a cyclist on the same road, the crack in the road may cause a crash, and the ability to read and predict what the cyclist ahead is doing, may be a very important factor in assessing whether or when to overtake the other cyclist. The merging of lanes ahead on the other hand has no relevance for the cyclist. In a daytime scenario, each user is largely free to extract the information, they need, by applying their focus to the elements that are important to them, but at night, the ability to extract different visual information is largely dictated by the street lighting. Furthermore, this readability is not solely a question of whether an important information-giving element is lit or not - it is a question of whether the street is lit in a way, that allows the extraction of information from this element by the user who needs this information, from a certain position on the road, moving at a certain speed with a certain orientation. The conclusion, we would like to draw from our example is, that good street lighting for one user group is no guarantee of good street lighting for another, and that good street lighting for all users requires an acknowledgement and an understanding of the different users' needs. Gehl's thoughts about senses are a valuable tool in thinking about these user needs.

Gehl touches the subject of health in his strategies, and describes the benefits of having a healthy population, both on a personal level and to society in general. Personally people will benefit from the increased level of exercise, which is implied when a person is moving around as either a pedestrian or bicyclist. On a socioeconomic level there is an interest in decreasing the population's need of medical care both in terms of accidents and lifestyle related health issues, which are extremely expensive to a society with universal health care. From this perspective, cyclism as an alternative to motorized traffic, provides a huge potential socio-economic benefit, in the form of countering lifestyle-diseases. However, the infrastructural facilities and their ability to provide safety for cyclists is crucial, and lighting is a fundamental part of this.

Regarding energy efficiency there is a huge potential in getting even fewer people to use their car as their main form of transportation within the municipality. Both in terms of a political agenda stating that we need to cut a large amount of our carbon dioxide emissions of today, but also from a perspective of pollution within city limits. The particle pollution at ground level is a health risk, especially for pedestrians and cyclists, and the presence of cars in the urban environment is a main contributor to the high levels of noise pollution in Copenhagen. Additionally, fewer cars would free a vast amount of space in the most dense parts of Copenhagen, which are also the parts that could utilize it most efficiently. Gehl uses statistics, that show the efficiency of commuting in the city by car, compared to pedestrians or bicyclists, using different measurement parameters. Pedestrians and bicyclists take up very little space, but are extremely efficient within that space, compared to cars.

"Pedestrian and bicycle traffic use fewer resources and affect the environment less than any other form of transport. Users supply the energy, and this form of transport is cheap, near-silent and non-polluting.

For a given distance the relative energy consumption ratio of biking to walking to driving a car is one to three to 60 energy units. In other words, biking will take you three times further than walking using the same amount of energy. A car consumes 60 times more energy than a bicycle and 20 times more than walking.

Pedestrian and bicycle traffic does not crowd city space. Pedestrians make very modest demands: two sidewalks 3.5 meters (11.5 feet) wide, or a pedestrian street seven meters (23 feet) wide can handle 20,000 people per hour. Two bike paths two meters (six feet) wide are sufficient for 10,000 bikers per hour. A two-lane, two-way street can take between 1,000 and 2,000 cars per hour (peak load).

A typical bike path can thus transport five times as many people as a car lane. And in terms of parking, there is plenty of space for ten bicycles in one ordinary parking slot. Pedestrian and bicycle traffic saves space and makes a positive contribution to green accounts by reducing particle pollution and carbon emissions." Page 105, Cities for People, Jan Gehl

In addition to environmental sustainability, efficiency and health, Gehl introduces a political angle to urban planning, and reflects upon the importance of the urban public space in regard to social sustainability and democracy:

"Social sustainability is a large and challenging concept. Part of the focus is to give various groups in society equal opportunities for accessing common city space and getting around town. Equality gets a substantial boost when people can walk and bicycle in combination with public transport. People without cars must have access to what the city has to offer and the opportunity for a daily life unrestricted by poor transport options." Page 109, Cities for People, Jan Gehl

"The city is seen as serving a democratic function where people encounter social diversity and gain a greater understanding of each other by sharing the same city space." Page 109, Cities for People, Jan Gehl

In relation to Gehl's reflections on the importance of urban spaces to democracy and coherence in a democracy, we think it is interesting to reflect on the governmental system, we have in Scandinavia, combining democracy with a strong state, and high taxes. This system depends greatly on a trust from the citizens in the fairness of the system that spends and redistributes the common wealth. Equally important is the basic identification of the people around you as fellow citizens and a trust in their will to participate in the common project. Gehl defines a democratic public space, as one that should secure access for all users. We think this is an ideal goal, but in the example of a street, where space is limited and each type of user poses a danger and obstacle to the others, prioritizing everyone equally can be impossible. Prioritizing one group will often be at the direct expense of another group in terms of space, efficiency and comfort. When forced with this prioritization, we think that a democratic design of our streets would mean that bicyclists and pedestrians should have a priority that reflects the high percentage of tax paying citizens using these means of transportation. Furthermore it is relevant, that cars are not equally accessible for everyone, due to their cost. In regard to social cohesion, Gehl mentions the public space as a place to meet social diversity and break down preconceptions. We think this point is very important, and would like to point out the perhaps obvious point, that travelling by car, bike or foot offers very different opportunities to meet and relate to other users of the public urban space.

In general many of Gehl's theories are today intertwined with the planning paradigm in Copenhagen. Gehl however only very briefly touches upon lighting, and the little that he mentions does not directly pertain to street lighting. We believe that lighting can and should play a role in this planning paradigm, since Copenhagen is at a latitude which gives us few hours of daylight in winter time and a lot of daylight hours in summer. This circumstance also makes it more comfortable to ride a bike in summertime because of higher temperatures and the daylight extending to the end of ordinary working hours. But, there is a potential for lighting to play a crucial role in how the city is perceived at night as well, especially in the winter months, where the idea of commuting by bike is less attractive. We think street lighting should be used as an active tool in extending an *invitation* to bicycle, and in creating a democratic and fair street in the dark hours.

As a clear indicator, that Gehl's theories are still prominent, and perhaps gaining more momentum than ever, on the 26th of may 2016 *Copenhagen Municipality* released the publication *Cykelredegørelse 2016*, which includes a number of current statistics regarding bicyclism in Copenhagen. It reflects on initiatives implemented to encourage citizens to use their bike as

Ill. 14 Latvian bicycle-advocates in RIga visually demonstrate the disproportionate amount of space demanded by single person use of cars in the city.

Ill. 15. A screenshot from the website of the Danish national newspaper Politiken, taken on 26/05-2016 shows that the debate about the roles of bikes and cars in Copenhagen is still very much alive and relevant.

their main form of transportation. The report concludes that three points must be met in order to get more people to ride their bikes*:

1) Accessibility must be increased - both for slow and fast cyclists.
2) Safety and sense of security must be higher.
3) Better conditions for bicycle parking.

To realize these points the report presents 24 proposals for bicycle friendly measures with a budget of 260 million DKK to reach its goals. Of these proposals, only one specifically describes working with lighting, even though many of the proposals in our eyes will not live up to their full potential at night, without attention to light. This to us underlines that whilst Gehl's theories and a bicycle friendly planning paradigm are continuing to gain momentum in shaping the city, lighting is a tool with a relatively unexplored potential in encouraging and improving bicyclism.

4.3 Håndbog Vejbelysning, Vejdirektoratet

Håndbog Vejbelysning is a handbook, published in april 2015, that comprises and updates several previous documents, into one document, that constitutes the road lighting regulations and requirements on a national level. The work group behind the handbook consists of people of various backgrounds within the field of lighting such as engineers, lighting designers, representatives of municipalities, representatives of danish road directorate etc., and the handbook is published by the Danish Road directorate, *Vejdirektoratet*. It contains binding requirements as well as non-binding recommendations, and it is this document that contains the lighting classes, that define by law the required light levels on different street types in different contexts.

This handbook is central to our thesis for two main reasons. Firstly, as mentioned, the document contains the, which has to be met on various elements in the road profile: Sidewalk, bicycle lane and roadway. These values are required by law in any new public project implementing infrastructure to its design, or any major renovation of an existing project. Secondly, The handbook contributes to an understanding of the priorities and motives behind the current street lighting requirements on a national level. This allows us to gain insight into subjects such as sustainability from an energy perspective, societal values of street lighting, economical incentives of street lighting, and a discussion of how quantitative lighting values relate to the quality of light and aesthetic impact. Therefore we will also analyse and discuss the argumentation behind different requirements and recommendations in the handbook. Our goal with this is not to directly propose new requirements, but to understand and discuss the thoughts behind the current ones.

We would like to start with taking a look at these general motivations, argumentations and explanations, that lie behind the regulations. Luckily for us, this handbook is the first legislative publication, that includes a chapter with background explanations to explain the motives of the legislative content. If we start on the most general strategic scale, we are introduced to the concept *nytteværdibrøken*, which is a fraction, meant to represent the utility value to society of establishing street lighting on a given road, based on international research about the effects of street lighting on traffic safety. The fraction is described as follows:

"Nytteværdien af belysning kan angives ved nytteværdibrøken, som er værdien af det sparede antal uheld divideret med vejbelysningens anlægs- og driftsudgifter udregnet pr. år set over anlæggets levetid. Vejbelysning har en nettonytteværdi for samfundet, når nytteværdibrøken er større end 1." Page 8, Håndbog Vejbelysning, Vejdirektoratet

On a national scale, this fraction has been a tool for assessment of the utility of street lighting, and as such, a strategic tool in deciding whether to establish street lighting on given road types. According to the handbook, roads in cities on average have a fraction of 2. On country roads, the fraction is above 1, if the road traffic exceeds an average of 3000 cars per day. The average highway has a fraction of 0,5. As a result, the majority of the danish highway system is unlit. We can conclude, that on a national strategic level, the decision of whether or not to establish street lighting on a given road type, is first and foremost based on economic incentive.

If we look at the roads, that do have street lighting (as mentioned, this includes all cities in Denmark), the main goals to be achieved by street lighting are described as follows:

"Belysningsanlæggets hovedformål er at skabe sikkerhed, tryghed og fremkommelighed, som sammen med et attraktivt visuelt miljø, er med til at fremme borgernes brug af det offentlige rum, og dermed fremme både kultur- og forretningsliv." Page 8, Håndbog Vejbelysning, Vejdirektoratet

"Yderligere bør der tages hensyn til vejbelysningens indvirkning på vejbilledet og dens visuelle fremtræden og indpasning i omgivelserne både nat og dag." Page 17, Håndbog Vejbelysning, Vejdirektoratet

"Belysningen kan og bør også være med til at give et område særlig karakter og identitet, samt skabe stemning og oplevelse." Page 8, Håndbog Vejbelysning, Vejdirektoratet

The primary goals revolve around the three words safety, security and accessibility. Secondary goals include a fitting aesthetical appearance of the lighting equipment, promoting the use of public spaces, and contributing to identity and experience of the street.

Following these overall goals, are a number of specifications of criteria, that should be met in regard to implementation and design. The following two quotes touch upon the need of adapting the street lighting solution and its intentions to the road and context in questions:

"De forskellige aspekter vægtes forskelligt på forskellige veje og gader og i forskellige miljøer." Page 8, Håndbog Vejbelysning, Vejdirektoratet

"Trafikveje og lokalveje mv. anskues forskelligt med hensyn til belysningsbehov med baggrund i deres anvendelse." Page 8, Håndbog Vejbelysning, Vejdirektoratet

"Vejbelysningen bør samordnes indenfor sammenhængende områder. Det anbefales, at en vejbestyrelse udarbejder en belysningsplan eller belysningsstrategi." Page 17, Håndbog Vejbelysning, Vejdirektoratet

In regard to energy consumption, there is a clearly defined goal:

"Energiforbruget til vejbelysningen bør holdes så lavt som muligt og beregnes for forskellige anlægsløsninger pr. kilometer vejstrækning i levetiden." Page 8, Håndbog Vejbelysning, Vejdirektoratet

*Politiken online, artiklen "Slut med favorisering: København vil tage plads fra bilister - og give den til cyklister"

In regard to the distribution of light, and the choice of street elements to be lit, the following two recommendations are made.

"Det er vigtigt at belysningen retter sig mod de arealer, genstande mv., hvis synlighed har stor betydning i den konkrete situation. Samtidig bør gener fra belysningen undgås." Page 8, Håndbog Vejbelysning, Vejdirektoratet

"Belysning (spildlys) af nattehimlen bør begrænses. Endvidere bør belysning af arealer og bygninger uden for vejens tracé begrænses, med mindre der er ønske om en vis belysning." Page 8, Håndbog Vejbelysning, Vejdirektoratet

The element of security is not discussed in any detail, but is described as a clear benefit of street lighting:

"Ud over den positive virkning på trafiksikkerhed har vejbelysningen en klar og åbenbar effekt på tryghed i nærmiljøet. [...] Samtidig er der en indikation for, at risikoen for kriminalitet reduceres." Page 11, Håndbog Vejbelysning, Vejdirektoratet

According to the handbook, the above constitutes the overall goals and values on which the regulations and technical specifications are based. Before we move on to the actual lighting classes that make up the core of the legislative content, a few important concepts and recommendations from the handbook will be included.

An essential element in the handbook is the classification of different road types. These classifications are essential to the lighting classes. The roads are divided into the following classifications: *motorvej*, *motortrafikvej*, *trafikvej*, *lokalvej* and *sti*. In the context of the thesis' interest in urban streets that facilitate bicycle traffic, we will only be looking at the two road types: *trafikvej* and *lokalvej*, which make up the vast majority of roads in Copenhagen. *Lokalveje* are typically smaller roads with a maximum of two lanes of car traffic. *Trafikveje* are streets with two or more lanes. A helpful rule of thumb in cases of doubt, is that the presence of bus traffic qualifies the road as a *trafikvej*. According to the handbook, the street lighitng serves different purposes on these two road types. For *trafikveje*, the purpose is described as follows:

"Trafikvejens belysning skal forbedre synsforholdene for de motorkørende. Virkemidlet er kørebanens luminans ("lyshed"), som tegner vejens forløb overskueligt og danner baggrund for forhindringer eller personer, der eventuelt befinder sig på kørebanen, så de på tilstrækkelig afstand bliver synlige mod denne baggrund, selv når objekter eller personers beklædning er relativt mørke." Page 8, Håndbog Vejbelysning, Vejdirektoratet

"Ved rundkørsler og større kryds på trafikveje er der udvidede trafikarealer og komplicerede trafiksituationer. Der er behov for at se vognbaneforløb, kørebaneafmærkninger, personer og objekter i flere retninger, også i retninger skråt til siden, hvor køretøjets eget nærlys er svagt." Page 9, Håndbog Vejbelysning, Vejdirektoratet

"Endelig skal kørebanens omgivelser og sidearealer i form af rabat, cykelsti, fortov samt stoppesteder mv. have en vis belysning, både fordi de skal kunne ses af de motorkørende og fordi de anvendes af personer til fods og på cykel." Page 9, Håndbog Vejbelysning, Vejdirektoratet

According to this description, it is evident, that providing good lighting for motorized traffic is the main priority on these roads. It is also quite clear that lighting of bicycle paths and pavements is to a large extent aimed at making these areas and their users visible for the motorists. For *lokalveje*, the following description is given:

"På lokalveje skal belysningen tilgodese fodgængere og cyklisters behov. Vejene er indrettet til lav hastighed og de motorkørende har god nytte af nærlysets begrænsede rækkevidde. Fodgængere og cyklister har i højere grad brug for at kunne se enkeltheder og overfladestruktur i rumlige genstande, som fx andre personer eller vejens eller stiens overflade, på kort afstand. Det gælder det samlede færdselsareal af kørebane, fortov, eventuelle rabatter, parkeringsarealer mv. Virkemidlet er belysning af både vandrette og opretstående flader, som samlet kvantificeres ved den halvrumlige belysningsstyrke og en vis regelmæssighed." Page 9, Håndbog Vejbelysning, Vejdirektoratet

When considering these two road type definitions together, a picture is drawn of *lokalveje* as being full of bicyclists, pedestrians and playing children, whilst *trafikveje* are roads for cars. Whilst this may be an appropriate approach to street lighting in some contexts on a national level, we find it to be a very lacking and inaccurate approach for a city like Copenhagen. It is important to remember, that in Copenhagen, *trafikveje* are in many cases the main arteries of the city's bicycle network, and sometimes see more bicycle traffic than car traffic.

