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Light Pollution
Consequences and Sustainable Lighting Design

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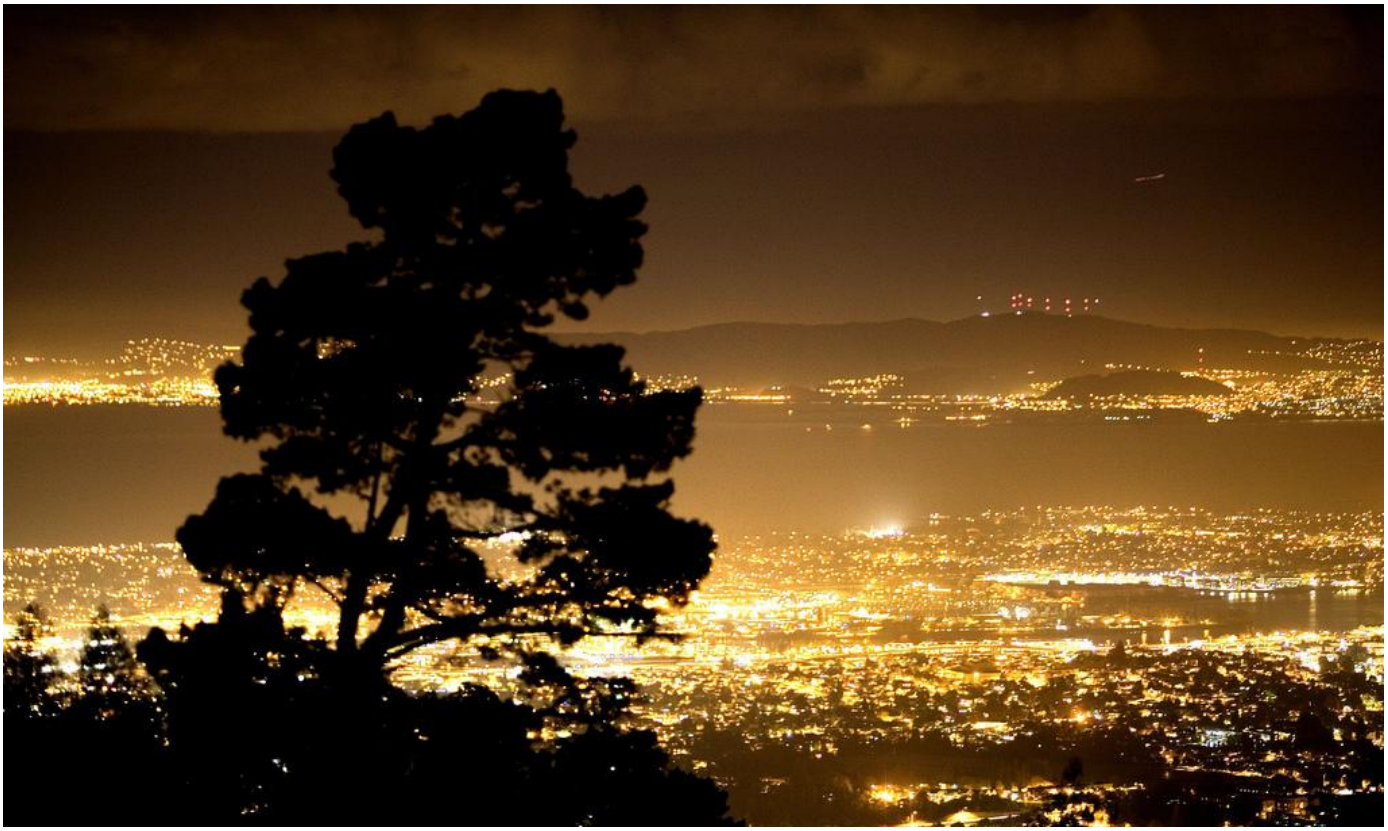