We are also introduced to *LCC-analysis*, which is an analysis, that all bigger new road lighting solutions must undergo. A brief description of the analysis is described as follows:

"Når valget står mellem flere mulige tekniske anlægsløsninger, bør man vælge den løsning, som over tid er bedst for samfundet som helhed. I beregning af livscyklusomkostninger indgår anlægsomkostninger, drift- & vedligeholdelsesomkostninger, anlæggets restværdi, meromkostninger for trafikken samt miljøomkostninger. For større anlæg bør der gennemfører en LCC-analyse." Page 13, Håndbog Vejbelysning, Vejdirektoratet

The reason we include this description, is that it is a very representative description of a way of assessing what is best for our society. This notion of being able to quantify societal benefit based solely on directly attributed economical cost and benefits, is one that we will challenge and discuss in chapter 4.7.

In regard to the lifespan of implemented street lighting, the following list describes the valid reasons to modify or replace an existing street lighting system:

"Et eksisterende vejbelysningsanlæg ændres, såfremt ét af følgende forhold er til stede:
- *Anlæggets energieffektivitet er for ringe*
- *Anlægget er uøkonomisk i drift*
- *Anlægget har for høj eller for lav belysningsklasse i forhold til den pågældende vej*
- *Anlæggets optiske ledning virker vildledende på trafikanterne*
- *Den type lyskilder, der anvendes i anlægget, er udfaset."* Page 17, Håndbog Vejbelysning, Vejdirektoratet

It should be noted, that the handbook also mentions an abnormally high amount of traffic accidents as a reason to consider changes to the street lighting. What we found interesting about this quote, is that there is no mention of changed usage, as a reason to redesign the street lighting system. Many components of street lighting equipment, such as poles or wire systems are very durable and often last for many decades, whereas usage patterns can change in very

few years, and have often done so in the case of bicycle-friendly measures and alterations to street profiles. An example could be the construction of bicycle bridges across central Copenhagen's central canal in the last few years. Even though the areas surrounding these bridges have not been altered physically, they now see a huge increase in bicycle traffic.

Another theme that is touched upon in the handbook is the reflective properties of the road surface as a factor influencing street lighting and visibility.

"Luminansen, og dermed synligheden af kørebanen, er meget afhængig af vejoverfladens refleksionsegenskaber" Page 11, Håndbog Vejbelysning, Vejdirektoratet

The main advantages of using a light surface material are reduced energy consumption, reduction of mirroring of automobile headlights in wet conditions, and perhaps most importantly, better visibility of objects, persons or irregularities on the road surface. Because of these advantages, the handbook includes regulations that specify the optimal lightness and reflective qualities for road surfaces. These regulations however only affect areas affected by lighting classes in the L and LE row which means that the regulations do not apply to bike lanes or sidewalk. We find this strange, considering that reading the asphalt surface is especially essential to cyclists, as bicycles are generally much more sensitive than cars to surface irregularities such as cracks or bumps.

At the core of the legislative content in the handbook is the system of lighting rows and classes that street lighting must satisfy. As they are legally binding, in contrast to the recommendations in the handbook, these classes, more than anything else in the handbook, influence how street lighting is implemented in Denmark. Therefore, we will go through the most relevant aspects of these classes. The following quotes from the handbook give a general description of how these classes are used and applied:

"Når det er besluttet at etablere eller ændre vejbelysning, fastlægges belysningens kvalitet ved valg af en belysningsklasse. En belysningsklasse er kun overholdt, hvis alle delkravene til den enkelte belysningsklasse er opfyldt. Valget af belysningsklasse sker med fokus på trafikanternes visuelle behov på forskellige vejtyper og omgivelser." Page 18, Håndbog Vejbelysning, Vejdirektoratet

"Der skelnes mellem trafikveje og lokalveje [...] Ligeledes skelnes der mellem, om vejen eller færdselsarealet ligger i bymæssige områder eller åbent land. Belysningsklassen specificerer, hvilke arealer på og ved vejen, der skal belyses og hvor meget. Dette angives ved hjælp af lystekniske parametre som luminans, belysningsstyrke og regelmæssighed. De luminans- og belysningsniveauer for forskellige vejtyper og områder, som er beskrevet i det følgende, er minimumsværdier, der bør følges. Eventuelle fravigelser fra disse minimumsværdier bør kunne begrundes ud fra det hensigtsmæssige heri. " Page 18, Håndbog Vejbelysning, Vejdirektoratet

It is mentioned that the choice of lighting class depends on the road type in question. This refers to the road classifications previously introduced in this chapter: *motorvej, motortrafikvej, trafikvej, lokalvej* and *sti*. The lighting classes are arranged in rows, where the row specifies, to which road classifications the included classes apply. Two rows cover the five above mentioned road types: The L-row contains the classes for *motorvej, motortrafikvej and trafikvej*, while the E-row contains the classes for *lokalvej* and *sti*.

In addition to these rows, there are other rows that cover special cases like pedestrian cross-

Belysningsklasser i L-rækken		Motorveje og motortrafikveje[2]			Trafikveje og motortrafikveje[2]				
		L1	L3	L5	L2	L4	L6	L7a	L7b
Tør kørebane:									
Middelluminans, minimum, (driftsværdi) [1]	L_m, cd/m^2	2,00	1,50	1,00	2,00	1,50	1,00	0,75	0,50
Regelmæssighed, minimum	R	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40
Langsregelmæssighed, minimum	R_L	0,60	0,60	0,60	0,30	0,30	0,30	0,30	0,30
Synsnedsættende blænding, maksimum	TI, %	6,1	6,5	6,8	6,1	6,5	6,8	7,0	7,0
Våd kørebane:									
Regelmæssighed, minimum	R	0,20	0,20	0,15	0,20	0,15	0,15	0,15	0,15
3,5 m langs kørebane:									
Belysningsklasse på de nærmeste 3,5 m langs kørebanen		E1	E1	E2	E1	E1	E2	E2	E2

[1] Når minimumkravet til middelluminans har stærkt uheldige konsekvenser for belysningsanlæggets udformning, og der opnås væsentlige fordele herved, kan kravet underskrides med højst 10%.
[2] Afhængig af motortrafikvejens udformning og trafiksituationens sværhedsgrad belyses disse enten som motorveje eller trafikveje.

Ill. 16. Table containing the requirements of the lighting classes in the L-row.

Ill. 17. Illustration showing how only the road surface is subject to a lighting class from the L-row, while the side area, including bike lane and sidewalk is subject to a lighting class from the E-row.

Belysningsklasser i E-rækken		E1	E2	E3	E4
Halvrumlige belysningsstyrker på færdselsarealet som helhed:					
Middelbelysningsstyrke, minimum, (driftsværdi) [1]	E_{hr}, lux	5,00	2,50	1,00	-
Regelmæssighed, minimum:	R	0,15	0,15	0,15	-
Blændingstal for armaturer		Se afsnit 3.4			

[1] Når minimumkravet til middelbelysningsstyrke har stærkt uheldige konsekvenser for belysningsanlæggets udformning, og der opnås væsentlige fordele herved, kan kravet underskrides med højst 10%.

Ill. 18. Table containing the requirements of the lighting classes in the E-row.

ings, tunnels, bridges, bus-stops etc, which generally need increased lighting values. We will however not go into these rows and classes, but limit ourselves to the L- and E-rows, which have most relevance to this thesis.

The description of the L-row is included below:

"L-rækkens belysningsklasser anvendes på steder, der i det væsentlige belyses af hensyn til motortrafikanter, som har brug for at kunne orientere sig og opdage forhindringer og personer på lang afstand, dvs. på motorveje, motortrafikveje og trafikveje. L-rækken er opstillet på grundlag af luminanser på kørebanen." Page 19, Håndbog Vejbelysning, Vejdirektoratet

The classes contained in the L-row are listed in illustration 15.

One thing, that is important to understand, is that when looking at the classes in the L-row, only the road surface is subject to the luminance-based L-class specifications. The bike lane and pavement are subject to an E-class, which in the majority of situations means, that these areas will receive noticeably less light than the road surface. In fact, as visible in illustration 16, an area of 3,5 meters on each side of the road surface is subject to an E-class, regardless of whether, there is bicycle or pedestrian traffic or not. This in our opinion underlines our earlier claim, that the lighting of bike lanes and pavements on *trafikveje*, is first and foremost aimed at creating good visibility for the motorists. If this was not the case, surely, a distinction would be made between a side area consisting of a grass ditch, compared to a side area with heavy bicycle and pedestrian traffic.

The description of the E-row is included below:

"E-rækkens belysningsklasser anvendes på steder, der i det væsentlige belyses af hensyn til fodgængere og cyklister. Disse trafikanter har i højere grad brug for at kunne se enkeltheder og overfladestruktur i rumlige genstande, som fx andre personer, fortovskanter, vejbump, gadeinventar samt vejens eller stiens overflade på kort afstand. E-rækken er derfor opstillet på grundlag af halvrumlige belysningsstyrker, der giver et bedre indtryk af lysets evne til at fremhæve rumlig struktur end belysningsstyrken på vandret plan. E-rækkens belysningsklasser anvendes på lokalveje, stier, parkeringspladser mv. Som anført [...] gælder E-rækkens belysningsklasser for færdselsarealet som helhed, dvs. både vejbane, cykelsti, fortov og øvrige sidearealer." Page 20, Håndbog Vejbelysning, Vejdirektoratet

The classes contained in the E-row are listed in illustration 17.

As evident in the above description, the E-row's classes aim to establish the same specifications across the street as a whole, including bicycle path and pavement. We are critical towards the way this aim has been implemented in the classes in the form of minimum values. It is very uncommon to see E-class roads lit with more than one light source in the road profile. This type of configuration will in most cases create an uneven distribution of light, with higher levels underneath the light source. As a result, in many of the cases we have examined in the course of this thesis, E-class roads exhibit the same overall distribution pattern as most of the L-classes, with higher illumination intensities on the road center, and a steep fall-off towards the road's sides.

The identification of the correct lighting class for *trafikveje* in an urban context, is explained in illustration 18 & 19 and for *lokalveje* in illustration 20.

Hastighedsklasse	
Høj (60-70 km/h)	Eventuel let trafik er adskilt fra biltrafikken ved mindst en kantsten. Behovet for kontakt på tværs af vejen er forsvindende eller kan tilgodeses ude af niveau, da krydsninger foregår via bro eller tunnel.
Middel (50 km/h)	Fodgængere bør altid være adskilt fra kørebanen ved mindst en kantsten. Cykler bør normalt være adskilt fra kørebanen ved rabat eller kantsten, eller eventuelt en stribe, afhængigt af blandt andet antallet af biler og cykler.
Lav (30-40 km/h)	Benyttes hvor der er mange cyklister og ingen cykelsti, hvor der er mange krydsende lette trafikanter, ud for skoler, institutioner, butikker samt stoppesteder, standsningssteder, trafikterminaler mv., eller hvor oversigtsforholdene i øvrigt taler for det.

Ill. 19. Table explaining the definitions of three speed categories used in determining the relevant lighting class for roads in the L-row in urban contexts.

Hastighedsklasse	Fodgængere på kørebanen	Cyklister på kørebanen	Blænding fra modkørende [1)]	Belysningsklasse på trafikveje		
				2-3 Spor	4 spor	6 spor
Høj	nej	Nej	ja	L7a	L6	L6
	nej	Nej	nej	L7b	L7a	L6
Middel	nej	Nej	ja/nej	L7b	L7a	L6
	nej	Ja	ja/nej	L7a	L7a	
	ja	ja/nej	ja/nej	L6	L6	
Lav	ja	Ja	ja/nej	LE4		

1) Besvares ja, hvis der findes kørespor med modsat rettet trafik uden adskillelse ved midterrabat, eller hvor midterrabattens bredde er under 3 m.

Ill. 20. Table for determining the relevant lighting class for roads in the L-row in urban contexts.

Lokalvejens beliggenhed	Belysningsklasse på lokalveje
Tæt, høj bebyggelse	E1
Lav eller spredt bebyggelse	E2

Ill. 21. Table for determining the relevant lighting class for roads in the E-row in urban contexts.

As a final note regarding the lighting classes, we will examine the following quote, describing how the lighting values in the lighting classes were chosen:

"Niveauerne er valgt som anbefalede minimumsværdier, der er hensigtsmæssige set ud fra den netto nytteværdi, der opnås for samfundet." Page 11, Håndbog Vejbelysning, Vejdirektoratet

This description is interesting, because it appears to reveal, that the lighting classes are based more on the economical utility thinking described in connection with *nytteværdibrøken* and *LCC-analysis*, than on the more holistic goals described in the early chapters of the handbook. We think this raises questions about to which extent, these goals are integrated in the actual legally binding content throughout the handbook.

The handbook contains an extensive collection of recommendations for choice and placement of lighting equipment for different road profiles in urban contexts, in order to practically implement the lighting classes. We will not be going into details about these recommendations, as they are not legally binding, but will stick to including a few excerpts, that are very relevant to our thesis, and our analysis of the street lighting in Copenhagen:

The very overall choice between a pole-based solution or a wire-mounted solution is described as follows:

"Masteanlæg vil som regel være den foretrukne anlægstype hvis:
• Pladsen i vejprofilet tillader master
• Det af hensyn til omgivelserne dvs. bygninger og private grunde kan accepteres at have master med armaturer nær vejskellet." Page 70, Håndbog Vejbelysning, Vejdirektoratet

In dense urban contexts with high buildings and limited space in the street profile, wire-mounted systems are however recommended:

"På veje mellem høje husfacader, fx med boliger tæt på vejen, vil der ofte være armaturer ophængt over kørebanerne i wirer mellem facaderne og/eller mellem gittermaster. Denne anlægstype kan udmærket være den bedste også i fremtiden, fordi:
• Armaturerne har en vis afstand fra facaderne og således ikke kaster meget lys ind ad vinduerne
• Der kan være problemer med at få plads til master i gaderummet." Page 70, Håndbog Vejbelysning, Vejdirektoratet

This general approach correlates well with our observations in Copenhagen. In the majority of Copenhagen's old quarters, space is limited and wire-mounted systems dominate, while newer parts of the city such as *Ørestaden* are dominated by pole-based solutions.
In this chapter, the handbook includes a list of pros and cons for different configurations. Again, we will not go through the list, but only include the following description regarding centered single-row wire-mounted solutions, which are very common in Copenhagen:

"Én række armaturer i wirer over kørebanen kan være nok, men ved bredere arealer kan belysningen på fortov og cykelsti opleves som utilstrækkelig." Page 70, Håndbog Vejbelysning, Vejdirektoratet

Considering, that this configuration is known to specifically compromise bike lanes, it is compelling to ask, why it is so widely used in a city like Copenhagen.

The handbook is a very extensive document, and includes a long range of descriptions of parameters and standards, that have not been mentioned in this resume. Examples include glare standards for luminaires, CRI and CCT of light sources, and so on. This should not express, that we consider these themes and parameters unimportant to the discipline of street lighting, but we have however had to limit the focus of this chapter by leaving out themes due to one of the following reasonings:

1) We were generally in agreement with the stances of the handbook, and did not wish to challenge or discuss the themes in questions.
2) We did not have the technical knowledge to engage in a discussion of the theme in questions. This pertains especially to very technical and calculation heavy standards.
3) The theme in questions was not relevant to the focus of the thesis.

All in all, our impression of the handbook is, that it is a very thorough document, that shows a very large amount of attention to a long row of factors, and is quite clearly built on very extensive research through the years. We are in agreement with a large part of the content, and in general find it to be a very strong framework and quality guarantee on a national level.
It has also allowed us to become acquainted with the legislative tools, used to control and influence how street lighting is implemented, and has given us an insight into the many complex factors that need consideration, when working with street lighting. We do however also have points of critique.

Firstly, we are left with the impression, that the handbook first and foremost sees street lighting as an infrastructural element supporting motorized traffic. Throughout this resume, we have mentioned numerous examples hereof. As a result of this mindset, cyclists' and pedestrians' needs take up quite little space in the handbook, and in many cases, these user groups are reduced to potential obstacles for cars. There is furthermore a tendency to treat these cyclists and pedestrians as one homogenous entity with identical needs, in spite of the obvious differences between them, of which speed is perhaps the most important. As a result, in the lighting classes, pedestrians and cyclists are always subject to the same lighting class, which is in most cases consistently lower than that on the adjacent road surface.

In several cases, we think that the handbook's analyses of motorists' user needs and the street lighting solutions to address these needs, could and should be adapted to cyclists. For example, we mentioned the handbook's description of benefits from light asphalt on the road surface. We see no good reason that light asphalt should not be used on bicycle paths too, offering bicyclists the same improved visibility. Another example is the L-row's lighting requirements for the side area to the road. This requirement is based on the idea, that motorists need to be able to identify possible obstacles, elements etc. outside of the road profile, because they move at high speeds and have a considerable braking distance. Again we see no reason, that cyclists would not benefit from the same consideration in regard to their need to read the space adjacent to their lane, in order to avoid dangers and increase comfort.