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Abstract

Light has always fascinated humans but ever since the invention of the first light bulb, the use of artificial lighting has accelerated dramatically. Darkness has never been as rare as today and the overuse of lighting has created a new phenomenon called light pollution. Most living beings are biologically dependent on the recurrent twenty-four-hour rhythm of light and darkness, called the circadian cycle. Human beings are evolutionary developed after this circadian rhythm and the effects of constant artificial light is yet unknown. Scientists fear the consequences of constant lighting and what it means physically, mentally and philosophically for the human species. New science show that the absent of darkness not only affect the sleep but might also lead to an increased risk of diabetes and cancer. Even animals and plants are controlled by the circadian cycle. Light pollution has therefore a great influence on nocturnal animals. The loss of darkness has influences on fundamental biological systems that scientists do not know the consequences of. Light pollution is therefore a crucial aspect for landscape architects to consider while designing with lighting. The purpose of my bachelor essay is to map out the negative consequences of light pollution. I chose to perform the research by literature studies but also through conversations with skilled people working with light. The results of the literature study showed sincerely negative effects of light pollution on wildlife and humans. The conversations with light designers and landscape architects gave though another point of view on light pollution. The results of the conversations also gave some easy aspects to be considered to reduce light pollution while designing with lighting. My essay finally discusses light pollution as a global potential threat that has to be considered while designing on the smaller scale.

Sammandrag

Ljus har alltid fascinerat människor, men enda sedan uppfinningen av den första glödlampan har användningen av belysning accelererat dramatiskt. Mörker har aldrig varit så sällsynt som idag och den överdrivna användningen av belysning har skapat ett nytt fenomen som kallas ljusförorening. De flesta levande varelser är biokemiskt beroende av en återkommande tjugofyra timmars rytm av ljus och mörker, alltså en dygnsrytm. Människan är evolutionärt utvecklad efter denna dygnsrytm och effekterna av ett konstant artificiellt ljus är ännu okända. Forskare fruktar konsekvenserna av konstant belysning och vad det kan innebära fysiskt, psykiskt och filosofiskt. Ny forskning visar att frånvaro av mörker inte bara påverkar sömnen utan också kan leda till en ökad risk för diabetes och cancer. Även djur och växter styrs av dygnsrytmen och ljusföroreningar påverkar därför nattaktiva djur. Förlusten av mörker påverkar grundläggande biologiska system som forskarna ännu inte vet konsekvenserna av. Ljusförorening är därför en avgörande aspekt för landskapsarkitekter att ta hänsyn till vid gestaltning av belysning. Syftet med min kandidatuppsats är att kartlägga de negativa konsekvenserna av ljusförorening. Jag valde att utföra undersökningen genom en litteraturstudie men också genom samtal med yrkesverksamma personer som arbetar med belysning. Resultaten av litteraturstudien visade påtagliga negativa effekter av ljusförorening på både djur och människor. Samtalen med ljusdesignens och landskapsarkitekter gav dock en annan synvinkel på fenomenet. Samtalen resulterade i aspekter att tänka på för att minska ljusförorening i samband med ljusdesign. Min uppsats diskuterar slutligen ljusförorening som ett potentiellt globalt hot som måste tas i beaktning vid utformning av ljusdesign i den mindre skalan.

1. Introduction

The starry sky has been an inspirational element for thoughts and stories in humans' life for as long as we know (Delius, Gatzemeier, Sertcan, & Wünscher 2000, p. 6). The documentary The City Dark (2011) showed that since the invention of the electric light, darkness has never been as rare as today. The electric lighting has created industrial progresses and economical wealth. The International Dark-Sky Association, IDA (2012) proclaimed that today's use of lighting is more than necessary and often without planning. The overuse of artificial lighting has created a new phenomenon called light pollution.