As we see it, the only apparent reason that these needs are described, researched and addressed for motorists, but not for cyclists, appears to be a favoritism of cars, and neglect of treating other user groups as equally important users of the street.

In a context such as Copenhagen, where cyclism is at least as important a means of transportation as motorized traffic, we think this type of systemic favoritism is problematic, and

ultimately stands in the way of achieving an urban infrastructure, in the limited public space available, that services and respects all its citizens and users equally.

Another point of critique, is that the motives and goals of the handbook seem to point in different directions throughout different parts of the handbook. In general, the expressed holistic goals introduced in the beginning of the handbook only seem to have influenced the legally powerless recommendations, whilst the majority of the legally binding content appears to be based on other success criteria. We do acknowledge that the integration of new ideas into a body of ongoing regulations and requirements, can take time, and we see the inclusion in this handbook of goals regarding urban life, identity, experience and aesthetic impact as a move in a welcome direction. We are nevertheless left with the impression that certain goals and motives expressed in the handbook ring slightly hollow.

4.4 Belysningsmasterplan København, Citelum

Belysningsmasterplan København provides the thesis with an understanding of the current guidelines and ideas that define the way the city's lighting is currently being implemented and renovated. We are interested in looking at which analyses, motives and success criteria are used, and we further wish to understand how the unique characteristics of Copenhagen are treated and reflected in a lighting strategy. One of these characteristics is the role of bicyclism as a means of transportation, and we will focus especially on how bicyclists are currently addressed in the masterplan.

The masterplan has been produced by *Citelum* in cooperation with *Copenhagen Municipality*. *Citelum* is a french company, which specializes in city lighting consulting, and is currently responsible for maintenance and installation of new lighting systems in Copenhagen from 2016 to 2025, after winning a tender. Part of the tender supplied by *Copenhagen Municipality*, required that the energy consumption would be reduced to half the level of 2012, which has pushed the bid created by *Citelum* to only incorporate LED technology in new luminaires.

The purpose of the lighting masterplan is to serve as a foundation of a large scale renewal project in *Copenhagen Municipality*, which includes replacement of 20000 street lamps and 8000 lighting masts in the city's residential areas. Furthermore, the masterplan expands to form guidelines for any modifications and new constructions of lighting systems, for the different districts of Copenhagen. These guidelines are based on a number of analysis of the identity, characteristics and current lighting conditions in each of the districts. These analyses are used to generate district-specific proposals on how to improve lighting. Each proposal assigns a luminaire design, and some of them also include modified lighting principles and color temperatures. All of the initiatives suggested are kept within the framework of the renewal project.

The masterplan introduces itself as being respectful to the urban design values, which have made up the paradigm of urban design in Copenhagen, in recent decades. *Citelum* uses the publications *Handlingsplan for Københavns Byrum* and *Metropol for Mennesker*, as reference. Both of them emphasize many of the values described by Gehl and *Citelum* sums up the points made in these publications like this:

"Byrum vil blive udviklet efter fire principper, som giver sig til udtryk i en styrkelse af forbindelserne i bykernen og mellem byens kvarterer:
- Forbedre byrummene, der udgør strukturen omkring handelsgaderne,
- Gøre byen tilgængelig for alle.
- Skabe nye muligheder for spadsereture, afslapning, iagttagelse, leg og fritidsaktiviteter.
- Skabe tiltrækkende og sikre områder for fodgængerne over hele byen og promenader ved havnen." Page 11, Belysningsmasterplan København, Citelum

These referenced goals are also intertwined with their own ambition for urban lighting in Copenhagen:

"Belysningsplanens centrale ambitioner er at:
- Videreføre de tiltag, København har foretaget angående planlægning og forbedring af byen, til også at gøre sig gældende om natten.
- Tilbyde hovedstaden muligheden for at udnytte alle belysningspotentialer (skabe atmosfære, forbedre opfattelsen af natten, forbedre sikkerhedshensyn, understøtte blød trafik, hierarkisering, byforbedring via belysning m.m.).
[...]
- Foregribe Københavns byudvikling ved især at støtte sig til "Handlingsplan for Københavns Byrum" og "Fingerplanen" for dermed at bidrage til en helhedsplanlægning, der tager højde for byplanlægning, transport og rekreative områder. Dette er ikke mindst med henblik på at reducere transporttiden, særligt biltrafikken, og gøre adgangen til de grønne områder nemmere for alle.
[...]
- Fremme nye måder at opfatte ting på og lette den rumlige aflæsning af København."
Page 8, Belysningsmasterplan København, Citelum.

First and foremost it appears that Copenhagen's urban planning strategies are to be very influential on the way the city will be lit, but the masterplan's ambition is also to create and enhance atmospheres and encourage new ways of perceiving and reading the urban space.

As *Citelum* are leaning against the urban design tendencies of city spaces formulated in *Handlingsplan for Københavns Byrum*, they are obligated to carefully consider the planning from a human scale. *Citelum* also mention that they aim to reduce transportation time, especially for car traffic. Good lighting does increase the capacity and accessibility, but in a context, where only 10% of the transportation to and from education and work, for Copenhagen citizens, happens by car, it might be a distorted priority to nurse facilities for people driving cars in the dense urban areas. Not meaning that there should be no light, but that the focus could serve the majority of people, who are commuting by bike or foot.

The masterplan does acknowledge how comprehensive bicyclism is to Copenhagen, by quoting statistics of the amount of transportation done by bicycle, but these numbers are not directly transferred into the goals and ideals of the masterplan.

"- Cyklen udgør 35 % af transportandelen i København. Målsætningen er inden 2015 at nå op på 50 %, og at 90 % (aktuelt 60 %) af indbyggerne maksimalt skal have 15 minutter til fods eller på cykel til en park, en strand, et naturområde eller en svømmehal.
- Københavnerne gennemkører 1,2 millioner km pr. år på cykel. Til sammenligning udgør deres transport med metroen kun 660.000 km, og der er flere cykler, end der er indbyggere."
Page 11, Belysningsmasterplan København, Citelum

The majority of the masterplan consists of detailed analyses of each city district, which in is used as the foundation for making lighting design decisions and proposals.

The analysis of each district follows a method, which describes the following, in chronological order: brief history, atmosphere, residential forms, important roads and links, attractive sites and cultural heritage.

This is followed by a mapping of the road network and the most typical road profiles, which are represented in cross section. The road profiles are then evaluated and fitting lighting classes are determined. The masterplan is bound by the national requirements in the form of the lighting classes, described in *Håndbog Vejbelysning*. In the masterplan however, a more detailed road classification system is used to define lighting classes for different road types, subdividing the two usual road types *lokalveje* and *trafikveje* into a number of types. This is presumably to be able to work with the city's road network in a more detailed and nuanced way. The road classifications used in Copenhagen are:

"Regionale veje / Færdselsveje De regionale / trafikale vejforbindelser mellem København og resten af regionen. [...]
Fordelingsgader / Distributionsveje Distributionsveje sikrer sammenhæng mellem de forskellige bydele. [...]
Bydelsgader Bydelsgader sikrer distribution og afvikling af trafikken i de enkelte bydele. [...]
Strøggader Strøggaderne er handelsmæssige samlingspunkter for bydelene med en stor koncentration af butikker samt café- og restaurationsmiljøer. [...]
Lokalgader / Villaveje Lokale gader / villaveje giver adgang til de funktioner, der er placeret i de enkelte lokale områder, herunder boliger, institutioner, kommercielle aktiviteter etc.
Stier / Fodgænger / Cykelområder Stier / områder, der kun er for bløde trafikanter. Lavet til at sikre strømmen af trafik for disse typer af brugere." Page 22-23, Belsysningsmasterplan København, Citelum

The lighting classes that apply to these road types are all derived from the L- and E-rows from *Håndbog Vejbelysning*. The appropriate lighting classes for given roads, are shown in illustration 21.

When the classification of a road types has been made, and a lighting class has been determined for each type, the existing solutions for the road types in question are analyzed including a registration of the current luminaire types and the current lighting atmosphere. The topics are assessed in the following way:

"Efter at have defineret vejenes struktur afdækkes de principper, der ligger til grund for deres nuværende belysning, samt hvilke belysningstyper, der findes i Københavns gader. Her forklares endvidere hvilke typer lysarmatur og mast eller ophæng (f.eks. flerarmet mast, wireophæng etc.), der bruges, og deres position.
[...]
Først undersøges lyskildernes ydeevne og dernæst stemningsaspektet ved lyskilderne.
[...]
Armaturerne er blevet klassificeret i forskellige kategorier:
Urban funktion: Armaturerne er alene valgt ud fra deres funktionalitet; normal monteringshøjde fra 6 til 8 meter.
Dekorativ funktion: Armaturerne kombinerer funktionalitet og design; normal monteringshøjde fra 6 til 8 meter.

Spor													Agrænset areal på 3,50m (med ét forhold)			Agrænset areal på 3,50m (med to forhold)		
KARAKTER								BELYSNING					BELYSNING			BELYSNING		
Netværk	Type	Klassifikation af vejspor	Antal vejbaner	Hastighed og trafikforhold (se tabel for forhold fra 1 til 8)	Tilstedeværelse af fodgængere	Tilstedeværelse af cyklister	Fysisk adskillelse af vejspor	Belysningsklasse	Luminans (Lm)	Lux	Ensartethed Minimum	Ti maksimum	Belysningsklasse	Lux	Ensartethed Minimum	Belysningsklasse	Lux	Ensartethed Minimum
Primære veje	Regional vej / Central færdselsåre		4	Hævet (60 - 70 km/t)	N	N	Y	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
					N	N	N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
				Gennemsnit (50 km/t)	N	Y/N	Y/N	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
					Y	Y/N	Y/N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
			6	Hævet (60 - 70 km/t)	N	N	Y/N	L4	1,50 cd/m²		0,4	6,5%	E1+	5 lx	0,25	E0+	7,5 lx	0,25
				Gennemsnit (50 km/t)	N	N	Y/N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
	Fordelingsgade / Handelsgade		2 til 3	Hævet (60 - 70 km/t)	N	N	N	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
				Gennemsnit (50 km/t)	N	Y/N	Y/N	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
					Y	Y/N	Y/N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
				Svag (30 - 40 km/t)	Y	Y	Y/N	LE4		15 lx	0,4	G6 eller D5	E1+	5 lx	0,25	E0+	7,5 lx	0,25
			4	Hævet (60 - 70 km/t)	N	N	N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
					N	N	Y	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
				Gennemsnit (50 km/t)	N	N	Y/N	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
					Y	Y/N	Y/N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
	Bydelsgade		2 til 3	Gennemsnit (50 km/t)	N	Y/N	Y/N	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
					Y	Y/N	Y/N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
				Svag (30 - 40 km/t)	Y	Y	Y/N	LE4		15 lx	0,4	G6 eller D5	E1+	5 lx	0,25	E0+	7,5 lx	0,25
	Gågade		1 til ...	Tværgående gade	Y	Y/N	Y/N	LE4		15 lx	0,4	G6 eller D5	E1+	5 lx	0,25	E0+	7,5 lx	0,25
				Gade med høj tæthed	Y	Y/N	Y/N	L7a	0,75 cd/m²		0,4	7,0%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
				Butikker/handel	Y	Y/N	Y/N	L6	1,00 cd/m²		0,4	6,8%	E2+	2,5 lx	0,25	E1+	5 lx	0,25
Sekundære veje	Lokal vej		Normale forhold	Område med høje bygninger	Y	Y	Y/N	E1		5 lx	0,15	G6 eller D5	E2	2,5 lx	0,15	E2	2,5 lx	0,15
				Villakvarter	Y	Y	Y/N	E2		2,5 lx	0,15	G6 eller D5						
			Særlige forhold (med ét forhold)	Område med høje bygninger	Y	Y	Y/N	E1+		5 lx	0,25	G6 eller D5	E2+	2,5 lx	0,25	E2+	2,5 lx	0,25
				Villakvarter	Y	Y	Y/N	E2+		2,5 lx	0,25	G6 eller D5						
			Særlige forhold (med to forhold)	Område med høje bygninger og villakvarter	Y	Y	Y/N	E1+		5 lx	0,25	G6 eller D5	E1+	5 lx	0,25	E1+	5 lx	0,25
	Grønne fælles-områder		1 til ...	Område med høje bygninger	Y	Y	Y/N	E2		2,5 lx	0,15	G6 eller D5						
				Villakvarter	Y	Y	Y/N	E2+		1 lx	0,25	G6 eller D5						
Forskellige områder	Havneområde eller sø				Y	Y	Y/N	E2		2,5 lx	0,15	G6 eller D5						
	Industriområde				Y	Y	Y/N	E2		2,5 lx	0,15	G6 eller D5						
	Særlige forhold				Y	Y	Y/N	E1		5 lx	0,15	G6 eller D5						
Stier	Sti langs trafikvej		Cykler, fodgængere	Cykelsti i byområde	Y	Y	Y/N	E2+		2,5 lx	0,25	G6 eller D5						
				Park, sæbred	Y	Y	Y/N	E2+		1 lx	0,25	G6 eller D5						
	Sti		Cykler, fodgængere	Ruter, sti, park, sæbred	Y	Y	Y/N	E2		2,5 lx	0,15	G6 eller D5						
	Tunnel		Cykler, fodgængere	Nærbelysning lavere eller lig med E2	Y	Y	Y/N	E2		2,5 lx	0,15	G6 eller D5						
				Nærbelysning højere eller lig med E1	Y	Y	Y/N	E1+		5 lx	0,25	G6 eller D5						
				Lang tunnel	Y	Y	Y/N			25 lx	0,4	G6 eller D5						

Ill. 22. Table for determining the relevant lighting class for the different road types in the masterplan's road classification system.

Beboelses- og fodgængerområder: Dekorative armaturer til stemningsbelysning; normal monteringshøjde fra 4 til 6 meter.
Historisk: Vidnesbyrd fra tidligere tider og bevarelse af belysning.
Lysten og væglamper: Punktvis belysning til afmærkning af fodgængerstier eller indgange til bygninger." Page 26-27, Belysningsmasterplan København, Citelum

The output of the masterplan is a proposal for each district, consisting of the assignment of specific luminaires for squares and road types within the district in questions, according to the results of their analysis.

Each luminaire is described and the reasons why it fits a certain environment is explained. The majority of these proposals consist of changing the luminaire or light source, without modification of the mounting system or the position of the luminaires in the street profile. In a few cases, however, new lighting principles for certain road types, paths and squares are proposed, often in the form of additional lighting fixtures, or different positioning of the existing fixtures, if the current lighting solution is considered especially inadequate.

The work presented in *Belysningsmasterplan København* is extensive, and assesses each district of Copenhagen individually, which produces a lot of material in its analysis. Yet, the large amount of analysis work, is practically used to determine very few design parameters, the most prominent being an array of luminaires picked specifically for each district, and a choice of color temperature. An example of such a selection is included in illustration 22.

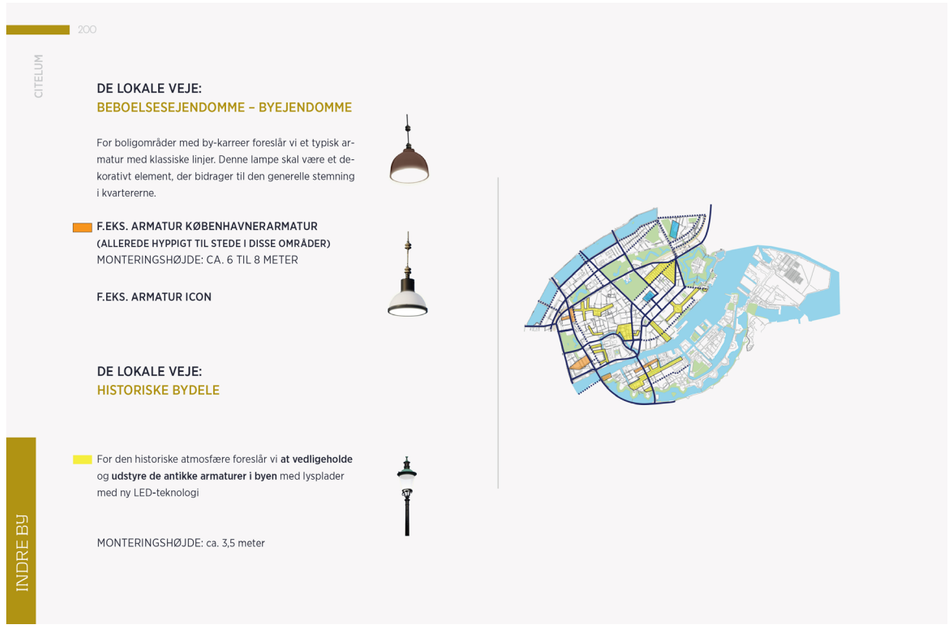
Furthermore, the choice of luminaires for districts appear to be based exclusively on the appearance of the luminaire and mounting, with little to no consideration to the way the luminaire and mounting system affect performance in terms of distribution. As an example, for the inner city historical squares, the design reflections are presented like this:

"For at understøtte atmosfæren på de historiske pladser foreslår vi et dekorativt armatur i linjer, som kombinerer antik og moderne stil. Denne elegante gadelygte har subtile ornamenter og diamantlignende armaturer." Page 201, Belysningsmasterplan København, Citelum.