Light pollution is unwanted, inefficient, annoying or unnecessary artificial outdoor light (Chepesiuk 2009). In larger cities light pollution has replaced the natural dark sky with a pinkish haze that hides almost all stars (IDA 2012, VI). The short-term ecological effects of this phenomenon are well documented and light pollution has an impact on both flora and fauna (Chepesiuk 2009). The long-term effects on human health, nocturnal animals or vegetation is however unknown. Many researchers, according to Chepesiuk, believe light pollution to be one of the fastest growing environmental pollutions. Light pollution does not only affect the human physique but also the human psyche. Philosophers have always used the stars to get perspective upon life and the universe we live in (Delius et al. 2000, p. 27). The loss of the dark night sky is a possibility that we do not know the philosophic long-term consequences of.

I wanted to elucidate these ecological and anthropological consequences of light pollution to increase the knowledge among landscape architects designing and planning with lighting.

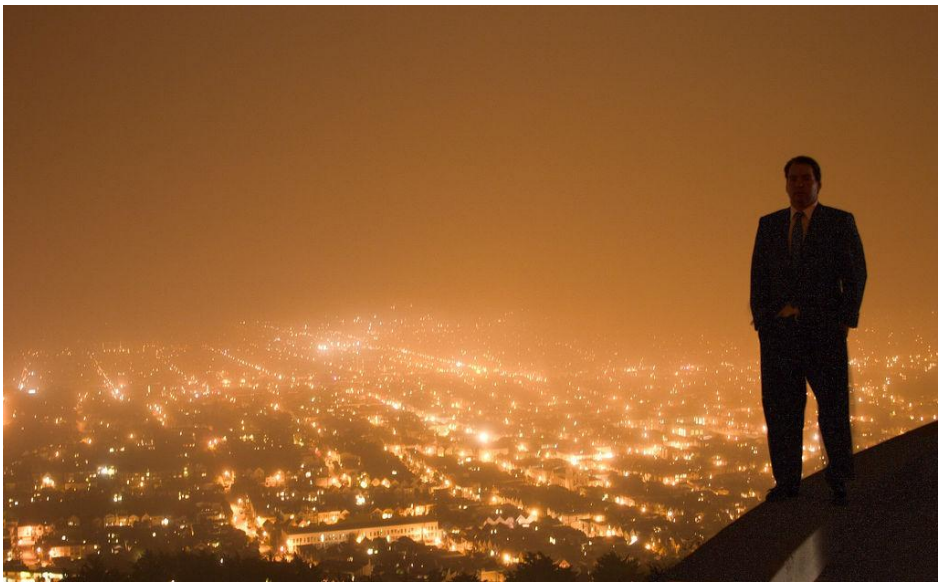
1.1 Background

The Big Bang occurred approximately 13.75 billion years ago and since the first human laid eyes on the night sky there were stars (Singh 2005). The starry sky probably evoked thoughts about who we are and our place in universe. The starry sky has also helped us find the answers to these questions. The ancient Greeks had a geocentric conception of the world and thought the *Earth* was the center of the universe (Delius et al. 2000, p. 6). Year 1543 Copernicus proclaimed, with help from stars, that the *sun* was the center of the universe (Delius et al. 2000, p. 27). Today, scientists and astronomers have solved many mysteries about our solar system and the universe. The stars still evoke questions about our galaxy and help us find the answers to these questions.

The first manmade light was created about 200 000 years ago when humans learned to control fire (IDA 2012, p. 15). Candles were developed about 5 000 years ago and the gas street lighting was possible in the mid-1700's (IDA 2012, p. 15). Before the turn of the 19th century, the light of day and the darkness of night had a much larger influence on every day life (Björk, Strömsten & Reppen 2000 p. 46). All daily activities were dependent on whether it was night or day. During the dark hours, lighting wax candles, light sticks or oil lamps created light. Björk, Strömsten and Reppen (2000, p. 46) also wrote that by the end of the 19th century as the kerosene lamps were introduced to the public, Swedish house owners were enjoined to put out gas lamps during wintertime. This lighting was

put up by practical reasons and for public safety. These light sources were a huge fire risk but also nasty-smelling (Björk, Strömsten & Reppen 2000, p. 46). By the year of 1879 Thomas Alva Edison invented the first electrical light bulb (Skovmand 2006, p. 310). The introduction of electric lighting was the end of the dark nights and since 1879 our nighttime planet never looked the same.