While we agree, that the aesthetic appearance of luminaires does influence public spaces, this concern primarily affects the daytime appearance, while other factors are much more important to the space as a whole at night. The distribution of light and the way this affects the readability of the space and the emphasis of certain elements and objects, is a factor that is not mentioned at all in relation to the choice of luminaires or mounting system.

The proposals emphasizes the support of the city's different districts in terms of atmosphere. It seems however that atmosphere is regarded as an exclusive result of color temperature. Again we think that an important and complex characteristic is narrowed down to one design parameter. Color temperature is an aspect of importance, but the atmosphere of a place is very much determined by the environment and what elements are being illuminated and made readable. Color temperatures are also used by *Citelum* to create a layer of ambient information, for the road users to determine where they are in the road hierarchy. This is a part of the general street light planning for the entire municipality, where a high color temperature is used for large arteries of infrastructure while lower temperatures are used for smaller roads with low traffic density.

"Det hvide lys bliver nuanceret efter hvert område, så der skelnes mellem kørebanernes



Ill. 23. An example of the recommendations of luminaires for a specific district, in this case the inner city. Arguments tend to prioritize atmosphere and aesthetics with little mention of light distribution or effect on the surroundings.

brug. Der bliver i første omgang foretaget en farvemæssig opdeling af strukturelle akser (regionalveje) og midterakser (fordelingsgader, bydelsgader) ud fra farvetemperaturen på det hvide lys. Denne nuancerede veksling mellem det dagslyshvide lys på strukturelle akser (regionalveje) og et neutralt hvidt lys på midterakserne (fordelingsgader, bydelsgader) gør det muligt at forbedre overblikket over hovedstadens vejnet." Page 66, Belysningsmasterplan København, Citelum

This general planning conflicts with the desire to use color temperature to emphasize a certain atmosphere, and no method is provided to deal with situations where the interests of atmosphere and road hierarchy are conflicting.

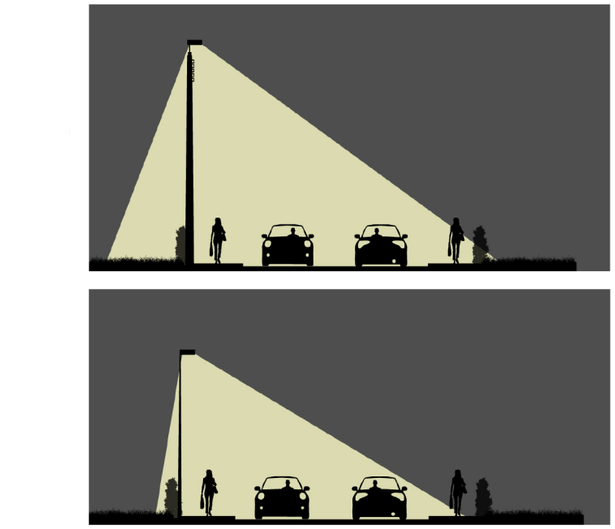
While we mentioned, that *Citelum* do present some new lighting principles, the principles do not seem embrace the results of their analyses. Neither do they seem to be driven by any new thoughts or motivations, but rather to be necessary fixes for very bad current solutions.
Furthermore, these new lighting principles are not suggested for streets, but for squares and other open urban spaces. As such, the assessment and rethinking of lighting principles appears not to be applied in general throughout the districts, but more exclusively to chosen sites of special importance in regard to heritage or recreational use. When no modifications are suggested, this thesis interprets that the existing lighting principles must have been satisfactory according to the creators of the masterplan.

If the ideology behind the masterplan is to be seen as one which builds on top of current city planning, there appears to be a lack of consideration of pedestrians and bicyclists, especially in the spaces that are not city squares. In general, cyclists are not mentioned in any way in the proposals, or in fact in general in the masterplan with the exception of facts included about current statistics on bicycle use. This appears to us to be an odd and unfitting omission in a city like Copenhagen, and we think that in this regard, the masterplan fails to specialize and adapt the lighting strategy of the city to the unique context of the city.

In general the proposals do not seem to embrace all the factors treated by the analysis, especially in the detailed descriptions of each district. From the way the masterplan explains its applied method, It is easy to get the impression that the results of each analysis inspire the proposals for each district, but we find that it is hard to identify the factors of demographics, current urban strategies, atmosphere, district identity, residential typology etc. in the luminaires suggested. All questions of distribution of light in the streets are treated either in the form of lighting classes for horizontal surfaces, or in simplified cross sections showing completely uniform cones of light extending downwards from the light sources. Examples can be seen in illustration 23.

Even though many streets are pointed out as locations that hold significance to each district, there is no apparent mention of using street lighting to emphasize any elements other than the road surface. Another general tendency of the masterplan is that it solves the lighting design from the same point in space relative to the road surface. They do modify the height of which luminaires are installed in selected path systems, but for the road lighting the design is solved from a point in space, which is usually right above the car lanes, and thus distributing most of the light there.

In conclusion, we think the masterplan has a very nuanced motivation and background, and performs an important analysis work, taking into account a lot important factors that influence the experience of different city districts at night. The output of the masterplan is however re-



Ill. 24. Examples of the type of section used throughout the masterplan.

duced to a selection of relevant luminaires, which is an important step in creating coherency of the expression of the lighting equipment in the city. We think however, that the opportunity to create a road lighting strategy tailored for Copenhagen's unique traffic culture is to a large extent unexplored, and that much of the analysis performed is not, from our perspective, used. As a result, the renovation performed by *Citelum* is essentially a one to one replacement exercise, creating energy savings, and streamlining the selection of luminaires and light sources used across the city. These benefits are important to the city, and we do think, that *Citelum* has done a good job of choosing relevant luminaires in a jungle of new LED luminaires of very varying quality. We do however also think, that such a costly renovation, which does not happen very often, could and should have put more effort into reconsidering the way we light our streets, the users being serviced, and the development of the context in questions, rather than only considering the equipment used.

4.5 På tværs af københavns gadebelysning 2014, Katja Bülow

På tværs af Københavns gadebelysning 2014 is a publication made as a part of a ph.d. project on interdisciplinary LED research by *Katja Bülow*. The publication documents the use of LED street lighting (among other light sources) in Copenhagen. It includes a precise and detailed mapping of luminaire- and light source types throughout the city, as well as photo documentation from a large number of locations. In some cases it also describes the poetry of the interplay between various light sources, which has been especially imminent as the collection of data and documentation for the publication was performed in the timeframe of *Citelum*'s ongoing replacement of light sources throughout Copenhagen. Even though the publication focuses on Street Lighting, the photo-documentation locations are often commented upon as experienced situations, focusing on the interplay between the street lighting itself and light from facades, shops and signage in the streetscape. Examples of photo-documentation, comments and mapping are visible in illustration 24 and 25.

Whilst the book's main focus is to map rather than to evaluate, there are certain evaluating comments made throughout the book, but these seem to be without a clearly communicated focus or priority. It is unexplained why certain parameters or effects are commented upon, whilst others are not. This makes these comments hard to use as a form of evaluation of the experience of the street lighting in question.

Another element, that limits the usability of the publication in our perspective, is that all images have been exposure-adjusted. This adjustment has been performed with the goal of approximating the experienced situation as well as possible. While there are obvious technical limitations (dynamic range of a printed image vs. that of the eye), we find this approach a reasonable decision. We have however cross referenced images from the book with our own experience of the depicted sites, and our own photo-documentation, which we have exposure-adjusted to match our experience on-site. The conclusion of this comparison was, that for several sites, the images in the book are very over-exposed, presumably to result in more presentable and print-friendly images. This in our eyes, unfortunately makes the photo-documentation untrustworthy, as a description of the experience, and the performance of the street lighting. If the photo-documentation had been accompanied by illuminance or luminance measurements, the photographs would have been of more use to our project. As the photo-documentation is in the publication now, it doesn't not allow for any comparison between different sites, situations or street lighting solutions.

„ lys fra pølsevognen og skiltning skaber elementer af lys i karreens mørke mellemrum "

„ boulevardens forløb understreges af LED-gadebelysningens optiske linjeføring "

Ill. 25. Examples of photo-documentation from Katja Bülow's book. Images are exposure-adjusted to look good in print. Observations often regard the street as a visual and architectural composition.

The work done by *Katja Bülow* can provide the thesis with a valuable foundation of data on the current state of street lighting in Copenhagen. Access to a structured pool of data and images is valuable to us in narrowing in on examples and case studies to examine ourselves. Furthermore, the methods of registration, can be of value and inspiration to the registrations we want to perform. This includes the elements, which we would like to let us inspire from, as for example the *dérive*, which is an informal choice of route and sites. On the other hand, some of the registrations performed, including the method of processing photos and the lack of any measured lighting data, can make us aware of registrations we need to perform differently from *Katja Bülow*, or completely new registrations, that must be considered.

In our own registrations, we would like to introduce a outspoken and clearly communicated focus of our evaluations of the experiences - in our case the critical perspective on the bicyclist's user experience. We would also like to introduce illuminance and luminance measurements performed alongside photo-documentation - in order to give a basis for comparisons between sites and solutions, and to give a point of reference to the photo-documentation.

4.6 Interview with Maja Hyveled Jakobsen, service manager for operation and maintenance of street lightning in Copenhagen Municipality.

We performed an Interview with *Maja Hyveled Jakobsen*, as a part of our general mapping of interests and practices relating to how street lighting is designed, implemented and operated in Copenhagen today. Maja works in the municipality with responsibility for maintenance and operation of street lighting. Since the majority of maintenance and operation work in Copenhagen is currently performed by *Citelum*, who have won a bid for a 12 year period, Maja's job is also to work closely with *Citelum*, and to oversee and approve *Citelum*'s work. The interview was not recorded or transcribed, but performed as a casual conversation. Our notes from the interview have been fact-checked by Maja, but the final angling and wording of the interview included in this chapter, strictly reflect our understanding of the topics discussed.

One of the themes we asked Maja about, was the cooperation between the municipality and *Citelum*. We wanted to know if the interest of a private company would clash with the interest of a public institution as *Copenhagen Municipality*. According to Maja, the municipality is in a continuous close dialog with *Citelum* about the work they and their sub-contractors perform. It is not our impression that this cooperation causes any significant conflicts of interest. Maja mentioned, that all new lighting projects must be validated in the form of calculations and drawings by the municipality before implementation, and in the case of large scale projects like the current renovation, documented in the form of measurements after installation. Maja supplied us with the work description document *SAB - Særlige Arbejdbeskrivelser - Belysning*, in which these procedures and processes are further described.

The final design goal of our thesis is to examine, how street lighting could be implemented differently, and our thesis furthermore has an interest in examining how street lighting can adapt to accommodate changes to the street in form and usage. We asked Maja how new inputs and ideas relating to the design of street lighting are currently generated and implemented. While Maja's department is always to some extent involved in any project involving street lighting, according to Maja, new ideas and initiatives can come in a number of forms from a number of different places. Examples include proposals from other municipal departments, citizen

H.C. Andersens Boulevard

Regionalvej / Regional Road

H.C. Andersens Boulevard / DI

armatur lamp type	lyskilde light source	farvetemperatur colour temperature	farve gengivelse colour rendering	rækker wire rows	udskiftes for 2016 replacement before 2016
	LED	3000 K	70-80 CRI	2	nej no

60

Ill. 26. Example of the parameters that are mapped in Katja Bülow's book.

inquiries, projects initiated by politicians, or initiatives coming from Maja's own department. As such there is not one fixed pipeline for the initiation of street lighting projects. In the case of larger renovations, separate projects will often be initiated, with or without the involvement of external private consultants, depending on the nature of the project. Such projects will usually require dedicated funding, separate from the ordinary budget for maintenance and operation.

Project-based funding was also touched upon in connection with another theme, that we brought up. We had observed examples in Copenhagen of bicycle friendly modifications to the street profile, without a corresponding alteration to the street lighting system, resulting in poor conditions. We asked Maja, how this type of mismatch arises. One possible explanation according to Maja, could be found in project-based funding of renovation projects. If the project's funding run out before addressing lighting, or lighting is not considered in project, there is not another budget to perform the necessary lighting adaption, once a problem becomes apparent.

In addition to the above included themes, we discussed a number of other subjects, that are not included in this chapter, because they are discussed elsewhere in the thesis. In general, the meeting also served as a good way for us to confirm our understanding of processes and procedures gained from our literature studies.

4.7 Discussion of Sources

In this chapter, we will discuss selected themes by comparing some of the views presented in the sources we have reviewed in the previous chapters. Our goal is that this process can spark a discussion that doesn't naturally occur due to a separation between academic fields, and that the opinions and stances expressed in the different sources are put in perspective.

One theme, that we find very interesting is the understanding of societal value as a concept and as an argument. Several of our sources use the argument of societal benefit or value, but the understanding of this concept differs greatly.

One key distinction in the understanding of the concept, is whether societal benefit is considered as ultimately being measureable strictly in terms of economical benefit or value.

In *Håndbog Vejbelysning*, the concept Nyttebrøken is a clear example of the use of societal benefit as a strictly economical concept. In this example, societal benefit is expressed through an equation, that balances two expenses. The saving made by choosing the lower expense, is the societal benefit.

Nyttebrøken addresses the question of whether to add street lighting or not to a road. If we were to address this questions using an understanding of societal benefit as a concept that was not strictly economically measurable, we might for example include ethics in the equation. We could ask ourselves hypothetically, how much we as a society are willing to pay as a cost, to save a human life. Or we could include aesthetics, and ask, how much are we as a society willing to pay to have beautiful roads?

These questions are more difficult to answer, and in turn make societal benefit harder to use as a tool and an argument in decision making. Therefore societal benefit is in many cases used as a concept that is strictly economically measurable. If we accept this prerequisite for understanding societal benefit, we are faced with another distinction, which is whether an equation expressing societal benefit should only include direct costs and benefits, or whether it should also include derived costs and benefits.

As an example, we can look at *LCC-analysis*, which was introduced in *Håndbog Vejbelysning*. This analysis compares different lighting solutions based on a number of costs and benefits, with the goal of making the choice of lighting solution that is best for society. The costs and benefits listed, do however not include any derived costs and benefits. If we hypothetically imagine that one lighting solution uses danish manufactured products, and another uses chinese products, there could theoretically be a derived benefit from choosing the danish product, because it might create jobs and tax revenue for the state. On the other hand, perhaps one solution might turn out to cast annoying spill light into a number of homes, causing the inhabitants sleeping difficulties and derived lowered productivity, or devaluing the price of these homes.

The above examples are theoretical and constructed in order to explain the distinctions in regard to the understanding of societal benefit as a concept. The reason this is relevant, is that societal benefit is used as an argument in several of our sources. *Håndbog Vejbelysning* uses societal benefit as an argument in determining whether or not to implement street lighting, as an argument in determining which solution and equipment should be chosen, and as an argument for the values in the lighting classes, that in turn determine how much light should reach the street. In some cases, the factors included in the assessment of societal benefit are listed, and in others they are not, but in general, it is our impression, that societal benefit is understood as economical societal benefit, based mainly on direct costs and benefits.

Jan Gehl introduces a quite different way of looking at societal benefit of infrastructural investments. One essential element of his theories in this regard, is his concept of *invitation*, and his claim, that the way a city's infrastructure is designed, influences the usage patterns of the city. As a result, an infrastructural change creating an *invitation* for bikes, can result in more people using bikes. And according to Gehl, this can have an enormous potential economic benefit for society - two of the perhaps most obvious ones being savings in relation to health care and more efficient traffic.

Gehl also describes societal benefits of bicycle friendly urban design, that are not economical, or that are difficult to quantify in terms of economical value. Examples include security, equality, social cohesion, better life quality, more stimulating commutes, reduction of carbon emissions, reduction of noise pollution, etc.