Today, the whole world is familiar with electricity and the entire Western World is lit at night (Cinzano, Elvidge & Falchi 2000, p. 690). During the last decades the interest in preserving a dark night sky has increased. So has the interest for lighting and the overuse of light has resulted in a new phenomenon: light pollution.



Picture 1. Sky glow over San Fransisco. Thomas Hawk. Used with permission from Thomas Hawk.

The long-term consequences of light pollution are unknown. The expanding global growth of the developed society increases the use of lighting (National Park Service, NPS 2012). The dark night sky is soon to become an extinct phenomenon. NPS also claimed that researchers predict that by 2025 no dark night skies will remain in the continental United States. Today, only one third of the American population can see the Milky Way from their backyard and the galaxy is dissolving from the view of nearly one half of Europe (IDA 2012, IX). According to IDA, light pollution is the illumination of the night sky caused by inappropriate artificial light. Not all outdoor-lighting is contributing to light pollution, but all unnecessary and unwanted lighting of the night sky is defined as such.

Since the invention of the electrical light bulb in 1879 artificial lighting is one of the most obvious demonstrations of technological and economical progress (NPS 2012). NPS also claimed that light pollution increases with air pollution. Since the light reflects on the smog of polluted air, light pollution increases in larger cities. Lighting is important for safety and orientation but in larger cities, lighting goes beyond necessity (IDA 2012, p. VII). IDA showed that the glow over a large city such as Las Vegas reach an untouched night landscape over 322 kilometers away.

The long-term consequences of light pollution on nocturnal animals are unknown but many animals depend on darkness in order to reproduce, hunt and

navigate (Chepesiuk 2009). A light at night can disrupt animal habitat or even affect their life cycles (NPS 2012). Trees and other plants are also affected by artificial light during the dark hours. Many medical researchers, environmentalists and other scientists believe light pollution to be one of the fastest growing environmental pollutions (Chepesiuk 2009). Recent studies showed in The City Dark (2011) proclaimed that the risk of breast cancer increases with artificial lighting during night. The long-term effects of this new phenomenon are therefore uncertain.

Electric light is only approximately 130 years old comparing to the millions of years of nighttime darkness on this planet. The City Dark (2011) described that electric light has erased the difference between day and night and people can work, shop, eat or watch a movie at any time. Lighting is a fantastic invention that has increased the feeling of safety in urban areas and is a foundation for social and economical progress. According to The City Dark this development has increased the economical growth of modern society but the ecological consequences are unknown. The evolution may have difficulties keeping up with our fast developing societies (The City Dark 2011).

1.2 Definitions

Following definitions describe the commonly used words and expressions in this essay.

1.2.1 Light Pollution

Most of the detailed definitions of light pollution contain two specific ideas: Firstly, only artificial light can potentially cause pollution. Secondly, the light must be problematically directed where it is unwanted, unnecessary or damaging (IDA 2012, p. 4). The International Dark-Sky Association define light pollution as:

> *Any adverse effect of artificial lighting, including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste. (IDA 2012, p. 4)*

This definition identifies the negative aesthetic effects of artificial light but IDA (2012, p. 4) also claims that energy waste is pollution. The definition indicates that light pollution is a waste of energy and therefore an indirect waste of nuclear energy and limited fossil resources.

1.2.2 Light Phenomenon Included in Light Pollution

The International Dark-Sky Association's definition of light pollution contains four lighting components that describe different kinds of light pollution:

- *Urban sky glow* is the brightness of the sky over large inhabited areas.
- *Glare* is a visual discomfort or decreased visibility due to excessive brightness.
- *Light trespass* is unintended, unwanted or unnecessary light.
- *Light clutter* is bright, confusing and excessive groupings of light that is common in urban areas.