One problem related to derived effects, is that they can potentially go on ad infinitum, and every added link in the chain of cause and effect contains a prediction, introducing a layer of uncertainty. In addition, there are practical consideration in regards to how long a list of derived effects that can be included every time a design choice must be made. We do however think, that as a minimum, it should be acknowledged, and included in a societal benefit analysis, that design changes to a city's streets are likely to influence future usage patterns. Furthermore, we believe that street lighting can contribute to achieving many of the derived societal benefits (economical and other) of better conditions for cyclists, that Gehl describes. It would be interesting to see, if the lighting requirements, contained in *Håndbog Vejbelysning*, would look different, if an understanding of societal benefit, more like *Jan Gehl*'s, was used.

Another theme, we would like to discuss in this chapter, is the way our different sources view the role of bicyclism. There are some quite pronounced differences in the way cyclism and cyclists are approached and talked about in *Cities for People*, *Håndbog Vejbelysning*, and *Belysningsmasterplan København*.

Gehl is very obviously pro-cyclism, and sees cyclism as a superior alternative to car traffic. According to Gehl, the promotion and accommodation of cyclism is something to strive for, due to a number of reasons, including health benefits, more efficiency, better urban design possibilities and increased city life. Gehl furthermore sees cyclism not as a constant, but as the result of an extended *invitation* to bike, and a constant conscious effort to promote cyclism through the design of streets and public spaces.

Håndbog Vejbelysning mentions cyclists as a user group that is important to accommodate. However the handbook also exhibits an understanding of cyclism as tied to small roads and paths, whereas on significant roads, cyclists are explicitly mentioned as secondary to cars or merely as potential obstacles for cars. Furthermore, cyclists are for the most part grouped together with pedestrians as a group with common needs and interests.

In *Belysningsmasterplan København*, *Citelum* describe cyclism as an integral part of Copenhagen's traffic landscape, but do not analyse, address or integrate cyclism in any meaningful way into the masterplan. In this sense, it is our opinion that they practically exhibit a more or less neutral stance in regard to cyclism.

In extension of this theme, we would like to take a look at the question of priority and hierarchy. In a dense city, it is not possible to prioritize all users at once on the same limited amount of space. Bikes, cars and pedestrians move at different speeds, and therefore present obstacles for each other. Therefore the road is divided into user specific areas, and in this division is an obvious compromise of space. Furthermore, prioritization of one user group is often at the price of another in other ways. More space for car traffic, results in more noise and pollution, which means lower comfort for bikes and pedestrians (and inhabitants). More pedestrian crossings cause waiting time and possible congestion for motorists. According to this line of thought, we think, it is important to have an active opinion in regard to this inevitable prioritization, seeing how an opinion of prioritizing all user groups, is not a practically applicable stance. Again our different sources take on different standpoints.

Gehl sees cyclists as a weaker and more vulnerable traffic user group in relation to cars, and therefore one that needs protection and priority in terms of design. This refers to the fact that a crash between a car and a bike will likely turn out to the car's favor, creating a skewed power balance. Another element is that a bike is smaller and harder to see than a car for other cars, which can cause a number of dangerous situations. From a lighting perspective, we think, cyclists furthermore have an extra weakness at night, in having less powerful lights than cars, resulting in in less visibility of the road for the cyclist, but also in less visibility of the cyclist for cars. Gehl also introduces the idea of a street as a democratic space that is obligated to supply equal access for all its users. Seeing how a bicycle is a much more space efficient way to transport a person than a car, getting people to bike instead of cycle, creates more space for everybody else, be it cars, busses, other bikes or pedestrians. Furthermore, a bike is a much more financially accessible means of transportation than a car.

In *Håndbog Vejbelysning*, the theme of prioritization seems to depend very much on the road in question. It is quite openly communicated, that the lighting on some roads should prioritize pedestrians and cyclists, while on others, it should prioritize cars. This makes perfect sense in the case of a highway or a path. As mentioned earlier however, the prioritization of cars is also applied to *trafikveje*, although this road type potentially facilitates a lot of bicycle traffic. A good thing about the handbook is, that it is quite clear about the prioritizations that it makes, allowing anyone planning or designing street lighting, to make the necessary additions to the requirements.

In *Belysningsmasterplan København*, *Citelum* in general wish to create better access for everybody, but also to aim at creating more efficient car traffic. They also address prioritization of different user groups in connection with their classification of road types, introducing a more gradual change between priority of cars to priority of bicycles, across the different road types, including several road types, which prioritize cars and bicycles equally.
It is hard for us to spot however, how this is reflected in the proposals or the lighting classes chosen for the different road types. We don't either see any examples of a conscious priority of bicycles or pedestrians in certain neighborhoods or on certain roads that are characterized by facilitating an especially large amount of bicycle traffic.

We think, it would have been very interesting, if *Citelum*, as part of their district-specific analysis, had mapped out which areas and which routes are especially important to bicycles, which would include looking at universities, areas with student accommodation, schools, gymnasiums, public transportation hubs and other important destinations, that cause a very large amount of pedestrian and bicycle traffic. Such a mapping, combined with an acceptance of cyclists' vulnerability, could have been an excellent basis for creating street lighting with extra attention to the needs of bicyclists, in the areas where it would have benefited most users.

5 Case Studies & Registrations

5.1 Purpose of Case Studies

As mentioned in chapter 3, we decided to perform a set of case studies, for several reasons. One reason is rooted in our wish to use ourselves, and to gain an intuitive understanding of the subject of our thesis, using our own senses as a supplement and perspective to the knowledge we can gain through literature studies. In this way we believe that we were able to create a link in understanding between the qualitative and quantitative aspects of our thesis' subject.

Another reason is, that we did not find a similar set of studies. The closest we came to a documentation of Copenhagen's street lighting, was in the form of *Katja Bülow*'s publication. This however did not include any measured data, and did therefore not provide any sort of reference point, and neither did it allow for any type of comparison between cases. By constructing our own case studies, we wished to collect a data set, that would allow us to exceed these limitations.

Yet another reason, is that our registrations provide us with a way of checking how the implemented solutions perform compared to the current requirements and descriptions in hand books and plans.

Furthermore, in choosing our own locations to include in our case study, we had the opportunity to pick a selection of cases, that would have a high relevance to our thesis.

5.2 Method of Registration

Initially, the registration phase consisted of exploring and observing street lighting in Copenhagen, in order to get an impression of the factors involved with different qualities of lighting around the city. We decided to conduct these observations by bicycle, in order to put ourselves in the user perspective, we wanted to evaluate.

We hand picked a number of destinations around the city, which we had experiences and memories from, regarding lighting design, and plotted them into a map. The plan was to visit each point on the map, and be aware of the lighting qualities of locations on the improvised routes in between each point, to form more explorative impressions of locations we were not aware of beforehand. This method is described by James Corner as a *dérive*:

"A dérive can be thought of as an unpredictable trip through the city where ambient architecture and geography subconsciously direct one's movements." p. 20, På Tværs af Københavns Gadebelysning 2014, Katja Bülow

The purpose of this way of conducting the initial research for the project was to form a common terminology and understanding of the street lighting in Copenhagen, by discussing the qualities on site, which would also help us get a very detailed impression of the environments surrounding each location.

As our overview expanded we narrowed in on a selection of locations, that together represented the typical solutions we saw around the city, and would thus serve as a basis for discussing the typical qualities and shortcomings, we had observed around the city. In addition to these sites, we included selected locations that were either particular problematic or particularly well functioning according to our assessment. Together this selection of locations makes up the case studies in this thesis.

Following the selection of locations to include as cases, we set up a manual for registrations to be performed on each location. The registration manual includes a qualitative assessment, registrations of the road profile's geometry, registration of the lighting system's components and geometry, photo-documentation and illumination measurements. These registrations were chosen for several reasons. At the time, we were not completely certain, what results we would get, and what we use them for, seeing as part of the goal was to explore and experience. One factor in choosing was the equipment available to us. We had unlimited access to measuring tape and illuminance meters, but didn't have access to a luminance camera. Another factor was the amount of time available to us, and the necessity of doing the measurements by bike. After conducting a couple of pilot registrations, we found that the listed registrations, gave us data, that would allow us to document and discuss our experiences on site.

Our qualitative assessment consisted of biking on the site and assessing the intuitive experience of this. We focused on how it felt to bike, and whether there were any factors that were especially comfortable, stressful, insecure, etc. We furthermore assessed the distribution of light in the street as a space, and the readability and visibility of the road, other uses and the elements that made up the surroundings. At the same time, we discussed our thoughts and observations, with an approach rooted as much in landscape architecture as lighting design. The focus was on the experience more that on the lighting.

The registration of the road's geometry consisted of measuring the widths of the different lanes in the cross section of the street with measuring tape, to get a precise depiction of the dimensions involved, which was important to understand how much space was dedicated to each traffic user group and the amount of road surface to be covered by the luminaires on site.

The registration of the lighting system consisted of determining luminaire type, and the light source as well as the mounting system. We furthermore determined the placement of the luminaires in the road profile, The height of the light source relative to the road was estimated by eye, while the horizontal placement in the road profile was measured using a tape measure. The distance between the luminaires was also measured in alignment with the road. If more than one type of lighting element was used, we conducted these measurements for each lighting elements as a separate system.

The combined measurements of road and lighting system geometry were used to produce section drawings of each road profile.

An essential part of evaluating and analysing the different sites, was to be able to understand how the light is distributed from the light sources to the different areas of the road profile. To understand this, we conducted a systematic measurement of minimum and maximum horizontal illuminance on the surface of each lane in the road profile. To asses the lighting pattern on location, we walked the distance from one luminaire to the next (or in more complex systems, the length of the system, before it would repeat itself) with the illuminance-meter facing upwards while monitoring the values showing. In this way we were able to understand the

general pattern of the lighting installation, allowing us to pinpoint the exact places where high and low extremes would occur.

For the precise minimum and maximum measurements, a semi-spherical illuminance-meter was placed facing upwards on the surface at the spot where we assessed the maximum and minimum illuminance. We then stepped away and read the values from a distance, to reduce disturbance from our own silhouette. In this way minimum and maximum horizontal illuminance measurements were conducted at the center of each lane in the road profile (roadway, bicycle path, sidewalk, parking, path etc.).

The reason we found this data to be valuable, is that it allows for a number of comparisons between lanes within the same road profile, or between lanes in separate profiles. It also draws a picture of the distribution of light across the street profile. Furthermore the data allows us to determine whether the horizontal illuminances live up to the requirements dictated by the lighting classes.

As an extra measurement we decided to investigate the vertical illuminance levels 170 cm above ground, to understand how much light would get to the face of the road user. This could be valuable to our analysis of the sense of security perceived by road users, since the ability to read facial features and body language is essential to the feeling of security, and to reading the intentions and predicting the actions of other road users.

The vertical illuminance levels were measured only on sidewalks and bike lanes. The illuminance-meter was oriented in the walking distance, meaning held at head height and pointing forward in the direction one would walk or bike on the sidewalk or bike lane. The illuminance-meter was always held at a 90 degree angle relative to the road surface. The illuminance- meter was held in stretched arm to reduce influence of our silhouettes, and with attention to eliminating self shadow, by avoiding to place ourselves between the illuminance-meter and the light source. Like for the horizontal measurements, a walk would first be performed to assess the lighting pattern and to identify minimum and maximum positions. Afterwards maximum and minimums values were noted. The vertical illuminance values proved in most situations to be similar for each direction of travel.

The collected illuminance measurement data is presented in connection with a cross section of the road profile to provide an understanding of the measurements in relation to the functional and spatial context and the lighting system.

From the horizontal illuminance measurements, we have calculated three sets of data, to describe different correlations and relationships.

To have one number representing the illuminance in each lane in a given profile, the maximum and minimum horizontal illuminance measurements have been reduced to one average value. This average is not a true average, as this would require many more measurements, than we have performed, but is an approximation reached by interpolating the average between the minimum and maximum measurement within each lane. The number is achieved by the following calculation:

For a given lane:
Eavg = (Emin + Emax)/2

To create a number, giving insight into the variation within each lane in a given profile (meaning the variance in illuminance when moving in alignment with the lane), we have calculated a ratio between the lowest and highest measurement in the given lane, expressed as a percentage. The percentage is calculated in the following way:

For a given lane:
*Variation = (Emin / Emax) * 100*

Finally, we were interested in finding a way to express the priority of a lane in terms of light, relative to the rest of the road profile. We have chosen to do this by generating a number for each lane, that expresses the amount of light it receives relative to the lane in the profile, receiving most light. We have called this number relative priority, and it is expressed as a percentage, calculated using the interpolated Eavg values. The percentage is calculated in the following way:

For a given lane:
*Relative priority: (Eavg of given lane / Highest Eavg present in the road profile) * 100*

This means that the lane with the highest Eavg, will have a hierarchy ratio of 100%. If another lane in the same road profile has a hierarchy ratio of 50%, it means that this lane, based on the Eavg values, receives half the horizontal illumination.

For each area we documented the visual impression of the lighting situation by taking photographs in RAW format for reference.

The photographs were taken from a tripod, adjusted to head hight (ca. 170cm), from a position on or partially on the bike lane (depending on the amount of bicycle traffic at the time of registration). The photographs were taken on each side of the road, representing the experience of bicyclists going in each direction, except in cases, where the bicyclists were sharing the same lane to move in both directions, in which case only one direction was documented.

One set of photographs were taken with a Nikon 3200 SLR camera using an 18 mm lens. These images were afterwards exposure adjusted manually in Adobe Photoshop, with the aim of conveying the situation as experienced by us. This method is similar to that used by *Katja Bülow*, but we have prioritized that our results should replicate our experience, to the best extent possible, rather than prioritizing that the images should look good in print.

Another set of images was taken using a camera equipped with a hemispherical lens. These images were taken as a series of bracketed photos from the same position with different exposures, ranging from heavily underexposed to heavily overexposed. We used these images to create High Dynamic Range images (32-bit HDR) in Photoshop. The goal of these images was to create false color images, allowing analysis of the luminances experienced from a bicyclist point of view. The images were processed using the software HDRscope, which is developed by the University of Washington. In this software it is possible to calibrate HDR images, using a reference illuminance or luminance measurement performed simultaneously with the capturing of the images.

Unfortunately, we were not able to achieve trustworthy luminance values by calibrating our images in HDRscope. We suspect, that our bracketing was too limited, and that as a result, we did not capture a large enough dynamic range, to produce useable results. We were still

able to generate false color images, but they can not be used to read luminance values. They can however be used to determine, which areas in the photo have higher or lower luminances relative to other areas in the picture. Therefore, we still consider the false color images useful, and have included them in our data set.

5.3 Data Set

The data set is included as *appendix 1.*

5.4 Discussion & General Observations

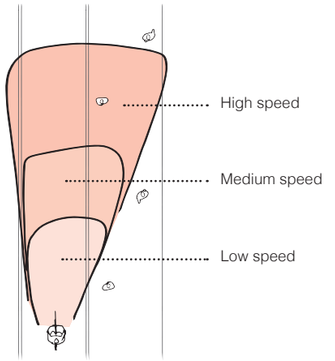
In this chapter, we will make some general observations based on the case studies as a whole, and discuss selected themes, that have surfaced during registration and analysis of the collected data.

If we start by looking at the cyclist's experience, in various cases, a very important aspect of the experience, is the readability of the street as a space. We use the term readability, as meaning the ability to delineate the space, and to identify and understand elements and objects that are present in the space, including other users. We found in several cases, that problems with readability can affect the cycling experience in a negative way, causing stress or in some cases insecurity. Stress was experienced as a continuous very alert state of mind, where the user is constantly spending attention and energy on preparing to break or maneuver as a result of unreadable obstacles. This stress was experienced as stronger, when moving at higher speeds, due to the increased break length necessary to react to obstacles. Insecurity was experienced more as a psychological effect, where the cyclist imagines ill-intentioned persons hidden in unreadable parts of the space. It is our assessment, that this type of insecurity varies depending on the age, gender and mindset of the user. Location can also play a role, as some districts have worse reputations for crime than others.

When looking closer at the cause of reduced readability across our case studies, we have identified two aspects, that we find important to describe.

One aspect relates to the ability to rule out the presence of possible obstacles, that would require braking or maneuvering to avoid collisions or accidents. We could call this aspect the *buffer zone* of the user (see illustration 26). As a cyclist, you are constantly aware of the braking distance necessary to avoid an obstacle, when moving at a certain speed. It is our experience as long time cyclists in Copenhagen, that many complications and accidents for cyclists, are caused by pedestrians, bikes, car doors, dogs, etc. that move onto the bike lane from adjacent areas. To be able to predict such movements, it is not necessarily enough to be able to identify other users, but it is also important to be able to read enough about their movement, body language or facial expression to be able to make predictions about their behavior and movement in the space. Therefore it is natural that these areas are also a part of the cyclist's *buffer zone*.

It is difficult to say exactly how much light is needed in this *buffer zone*, but it should be noted, that it is not necessarily enough to be able to identify other users, but it is also important to be able to read enough about their movements, body language, facial expressions, etc. to be



Ill. 27. Illustration of our introduced concept of a buffer zone. This zone describes the area, where a cyclist has a visual need to rule out the presence of potential obstacles, in order to avoid stress. The zone includes the bike lane, but also adjacent areas, where people could step out from. When cycling at higher speeds, braking distance is increased, causing a larger buffer zone.

Ill. 28. On Nørre Søgade, a row of horsechestnut trees form a visual barrier between the bike lane and the adjacent footpath, adding complexity to the reading of the surroundings for the cyclist.

able to make predictions about their behavior and movement in the space. It is our opinion and claim, that when areas or objects inside the *buffer zone* of a cyclist are unreadable due to darkness or other factors, this causes stress for the cyclist - the poorer readability, the more stress. In several cases, we experienced, how physical elements in the street profile could create blind spots in the *buffer zone*, typical examples being trees between the bike lane and sidewalk, making it much more complex to read the sidewalk and assess possible pedestrians or other obstacles. In these situations, a lack of light and a lack of uniformity can worsen an already complex situation for cyclists. Examples of this problem are visible in the cases: *Øster Voldgade, Nørre Søgade, Jagtvej, Sortedam Dossering and Amager Boulevard*.

The second aspect influencing readability relates to the ability to delineate the street as a space. By delineate, we mean ability to read the boundaries and the shape of the space. We have talked about this aspect as the *viewing background* of the street. Delineation is typically not a problem in the case of a road between two facades. In several of our cases however, including *Bülowsvej, Øster Voldgade* and *Sortedam Dossering*, the road was bordered by very dark areas, making it difficult to read the depth of the space, and resulting in what could be described as a lack of *viewing background*.

This lack of *viewing background* is problematic, because it makes it very hard to read silhouettes of people. Generally, because street lighting is aimed downward, horizontal surfaces tend to receive more light than vertical surfaces. As a result, we commonly read other users as negative silhouettes against a brighter background.

In the case of a dark *viewing background*, this becomes difficult or impossible, and we found that these cases resulted in a particularly poor ability to determine the presence of other users, even at quite short distances, which in turn resulted in a stressful experience. We found, that a useful *viewing background* doesn't necessarily need to be a uniformly lit surface, like a facade, but can also consists of points of light, or of elements lit in the distance.

Based on our observations and discussion regarding readability, *buffer zones* and *viewing backgrounds*, we can conclude, that not only the road surface itself, but also the surroundings have a large influence on the experience as a cyclists. Most important is the area adjacent to the bike lane, but also areas farther away can have importance. In general, assessing the readability of the street as a space, requires an approach that acknowledges and treats the street as a spatial composition of borders and elements, and equally importantly, as a visual composition, where the user's point of view is dynamic. This way of viewing the street could offer an alternative or supplement to the current tendency, we have encountered in regulations and plans, of approaching street lighting with a two-dimensional top-view approach.

Another theme relating to the user experience, is the theme of the street's identity. In several cases, we experienced, that the identity of the street was noticeably different compared to the daytime identity. A very clear example is the case *Jagtvej*. In daytime, this street is dominated by a row of old lime trees, placed between the sidewalk and bike lane on the cemetery side of the street. In daytime, this row of trees contributes to the impression of the street in many ways: The characteristic bark of the old trunks lends an organic tactility to the experience as a pedestrian or cyclist, the foliage creates a roof over the cyclists and pedestrians, the trees match the scale of the facades on the other side of the road, balancing the proportions of the street. All these effects, are important to the identity of the street. At night, the trees receive little to no light, and the perception of the street is noticeably different.

Ill. 29. On Øster Voldgade, the bike lane is relatively lit, but the light does not provide a sufficient amount of light on the adjacent footpath, making it difficult to rule out the presence of pedestrians. The low refelctivity of the dark surface on the footpath and a lack of viewing background contribute to the poor conditions.

Ill. 30. The reading of silhouettes requires a contrast between the person and the viewing background. On the right, pedestrians are clearly detectable as dark silhouettes against a bright background, even at long distances. On the left, even nearby pedestrians are hard to detect due to the dark background.

This effect is not necessarily a problem in relation to traffic safety or function on the street, but we would argue, that it is an aesthetic impoverishment of the street. Furthermore, we think that this reduction of identity, can reduce the experience of familiarity and recognizability for the users. If we look to the influential urban planner, Kevin Lynch, and his documentation of users' mental maps of the urban landscape, it is clear, that many types of urban elements can function as landmarks, nodes and boundaries. A row of trees could therefore easily be considered an important factor in ensuring familiarity and recognizability, influencing wayfinding and orientation. If we look to the case *Rolfsvej*, we can see how uplighting of trees can be integrated into the design of street lighting, and how much a few lit trees influences the identity of the street.

It struck us, that at the moment, street lighting emphasizes the elements of the street, which are the most anonymous and identical on all streets: the asphalt surfaces, the curbs and the paving stones. We don't wish to challenge the very good reasons for lighting these elements, but think it would be interesting to discuss, whether street lighting could also encompass the lighting of elements in the street, that do not at first glance serve a practical function, but which are important to the perception of the street's identity. By using this approach, especially on streets that have very characteristic elements, we think it would be possible to create a more beautiful, tactile, stimulating and varied streetscape at night for all types of users.

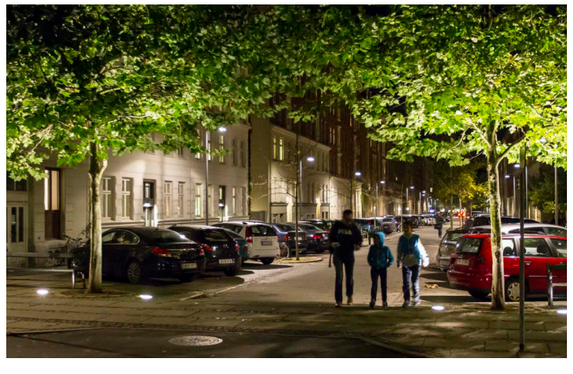
If we move on to look at our measured illumination data, one purpose was to evaluate, whether the current street lighting solutions live up to the current regulations and lighting classes. As our measurements are performed with an illuminance meter, we can only conclude on the areas subject to the E-classes, where the requirements are given in illuminance values. Furthermore we do not have detailed enough measurements to assess uniformity requirements. Our measurements show, that in the majority of cases, the illuminance values given in the E-classes are met on the bike lanes, while about half of the sidewalks and pedestrian areas do not live up to the same requirements.

A theme we have found very interesting, when looking at our measurements, is the distribution of light on the street's different areas, and the resulting hierarchy of user groups. It is our opinion, that it makes sense to look at the road as a composition, and to evaluate illumination values relative to the rest of the road, rather than only looking at the absolute values. This conclusion was reached through discussions while performing registrations. We discovered, that the absolute illumination values, we measured did not necessarily correspond with what we perceived as dark or bright. We found that due to adaptation of the eye, a certain number of lux could seem dark in one case and bright in another. As a result, we became interested in looking at lighting levels relative to the surrounding areas, to take into account the effect of adaptation to the street as a visual environment.

Across all our cases, it is a clear tendency, that road surfaces receive more light than bike lanes. Likewise there is a clear tendency that sidewalks and footpaths receive less light than bike paths. Our measurements show that the horizontal illumination of bike lanes ranges from 27,5% to 86,9% of the level on the road surface next to it, averaging at 53,3%. The horizontal illumination on sidewalks ranges from 9,3% to 71,7% of the road surface, averaging at 33,2%. This clear hierarchy is in part explainable by the way the lighting classes are constructed. The difference between bike lanes and sidewalks however is not a logical extension of the lighting classes. In all cases, bike lane and sidewalk are subject to the same requirements. The clear tendency of lower illumination on the sidewalk appears to be a recurring bi-product of lighting solutions that are centrally positioned in the street profile.

Ill. 31 & 32. In the daytime (left), Jagtvej is characterized by a row of tall lime trees, creating a roof over the street. At night (right), the trees are all but invisibile, expecially so in wintertime.

Ill. 33. On Rolfsvej, even small naked trees in wintertime can add identity to the street, when emphasized with light.



Ill. 34. An image from Rolfsvej or a neighbouring street in summertime. Trees can play an important role in the street's spatial composition, by providing a roof. Lighting the foliage and bark of trees can add organic and lush textures to the street, which is otherwise often dominated by hard flat surfaces.

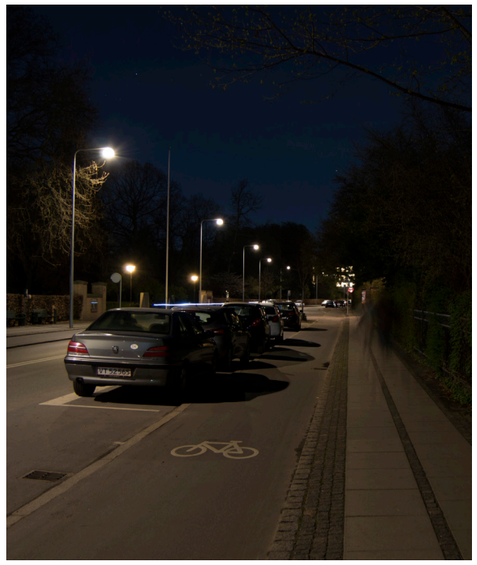
According to our observations, there is no clear pattern in regard to which lighting configuration creates the largest differences between road, bike lanes and sidewalks. The only rule seems to be, that the largest differences arise, when the lighting solution is under-dimensioned for the width of the street profile. Clear examples of this include the cases *Nørre Voldgade, Sortedam Dossering* and *Amager Boulevard*. Furthermore, there are some quite predictable effects related to the placement of the light source in the street's profile. Placement of one row of wire mounted luminaires centrally over the road surface, tends to create a symmetrical falloff towards the sides of the road. Placement of two rows of luminaires, each over the bike lanes, creates a much more uniform distribution between user groups, as visible in the case *Nørrebrogade*. Placement of pole-mounted luminaires in one side of the road gives a very asymmetrical distribution, prioritizing users on one side of the road, as visible the case *Bülowsvej*.

A consequence of the general hierarchy of illumination between the road surface, the bike lane and the sidewalk, is that bicyclists is put in a less than optimal position to read the information, they need from the street. In most situations, the bike lane is positioned between the road and the sidewalk or other pedestrian traffic area. According to our measurements, this will almost certainly mean a brighter area on the left, and a darker area on the right. We should add to this situation, that most roads will have steady car traffic, resulting in significant glare from headlights of cars going in the opposite direction. Furthermore, according to our thoughts about *buffer zones*, we should consider, that the cyclist primarily needs to assess dangers and obstacles to the right, in the darker and often more spatially complex area, due to the presence of trees, signs or poles. The result is, that the cyclist is put in a very visually challenging situation, where it is impossible for the eye to adapt to the darker area on the right, due to the constant brighter surfaces in the left side of the cyclist's field of view, and the glare caused by headlights and street lighting luminaires typically mounted over the road surface. In the case of wet roads, this problem is even more outspoken.

A theme, we would like to touch upon shortly, is the shadows cast by elements positioned between the bike lane and the street lighting luminaires. These elements are typically trees, parked cars or trucks, signs and poles, and each type of element casts a different kind of shadows. Tall narrow elements such as signs, trees or branches in winter, can cast long thin shadows, on the bike lane, that can be hard to distinguish from cracks or patches in the asphalt, which would require attention or maneuvering from the cyclist. Parked cars or trees in summertime tend to cast large shadows, that can cause areas to seem darker than the surroundings - and in certain cases cause the majority or entirety of the bike lane, including other users, to be hard to read. Typically, shadows have not in themselves been a factor, we have assessed to cause greater stress or discomfort from a cyclist's point of view. In some cases however, we have assessed, that shadows in connection with other factors, have resulted in a stressful experience. In conclusion, we think that in certain cases, it should be considered, if light sources should be moved or supplemented to minimize shadows on the bike lane.

In the selection of cases, we have studied, luminaires have been equipped with Metal halide light sources and LED sources. We purposely chose two cases, that examine different sections of the same road. The case *Jagtvej* examines a stretch of the road, within *Copenhagen Municipality*, in an area, that has been renovated by Citelum, replacing the metal halide light sources with new LED light sources. The case *Falkoner Allé* examines another section of the same road, located in *Frederiksberg Municipality*, where the light sources are still metal halide.

Ill. 35. Cyclists are often faced with an assymetrical distribution of brightness in their fields of view due to large areas of road surface with high illumination and glare from headlights and streetlights. As visible on Enghavevej, wet roads increase this effect by causing specular reflections of light sources.



Ill. 36 & 37. On Bülowsvej (left), parked cars and an assymetrical pole configuration create sharp shadows that cover more than half of the bike lane's width. Enghavevej, wet roads increase this effect by causing specular reflections of light sources. On Gyldenløvesgade (right) trees cast shadows that leave an entire stretch bike lane and sidewalk in the dark.

A comparison of the illuminance measurements registered in the two cases show very similar light levels and an almost identical light distribution on the different areas of the street. We did not register any noticeable difference in experience from a cyclist's point of view, that we would attribute to lighting, apart from the optical guidance provided by the opal Thor luminaires used on *Jagtvej*, and perhaps a slightly increased glare, when looking straight into the LED luminaires. We concluded from this comparison, that the retrofitting of metal halide light sources, that Citelum has done across much of Copenhagen, does not affect the experience of the street. The effect is limited to energy savings, and in some cases an update to the aesthetic appearance of the luminaire itself.

A final general observation, we would like to mention in this chapter, is the variation in reflective properties of different surface materials. In several cases, we observed, that the bike lanes were paved with a darker asphalt than the road. The most dramatic differences were in the cases *Falkoner Allé* and *Nørre Søgade*. It was our impression that the darker asphalt reduces the ability to spot irregularities or small objects on the surface. From a lighting perspective, this choice of asphalt does not make much sense, and seems to enforce the existing falloff towards the sides ofthe road created by the lighting distribution. If we take into account the fact that bikes are normally equipped with weaker lights than cars, it would seem more fitting to us, to pave the bike lanes with a lighter asphalt than the road.

The same problem of low reflectance resulting in a lack of readability was even more pronounced in the different cases of gravel or earthen footpaths, as visible in the cases *Nørre Søgade*, *Øster Voldgade* and *Sortedam Dosering*. The lack of readability caused by the dark surfaces first and foremost makes it less comfortable for pedestrians, but can also contribute to a stressful experience for cyclists biking besides the pedestrian area, according to the previously described *buffer zone* aspect.

In conclusion, the process of registration, and the data gathered, has served as a very important basis for analysing different aspects of the functionality and experience of the current street lighting in Copenhagen. Besides from helping us to identify and describe a number of themes and problems, the case studies are especially important to this thesis, because they document how many of the themes and critiques, we have introduced in earlier chapters of the thesis on a more theoretical level, do in fact influence the experience of the end user on the streets. The priorities that permeate the regulations, plans and practices, that we have analysed, have been very clearly visible in the implemented solutions, and these case studies have given us a certainty that our critical reflection upon the success criteria behind the current street lighting paradigm, is important, if the end goal is an improvement of the experience for the end user.

Ill. 38. On Nørre Søgade, we observed the use of a distinctly darker asphalt compared to that used on the road.

6 Design

6.1 Proposed Design Principles

In this chapter, we propose a collection of design principles to illustrate and exemplify how the products of our registrations and literature studies can find an applied use in the future design of street lighting. This list of design principles is not exhaustive in terms of including all the themes discussed and explored throughout the previous chapters of the thesis, which could have an application in a design context. The selection of design principles included in this chapter, reflects our assessment as lighting designers of which themes would be most relevant and directly applicable to the process of designing street lighting. As a result, we do not include principles that directly propose changes to regulations or standards, but it is our hope that the discussions and critiques of these, presented elsewhere in the thesis, can provide new perspectives and inputs for a discussion within the academic fields, who work directly with the creation and definition of these regulations and standards.