1.2.3 Sustainability

According to Statens folkhälsoinstitut, FHI, the definition of sustainable development was stated by Bruntlandkommisionen in 1987 and is defined as:

> *Sustainable development is a development that meets present needs without compromising the environment for future generations to meet their own needs. (FHI 2011)*

In this essay, the definition of sustainability primary defines the use of lighting as socially, ecologically and economically sustainable.

1.2.4 Circadian Rhythm

This definition of the circadian rhythm/clock is presented in Psychology Today (2012) and is described as *a daily cycle of biological activity based on a 24-hour period*. This period/rhythm is influenced by regular variations in the environment, such as the alternation of night and day. The circadian rhythm is present in numerous organisms and is generated by an internal clock that is synchronized to light-dark cycles.

1.2.5 Long-term and Short-term effects

The use of *long-term effects* of light pollution is intended to describe the future consequences of the phenomenon. These effects are not dramatically arising but a possible threat throughout the evolutional changes.

Short-term effects are primary used as the consequences of light pollution in the span of our lifetime. These effects are arising rapidly and are possible to survey throughout our lifetime.

1.3 Purpose and Aim

The purpose of this essay is to answer the question: What are the negative consequences of light pollution? The aim is therefore to map out these negative aspects and discuss how landscape architects can reduce light pollution while designing with light. The aim is also to increase awareness about light pollution among landscape architects designing and planning with lighting.

2. Methods and Implementation

To map out the negative consequences of light pollution and to increase awareness of its different aspects a literature has been implemented. The literature study was consisting of electronic and non-electronic sources. Keywords for all electronic searches on Google, Epsilon or Libris have been *light pollution* and *lighting design.* Dialogues have then been held with professional light designers and landscape architects working and planning with lighting. Their knowledge resulted in aspects to consider while designing with lighting. These aspects

2.1 Literature

The main literature of this essay was *Fighting Light Pollution: Smart Lighting Solutions for Individuals and Communities* by The International Dark-Sky Asso-

ciation (2012). The International Dark-Sky Association, IDA, is a nonprofit organization based in Arizona, USA, fighting to preserve the night.

The article *Missing the Dark: Health Effects of Light Pollution* by Ron Chepesiuk (2009) was also used as a main reference. Ron Chepesiuk is a journalist and author. This article was published in the online medical journal *Environmental Health Perspective.*

Secondary literature was *Lighting the Landscape: Art, Design and Technologies* by Roger Narboni (2004), a lighting designer with a degree in electronic engineering who has specialized in urban and architectural lighting.

Light pollution: Responses and Remedies by Bob Mizon (2002) was also secondary literature. Bob Mizon is the UK coordinator of the British Astronomical Association's Campaign for Dark Skies and an active observer of the night sky.

Secondary literatures were supplementary books, articles or compendiums. Some research reports and other electronic documents have also contributed with information in the subject of light pollution.

2. 2 Dialogues

I decided to investigate the knowledge about light pollution among a selection of skilled lighting designers and landscape architects. The aim was to analyze their professional experience of planning and designing with lighting considering the consequences of light pollution.

The assortment of skilled people was dependent on the geographical location and size of the company. A criterion was that I met them in person and that the company was generally known. Following persons were contributing with their knowledge:

- *Andreas Milsta* is an architectural lighting designer at White in Gothenburg. He had a commission in Uppsala and we met the 12th of April 2012.
- *Mikaela Pärsdotter Andersson* is an architectural lighting designer who works at Tengbom in Uppsala. We met in Uppsala but had the conversation over telephone the 4th of May 2012.
- *Lars Johansson* is a landscape architect who works as a city gardener at Uppsala Municipality. We had the conversation in Uppsala the 7th of May 2012.
- *Lena Hildeman* is an industrial- and architectural lighting designer at Bjerking in Stockholm. We met at the office in Stockholm the 8th of May 2012.
- *Disa Löfvendahl* is a landscape architect at Bjerking in Stockholm. She was partly present during the conversation in Stockholm the 8th of May 2012.
- *Maria Handberg* is a landscape architect at Bjerking in Stockholm. She was also partly present during the conversation in Stockholm the 8th of May 2012.