The following design principles aim to be presented in the form of condensed clear principles, that are easy to understand without engaging with the rest of the thesis. At the same time, we have chosen to keep the principles on a detail level, that doesn't go into specific technical solutions, in order to allows planners and designers to adopt the principles and adapt them to their process and task at hand. We therefore hope that while the thesis has dived into theoretical discussions and a number of detailed analyses, these design principles are simple to understand, and manageable to implement. We furthermore hope, the principles can prove relevant to a wide array of applications and contexts, primarily within the field of street lighting design and secondarily within the more general fields of urban planning and lighting design.

The principles do not go into detail in regard to technical solutions, but aim above all to be tools for thinking about the design of street lighting. In regard to implementation and solutions it should however be noted, that each principle does not need to be implemented through a dedicated lighting element. A lit tree can create identity and provide a *viewing background* simultaneously. A row of bollards along a facade in the periphery of the sidewalk could provide a more equal hierarchy across the road profile, create a small scale lighting experience, provide a *viewing background*, increase the readability of the sidewalk and minimize shadows all at once. So even though we propose seven principles that each deal with an aspect of the user experience, the implementation of these principles can happen through simple and economically feasible technical lighting solutions.

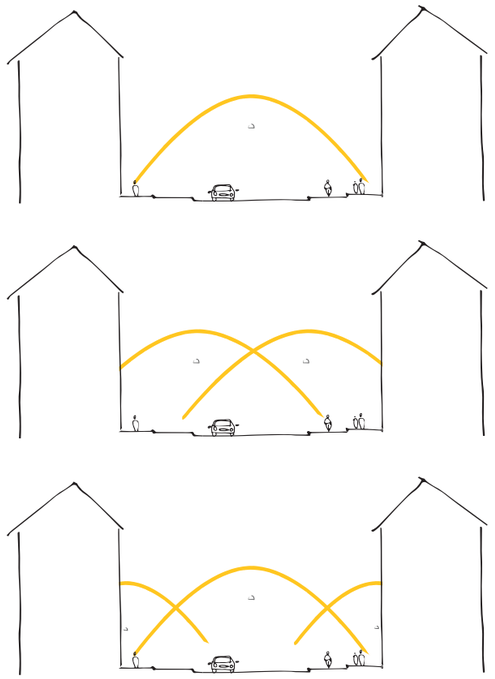
1. Map the city's bicycle network, and identify important destinations and connections.

In order to plan good street lighting for cyclists, we think a logical starting point is to map the usage pattern of cyclists on a city level, identifying which destinations generate a lot of bicycle traffic, and which connections are used the most. To make such a mapping further relevant to the planning of street lighting, the mapping of bicycle usage should be linked to different times of day and night, and different times of year. A thorough mapping, performed separately from the mapping of car traffic, would allow and encourage planners and designers to look at the city's bicycle network as an important, separate network. This in turn would make it possible to plan for quality and continuity in the lighting experience for those who rely on bicyclism as their primary means of transportation. Furthermore, a mapping could be used to identify relevant locations and connections for smaller scale bicycle friendly efforts, as those described in the following design principles, hereby ensuring the maximum value of such investments.

Ill. 39. A mapping of the city's roads according to importance in a bicycle network would provide a completely new planning tool for the design of street lighting.

2. Create a more even distribution of light across the road profile, giving all users an equal opportunity to see and be seen.

This design principle challenges the existing hierarchy present in Copenhagen's street lighting, by proposing a more equally lit situation, where the visual needs of all user groups are satisfied, and all users can be seen by others. The current hierarchical tendency puts bicyclists in a situation, where visual adaptation is difficult, due to the constant difference in brightness of the areas to each side of the bike lane. The result is a poor ability to read the visual information that the cyclist requires and desires from the surroundings. Creating a more equally lit situation is often a matter of repositioning the typical wire mounted luminaires, moving them from the center of the road, towards the sides. Other design solutions, can include supplementary lighting elements along the side of the road profile, or even integrated in facades or walls, which would support the human scale of the speed at the periphery of the road, increase vertical illumination, and be easier to control in regards to potential problems related to spill light entering homes.
One can argue that cars require less light from the street lighting system than other users, since they have their own headlights to illuminate the street and obstacles in the direction of travel. Along this line of thought, it would be possible to explore not just uniform hierarchy, but also an inversion of the existing hierarchy, where bike lanes and sidewalk would receive more light than the road surface. The lack of current implementation of such an inverted hierarchy however makes it very difficult to study the resulting effects of such a distribution on different user experiences.

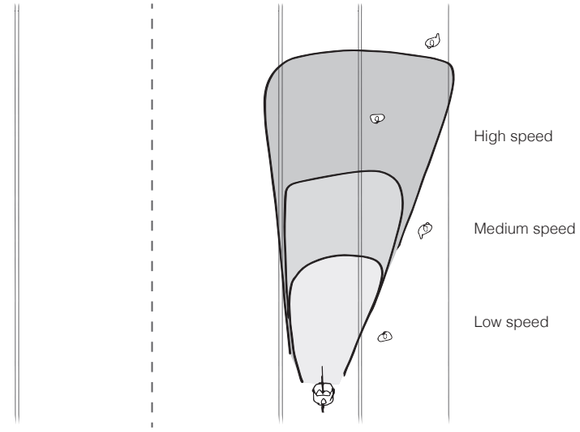


Ill. 40. Sections illustrating how placement of light sources can help to achieve the principal of a more equal lighting hierarchy across the road profile.

Ill. 41. A more equal hierarchy doesn't have to require advanced solution. On Nørrebrogade, the use of two rows of wire mounted luminaires instead of one centrally mounted row creates a relatively equal hierarchy across the street's profile, resulting in good overview for all users.

3. Increase comfort for cyclists by ensuring the readability of areas adjacent to the bike lane.

For bicyclists, it is imperative for a comfortable user experience, to be able to become aware of obstacles and dangers at a comfortable distance. This includes reading the areas adjacent to the bicycle lane, where the sidewalk is most often placed. A lack of readability of these areas, is not only undesirable in terms of safety for cyclists and pedestrians, but also makes the bicycle ride more stressful and uncomfortable. Just like it is integrated in the national street lighting requirements, that cars need a lit area adjacent to the road, cyclists should be ensured the same ability to assess dangers and obstacles in the areas adjacent to the bike lane. How much light is required on the adjacent areas depends on other factors - an open space might not need much light, while a complex spatial composition, for example a row of trees, might need more light, to be readable. The lighting of these areas does not necessarily have to be solved by traditional means. As long as the lighting makes it possible to read the space and determine if anyone or anything will pose a potential danger, the lighting can be solved from a wide array of lighting solutions.



Ill. 42. We propose that cyclists - just like cars - don't only need good visibility of their own lane, but also to be able to read the adjacent areas for potential obstacles or other reasons to brake. Making this reading possible through an attentive lighting design will increase the comfort for cyclists.

Ill. 43. By manipulating photos taken on Amager Boulevard and Sortedam Dossering, we illustrate the effect of making the adjacent areas to the bike lane readable.

4. Strive to create a continuous viewing background, enabling readability of the silhouettes of other users and elements in the street.

When present in the street, users continuously read the space and the people and elements present in it. Being able to identify silhouettes is a very important aspect of this reading. In a split second, silhouettes make it possible to assess whether there are other people present, if they are moving in a predictable way, and whether they pose a potential threat. This visual information is essential to our feeling of security. Reading a silhouette of a person requires contrast, and in the majority of situations in the street, silhouettes are read as dark shapes against a lighter background. In some cases, however, completely dark surroundings to the street, make it impossible to read silhouettes, while simultaneously making it impossible to assess the depth of the space. The street so to say falls off into an infinite darkness. These surroundings are often parks, derelict sites, railway areas, bodies of water etc. In such cases, light should be used to consciously create a *viewing background*. This can be done in a variety of ways, and does not have to create a uniformly lit surface. Points of light, or spaced lit elements, often create enough *viewing background*, to enable the reading of silhouettes moving in the foreground.

Ill. 44. Reading the silhouette of a person in a space requires a contrast in brightness between the person's vertical surface and the viewing background. In far the most cases, in the context of city streets at night, it is usually easiest to read people as dark silhouettes against a lighter background. Avoiding completely dark viewing backgrounds can greatly increases the ability to read people and objects in the street.

Ill. 45. Lots of different lighting elements can contribute to creating a viewing background, and often the reading of silhouettes only requires a little bit of contrast to the background. Special attention is mainly necessary in the case of large unlit areas such as parks, bodies of water or derelict sites, bordering streets.

5. Ensure the street's unique visual identity at night, by using light to accentuate characteristic elements.

Identity and familiarity is both an important in regard to way-finding and orientation, but can also affect the perceived security of the street's users. This should be acknowledged in terms of lighting, by pointing out positive and characteristic elements which contribute to a certain identity, and ensure that they are noticeable at night as well. Elements to enhance could be characteristic architectural elements, vegetation and other landscape elements, urban furniture or art in the public space. If no fitting elements are present, light as an element itself can also be used to add identity to the street at night in the form of light art, or scenographic lighting installations. Using light to enforce identity will help to counteract a tendency for streets to transform into more generic and anonymous spaces at night, when only the horizontal surfaces receive light. From a functional point of view, this does not solve any traffic or safety related problem, but it is an initiative, which help achieve many of the secondary intentions of street lighting in regard to security, experience, identity and aesthetic appearance.

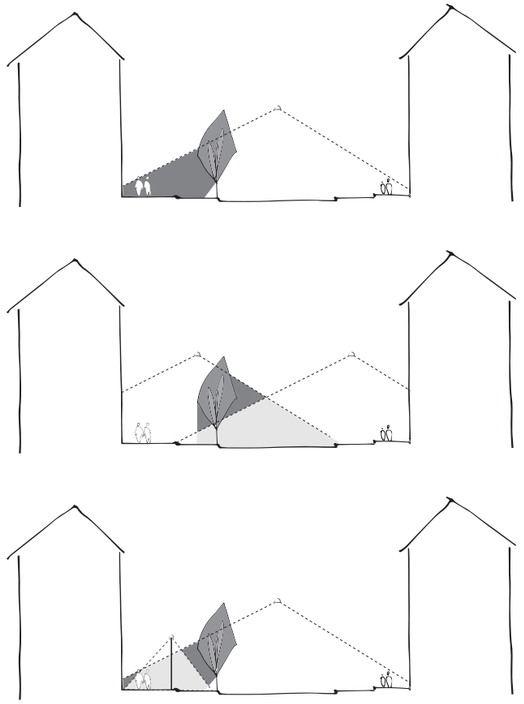
Ill. 46, 47, 48. Examples of lighting design used to add artistic elements to streets at night. Two photo-manipulations show how light could be used to bring existing murals or street art to life at night (left and mid). Light alone can also be used to transform existing infrastructural, as for example electricity wires into artistic installations (right).

Ill. 49, 50, 51. Existing architectural qualities can be enhanced at night, by lighting them with neutral white light from a distance, like done at Rådhuspladsen (left). Other options include the integration of light in new constructions, to ensure from the beginning that they are designed with a day and night identity in mind from the beginning, as exemplified by the new Cirkelbroen (mid). A third option is to emphasize existing architectural qualities by giving them a new transformed identity by night, as exemplified by Jesper Kongshaug's lighting installation underneath Langebro, which uses colored light to create a unique night-time identity for a familiar piece of architecture.

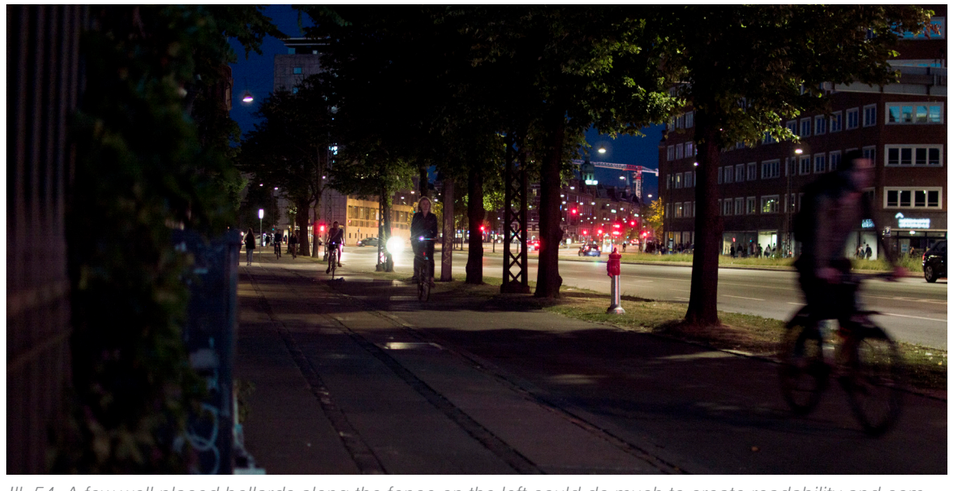
Ill. 52. Landscape elements and vegetation offer good elements for lighting. For example trees are a very common element, that could be used to create identity. Above, a photo-manipulation shows the effect of uplighting a row of trees on Jagtvej.

6. Minimize shadows on bike lane and sidewalk, through attention to placement of lighting equipment relative to vertical elements in the street.

The attention to avoiding shadows on the bike lane is perhaps not in itself a design principle, but it is certainly a relevant success criteria, to keep in mind, when choosing and placing a street lighting solution. Shadows can contribute to stressing cyclists, either because they can be hard to distinguish from irregularities or obstacles on the bike lane, or in the case of bigger shadow casting objects such as trees, because they can create larger areas that are insufficiently lit. Avoiding shadows can be achieved through attention to the vertical elements in the street profile, when placing poles or wire mounting systems, or through the use of supplementing light sources, that ensure a direct unobstructed in-fall of light on the bike lane.



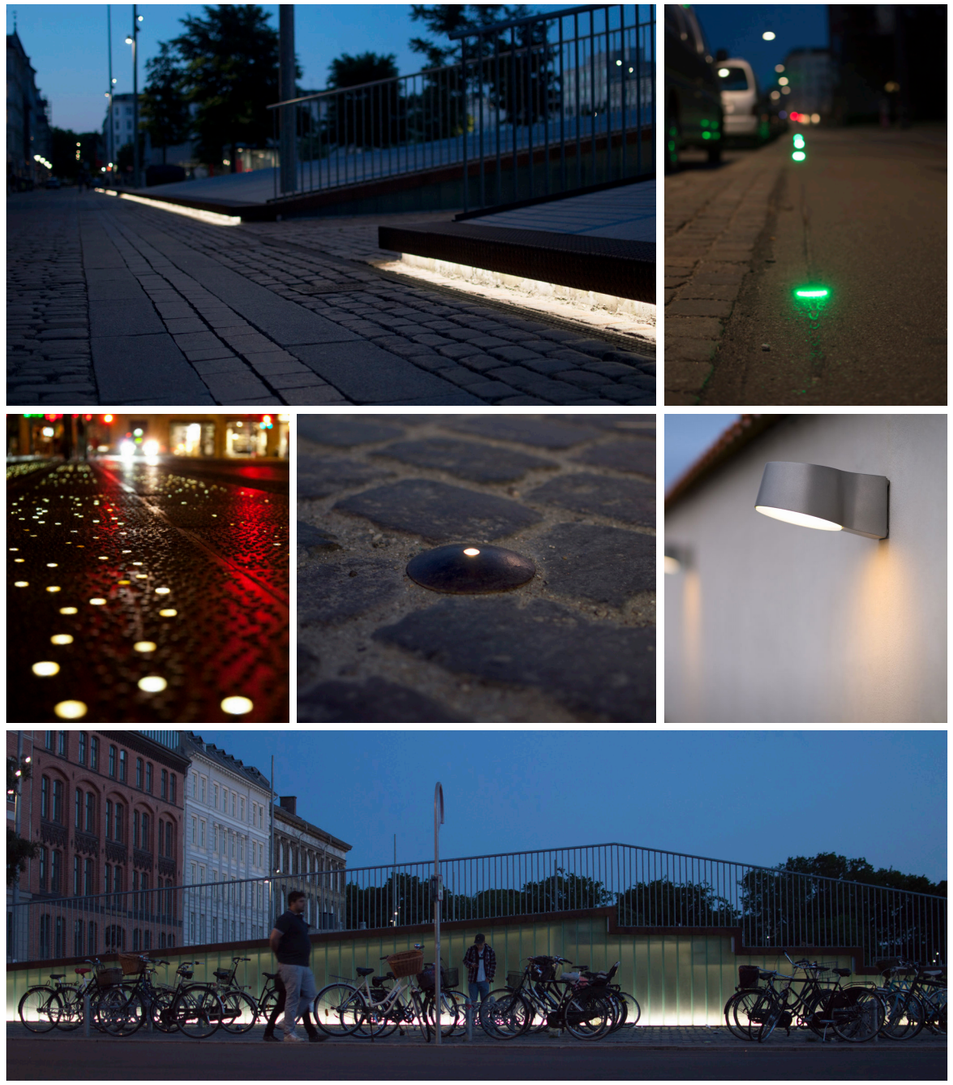
Ill. 53. A set of principle sections illustrating how placement of lighting elements or the use of supplementing lighting elements can help to avoid shadows on the bike lane and sidewalk.