2.3 Delimitations and Source of Errors

The thematic delimitation of light pollution was from a landscape architectural point of view. All facts and research were therefore considered from the designers view, rather than a deep going theoretical technical view. The ecological consequences of light pollution were showed as aspects to consider while planning and designing with lighting. I hope these aspects are considered while designing with lighting and that landscape architects are working to prevent light pollution. I chose not to handle the aspects of different wavelengths of lighting nor the energy wastes that light pollution signify. This essay was also delimited to strictly

consider the negative consequences of lighting. Since lighting often is referred to as positive I wanted to map out the negative aspects of lighting.

Dialogues with lighting designers and landscape architects were geographically delimited to Stockholm and Uppsala. These skilled people have varying work experiences and were chosen from different companies. Since landscape architects often are working with lighting, I thought their experiences of the consequences of light pollution were interesting to include. I also wanted to examine the knowledge of light pollution among educated lighting designers.

Source of errors in this bachelor essay might have been the dialogues held with a limited amount of skilled people. The small selection of lighting designers and landscape architects are not representative for the whole designer-staff working with lighting. Another source of errors may have been the information from the book *Fighting Light Pollution: Smart Lighting Solutions for Individuals and Communities* by The International Dark-Sky Association. This association has an agenda, though it is non-profitable, in preserving the night and this book can therefore be angled in their advantage.

Since light pollution might be a global potential threat the examples of its consequences were geographically unlimited. This bachelor essay was temporally bound to ten weeks of studies.

3. Results

Following results were divided into separate parts depending on whether it was results of the literature study or results from the discussions with lighting designers and landscape architects.

The results of the literature studies were intended to illustrate the different negative aspects of light pollution and therefore answer the purpose of this essay. These negative effects are not well known among landscape architects, though the effects of light pollution are observed and noticed more frequently. The result of the dialogues held with lighting designers and landscape architects are intended to map out their knowledge about the consequences of light pollution. The results were also intended to show how landscape architects could reduce light pollution while designing with lighting.

3.1 Effects on Human Health

Humans have, like many other organisms, evolved during the daily light-dark cycle as an effect of the earth rotation. This light and dark signal on a twenty-four-hour day, called the circadian cycle, has according to IDA (2012, p. 15) created a powerful evolutionary adaptation. IDA also presented specialized adaptations that have evolved to optimize behavior and physiology. These mechanisms are depended on the time of day, season and solar orientation but also the quantity of dark or light in the environment. Artificial light has, according to Chepesiuk (2009), been a condition that benefited society through extending the length of the productive day. Electric lighting has offered more time to work but also the possibility for recreational activities that requires light. IDA (2012, p.

15) stated that the creation of electric light has dramatically increased the ability to alter the environment and researchers has only begun to fully understand the impact of artificial light on human health. Since humans evolved in a distinct light-dark cycle, the circadian cycle, it is possible that exposure to artificial lighting during night signify a health hazard (IDA 2012, p. 15). According to Chepesiuk (2009) a disruption of the circadian rhythm can cause a lot of health problems since the circadian cycle control from ten to fifteen percent of our genes.

3.1.1 Physical Effects of Artificial Light

Many aspects of human physiology, behavior and metabolism are dominated by the twenty-four-hour rhythms of light and dark and these evolutionary cues have a major impact on health and well being (IDA 2012, p. 17). These rhythms effect sleep-wake cycles, performance and alertness pattern but also core body temperature and production of the hormones cortisol and melatonin. These processes also include brain wave patterns and cell regulation (Chepesiuk 2009).
Vetenskapsradion (2012) presented a recent study showing a connection between being awake during night and decreased insulin production. This study also showed that reduced metabolism is a consequence of light exposure at night. Light pollution therefore has an indirect effect on diabetes and overweight. IDA (2012, p. 18) agreed that inappropriate light exposure could cause circadian rhythm to become desynchronized with an impact on the human physiology and metabolism.