Ill. 54. A few well placed bollards along the fence on the left could do much to create readability and comfort for the cyclists and pedestrians who currently approach a busy intersection in the dark due to shadows.

7. Explore the use of smaller scale lighting elements to add functional and experiential value for cyclists and pedestrians.

Lighting installations in human scale, could help create a more exciting and attractive urban environment, where the level of detail will improve the experience of traveling in the urban space by foot or by bicycle. Downscaled lighting designs offer a way to create exclusive experiences for pedestrians and cyclists, without interfering with the car's need for clear optical guidance and ability to read the surroundings while traveling at high speeds.
An existing example of this approach can be found in *Den Grønne Bølge*, which is a system of LED dots integrated in selected bike lanes, communicating the speed that should be sustained in order to avoid red lights. This type of communication with light could be used to create attention, guidance or way-finding, but could also take on a purely aesthetic goal with no functional purpose. The relevant technical solutions could take on a number of forms and include lighting elements integrated in horizontal or vertical surfaces and edges, washing or grazing of surfaces, bollards, lanterns etc.



Ill. 55, 56, 57, 58, 59, 60. A selection of examples of small scale lighting effects used to create functional, aesthetic or communicative value. Horizontal surfaces can be activated using diodes or fiber lighting for decorative or communicational purposes (upper right, mid left, mid center). Edges and level-differences can be used for integrating linear light sources, to emphasize spatial or architectural lines (upper left). Vertical surfaces can be grazed or luminous using integrated or externally mounted lighting elements (bottom, mid right).

7 Evaluation & Conclusion

7.1 Evaluation

in this chapter we will discuss methodical choices made in the course of the thesis, with the aim of identifying possible errors and biases and evaluating how these may have influenced our results. Furthermore we will reflect upon possible methodical improvements for future reference.

Our approach to knowledge mapping was in many ways affected by our background in landscape architecture, where we first were introduced to urban design theorists like Jan Gehl. Our familiarity and sympathy with the views of Jan Gehl has created an interest in bringing his theories into the thesis. One could argue that other sources than Cities for People might represent current planning strategies better. A more neutral choice could have been to examine strategies formulated by Copenhagen Municipality instead of Jan Gehl's theories. Throughout the thesis, we think however, that the link between Gehl's theories and the current planning strategies of Copenhagen have been documented, making it an appropriate source to include representing current planning tendencies. Furthermore, by introducing Gehl as a source, we were able to draw on all the depth and detail of Gehl's theories, developed through four decades of research. As such he was not only representative of a tendency but also a consciously chosen theoretical and political lens for us to use during our own registrations and development of design principles. Gehl is of course not alone in representing the tendencies in current urban planning. There are many conflicting views on the subject, and the current tendencies are often subject to political debate and as such subject to change. We could have chosen to include urban planning theories, that are not as pro-cyclism as Gehl's as counterpoints, but since we openly share Gehl's pro-cyclism stance, and Gehl's work is scientifically founded, we think we can defend our choice of his theories as a primary source.

An option we have considered carefully in regard to gathering qualitative data, was to form a focus group, and guide them through our cases, whilst interviewing them about their experiences. Ultimately this option was abandoned in preference of using our own assessments of the user experience. This choice was mainly due to the fact, that it would have been a very comprehensive and time consuming task to organize this focus group, and that it would have been hard to validate the results, considering the limited amount of people, we would be able to interview due to time constraints. By using our own qualitative assessments, we were able to constantly make observations throughout the four month period of working on the thesis, and we have been able to include the valuable observations and discussions, that occurred on our many site visits, conducted in a variety of conditions regarding weather, traffic and season.

Nevertheless, we think that it would be a most relevant and interesting to perform a study based around a focus group of bicyclists without a background related to lighting or urban planning, representing a variety of age and gender. We think this study would in particular be helpful in regard to assessing the importance of street lighting compared to other non-lighting factors influencing the user experience. This question is difficult for us to address in an unbiased manner, considering our backgrounds as lighting professionals and our strong academic focus on the subject of street lighting throughout the thesis period.

The case studies include include false color images of all the locations processed. These images were supposed to show the luminance values of the surfaces on the road profile and surrounding environment, but something went wrong in the calibration of these images using the HDRscope software, that we had been recommended to use by our supervisor. This meant that the creation of false color luminance photos was not possible.
If these mappings had been successful it would have been possible to create a more detailed comparison between road surfaces, which would differ from the illuminance measurements by taking the material properties into account. This could have provided new insights, but is not considered by us as compromising our case studies or the findings we made with the valid data, that was at our disposal.

The software that failed us in creating the false color images was HDRscope. We do not full understand the cause of the inability to create a valid luminance calibration, but one explanation could be, that we did not capture a wide enough dynamic range, which would have required more exposures as basis for the creation of HDR images. We did not attempt to test this due to time constraints. Two other options could have been investigated further as alternatives to HDRscope. One is an online tool, Jaloxa, which can create similar images, but does not have a calibration tool attached to it. The calibration of images with this tool is based on metadata about camera settings rather than reference measurements performed simultaneously with the photo capture. Unfortunately the tool was offline for the majority of our thesis period, making its use as an alternative impossible.
The other possibility was to borrow a luminance camera from SBI at Aalborg University Copenhagen, which is made for the purpose of creating false color images, but insurance conditions meant that we did not have authority to bring it out of the university as students.

We performed an interview with Maja Hyveled Jakobsen, service manager for operation and maintenance of street lightning in Copenhagen Municipality, but it would have been preferable if we had secured interviews with other stakeholders as well.
We did reach out to both Citelum and a department under Copenhagen Municipality called Center for Byens Udvikling, but did not receive any replies. It would have nuanced our understanding of the pipeline and street lighting practices in Copenhagen to have interviewed these stakeholders as well. Citelum might have changed the way they implement lighting, assessing the experience gathered after two years with Belysningsmasterplan København, and Center for Byens Udvikling would have had an opportunity to elaborate on their urban design ideals and the way they think about the dialogue between urban design and street lighting.

The equipment used to measure luminance and illuminance are at risk of being calibrated wrong. The illuminance meter appeared to be working flawlessly throughout the period of registrations, but it was exposed to temperature changes underway and might have taken a hit without us noticing, which could have affected its sensitivity to light.

The mounting height of the luminaires was assessed as an estimation on site, but other ways of determining the height with equipment for measuring vertically could have been an option as well. A laser distance-measuring tool could have been appropriate for this. We could however conclude from our literature sources, that wire mounted luminaires are mounted at 6-8 meters, which limited our margin of error to 2 meters. Considering furthermore, that the height data was not directly used in any calculations, we do not consider this error of margin to compromise our results.

A method of registration, that we would have liked to perform as part of our case studies, was the use of a go-pro camera mounted on a helmet along with a smart-phone compatible

illuminance meter, that could record illuminance measurements as a data feed over a time period. By filming video whilst wearing this helmet, we could have documented the connection between the visual experience and the amount of light entering the eyes of the user. This would have given us a way to assess the need of adaptation of the eye as a consequence of different lighting solutions and different speeds of travel. Time and equipment constraint however caused us to abandon this plan.

Based on the above chapter, we have not found any reasons to believe that errors in our knowledge mapping or case studies have produced inaccurate results. As mentioned, the lack of direct communication with certain stakeholders may have resulted in a lacking understanding of their roles. This has however not been our choice, and we have performed the analyses, we found possible based on the sources available to us representing each stakeholder.

The evaluation of our final output consisting of 7 design principles, is not possible based on the scope of the work performed in this thesis. Future testing of the effect on user experience would be required, either through mock-ups, pilot projects or virtual simulations, to make an evaluation of the principles' ability to improve the user experience.

7.2 Conclusion

In this chapter, we will return to our hypothesis and conclude upon whether we were able to test it. In addition we will perform a short summary of the results produced in the thesis.

We will furthermore reflect upon the usability and relevance of the knowledge and results produced, and reflect upon future works and natural extensions of the research contained in this thesis.

Our hypothesis was formulated as follows:

By performing a critical analysis of the current street lighting in Copenhagen, including registrations of photometric performance, assessment of user experience and discussion of the paradigm behind current planning and legislation, it is possible to develop new principles for the design and implementation of street lighting, resulting in an improved user experience for cyclists in Copenhagen.

An essential aspect of testing the analysis was to perform the mentioned critical analyses. These analyses can further be divided into three sub-analyses:

The first is an analysis of the photometric performance of existing lighting solutions. We think, this analysis was successfully achieved through our registrations and case studies. While we cannot say that we have fully examined the performance of Copenhagen's street lighting in it's entirety, we can say that we have examined what we believe is a representative selection of cases. In regard to the parameters registered in assessing, the performance, we similarly can't claim to have examined all aspects of the lighting systems' performance. We think however, that the chosen registration parameters have given us a good and unskewed platform for discussing performance. Bases on this analysis, we found and described a number of themes related to the photometric performance of existing street lighting. One theme regards the importance of the placement of luminaires in relation to the street profile and vertical elements. Another theme was the importance of lighting distribution across the street profile and the resulting implemented hierarchy between different user groups. A third theme was how national regulations were reflected and interpreted in specific street lighting solutions.

The second sub-analysis is the analysis or assessment of the user experience. To examine this aspect, we chose a research path, where we relied on the use of our own senses, perceptions and experience, to understand the user experience. This introduced a number of biases, and was not a scientifically strong choice in terms of validation of our results. We think however, that we have increased the validity of our observations by combining our analyses of photometric performance and user experience into a combined set of case studies. Hereby we support our assessments with photo-documentation and photometric measurements, giving others a basis for evaluating or questioning the validity of our assessments.

Our assessments of user experience resulted in several observations and conclusions about the positive and negative influencing factors, that make the user experience more or less comfortable. A number of Important themes were uncovered through this analysis. One was the importance of cyclists' ability to read other areas than their own lane of traffic in the road profile. Another was the identification of different stress-inducing factors to the cyclist's experience. Thirdly we became aware of the importance of visual composition when reading people and elements in a space, including the importance contrast to the reading of silhouettes. A fourth theme we recognized was the importance of lighting for the perceived identity of spaces at night.

The third sub-analysis was an analysis of the paradigm behind the current design and implementation of street lighting in Copenhagen. This analysis was performed through a mapping of relevant stakeholders, and a study of their roles, stances and priorities through studies of relevant publications, plans or regulations or by direct contact with the stakeholders. Direct contact with all stakeholders would have been greatly prefered to a literature based study, in order to gain a deeper insight into the priorities and interests of each stakeholder, but this was not possible, in part due to lack of cooperation from certain stakeholders. Accepting the premise of a dominantly literature based study, we were able to gain an understanding of the the roles that each stakeholder plays in affecting the design and implementation of street lighting. We were also in many cases able to identify the relevant success criteria used in creating plans and regulations.

From this analysis, we were able to uncover several important themes. One was the variation in the concept of societal benefit as a success criteria. Another was the common systematic prioritization of motorized traffic in regulations. Thirdly we were able to uncover the different understandings of the role of bicyclism in traffic and urban planning, expressed by different stakeholders.

In conclusion, all three sub-analyses were performed - in some cases to an extent restricted by our limitations in regard to time, access to equipment, skill, and cooperation with stakeholders. Most importantly however, our analyses yielded results, that were directly applicable to our goal of proposing new design principles.

As such, we have proved that a critical analysis of these three aspects of street lighting, can be used as a base for proposing new design principles. The part of our hypothesis that we can't verify, which is perhaps also the most important one, is whether these new design principles will in fact lead to a better user experience for bicyclists. We strongly believe that they

will, but it is not something, that has been possible to test within the scope of this thesis.

Therefore, the work we have performed births a new hypothesis to test, which is the claim that the use of our 7 design principles for street lighting, in fact results in a better user experience for cyclists.

The testing of this hypothesis could be performed in a number of ways. An essential element in assessing the design principles' effects on user experience, is to perform some form of user testing. This could be in the form of a test performed using a test installation or pilot project, implementing our design principles, and letting users evaluate the experience.
Another direction could be to perform user tests using rendered images or animations or by the use of a virtual environment for use with virtual reality hardware.

In both cases, a step needed to test our principles on users, is the implementation of our design principles as specific design solutions, and the adaption to specific street types. This could be done in the form of a design solution catalogue, with a number of solutions adapted to typical road profiles and contexts. Such a catalogue could then in turn lead to implementations of pilot projects, that would allow on site user testing, which we view as a superior form of testing regarding landscape architecture and urban planning. By performing the user testing on site, all relevant factors influencing the experience are present, which is impossible to simulate in virtual tests.

Aside from these suggested directions of future work, we would like also to reflect upon the potential use of the thesis output in its current form, meaning the proposed design principles and the discussions of findings from sources and case studies.

We think the design principles could be useful to lighting designers such as ourselves - directly in the use of street lighting design - but also more generally. The principles hold several more broadly applicable ideas, for example regarding the reading of spatial depth, and the importance of foreground and viewing background. Another example is the idea of the necessity of a buffer zone, the size of which is tied to the speed of the user in questions. This idea could be applied to other contexts, than roads. Also relevant more generally are the thoughts on the relation between daytime and nighttime identities and the role of light in connecting or consciously differentiating them.

These ideas can be thought of as tools for thinking about the design and experience of light and space, and as such applied to many other lighting design contexts than street lighting.

Secondly, we think that the content of the discussions included in the thesis can serve as input for a more nuanced discussion regarding the success criteria and priorities behind the way street lighting is planned and regulated. The use of concepts such as societal benefit, without an accompanying discussion of this concept, introduces causalities into the regulations, that in turn end up shaping the final design results. Therefore, a continuous discussion of these concepts are as important to include in a design discussion as the final design choices are. We believe we have brought a number of new nuances and inputs to the table in this thesis, and hope that they will feed into future discussions, with the purpose of challenging and being challenged, either through our thesis, or through our onward work within the field of lighting design.

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Illustration 9: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 10: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.

Illustration 11: Front pages of the following publications:
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Illustration 27: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 28: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 29: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 30: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 31: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 32: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 33: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.

Illustration 34: Bahl, Lars. 2014.
Found on 09-06-2016 at website:
http://af-lighting.com/?project=frederiksberg-municipality

Illustration 35: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 36: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 37: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 38: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 39: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 40: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 41: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 42: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 43: Own photos and manipulation. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 44: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 45: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.

Illustration 46: Photo manipulation of image by Christian Henrik Ankerstjerne and Anders Dahl.
Original image found on 09-06-2016 at website:
https://blog.vandalog.com/tag/hyuro/

Illustration 47: Photo manipulation by Christian Henrik Ankerstjerne and Anders Dahl.
Original image found on 09-06-2016 at website:
https://www.flickr.com/photos/metronyt/8231327297

Illustration 48: Thiel, Olof. 2015.
Found on 09-06-2016 at website:
http://af-lighting.com/?project=electricity-pylons-in-borensberg

Illustration 49: Ebbesen, Niels Riis. 2010.
Found on 09-06-2016 at website:
http://fotonation.dk/?module=profile&page=gallery_image&gallery=309978&gallery_image=6427

Illustration 50: Berg, Anders Sune. 2015.
Found on 09-06-2016 at website:
http://nordeafonden.dk/projekter/cirkelbroen-paa-christianshavn

Illustration 51: Ukendt fotograf. 2015. Københavns Kommune.
Found on 09-06-2016 at website:
http://www.kk.dk/nyheder/lyskunst-skal-give-liv-under-langebro

Illustration 52: Own photos and manipulation. Credit: Christian Henrik Ankerstjerne and Anders Dahl.

Illustration 53: Own illustration. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 54: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 55: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.
Illustration 56: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.

Illustration 57: Rose, Lene Sørensen. 2015.
Found on 09-06-2016 at website:
http://www.dac.dk/media/8818/Frederiksberg_nye_pladser_figur.jpg

Illustration 58: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.

Illustration 59: Unknown photographer. Focus Lighting.
Found on 09-06-2016 at website:
http://focus.dudal.com/showproduct.php?productId=15&productVariantId=33

Illustration 60: Own photo. Credit: Christian Henrik Ankerstjerne and Anders Dahl.