Light also affects the melatonin production, which is a major biochemical signal depending on darkness (IDA 2012, p. 18). Melatonin production is increased during the night and maintains the circadian cycle. Scientists have found that melatonin production decreases with the impact of light. IDA (2012) also stated that synthesis and timing of melatonin production are coordinated by signals from the brain directed by the circadian clock. A disruption in the circadian rhythm, like light exposure during the night, inhibits the signal system and therefore the production of melatonin. According to IDA (2012) melatonin suppression occurs instantly upon light exposure and stops when the lights are turned off. IDA (2012, p. 18) maintained that a prolonged, daily occurring, exposure to light during the melatonin-producing phase at night, could lead to chronic melatonin suppression - which could evoke depression. IDA (2012) also claimed that light exposure at night could cause elevating heart rate, irregular core body temperature and affecting cortisol production. These effects are still small and transient but the long-term consequences are unknown (The City Dark 2011).

3.1.2 Effects on Sleep

Circadian rhythm sleep disorder is the best-established disorders caused by inappropriate exposure to light (IDA 2012, p. 19). Vetenskapsradion (2012) also explained these disorders as commonly caused by exposure to light during night. Many shift-workers experience sleep problems, fatigue, forgetfulness, performance problems and gastrointestinal problems. The long-term effects of these problems might be increased cardiovascular disease, type-2 diabetes and some types of cancer (Vetenskapsradion 2012). The underlying source of these problems is disruptions in the synchronization of the circadian cycle but the precise mechanisms of these long-term health hazards are not identified. There are an

increased numbers of studies detailing the detrimental effects of sleep restriction, light and the underlying disruption of the circadian cycle (IDA 2012, p. 19).

3.1.3 Cancer Risk

The relationship between shift-work and cancer risk has been observed for decades but in 1995 studies in several medical journals examined female employees working a rotating night shift (Chepesiuk 2009). These studies found that a fifty percent higher risk of breast cancer was connected with occupational exposure to artificial light at night. According to Chepesiuk these studies noted that permanent shift workers were less likely to be disrupted by night work if the light-dark rhythm were controlled. The permanent shift workers circadian rhythm could then be readjusted to the night work. IDA (2012, p. 20) also presented several epidemiological studies that have shown the same connection between shift-work and prostate cancer risk in men. These studies could not address the mechanisms causing cancer but several hypotheses were put forward.

Since shift-workers by definition are awake at night, IDA (2012, p. 20) presented one hypothesis that proclaims light exposure at night as a potential mechanism for the increased cancer risk. IDA described the thesis as:

> *This hypothesis (first proposed by cancer epidemiologist Richard G. Stevens) is based on the finding that cancer rates increase as nations become more industrialized – increased artificial lighting is a common consequence of industrialization. (IDA 2012, p. 21)*

This quote describes lighting as one of many common elements of industrialization. The effects of artificial light exposure during night are therefore indirectly connected with light pollution. The City Dark (2011) presented that even non shift-workers run the risk of artificial light exposure during night. Glare, light trespass or other urban lighting penetrating the bedroom windows can affect the mechanisms causing cancer. Some scientists in The City Dark (2011) also claimed that if the light outside a bedroom window is bright enough to read a book in, the risk of breast cancer while sleeping increases with 73 percent.

As stated earlier, one effect of light exposure at night is the suppressed production of melatonin (IDA 2012, p. 20). Experiments on rodents showed that a suppression of melatonin by exposure to constant light would increase the development of mammary tumors. Rodents that had a light-dark circadian circle had a slower mammary tumor growth (The City Dark 2011). These results show a strong connection between light exposure, melatonin and cancer but IDA indicated that there is no direct evidence proving that an alteration of melatonin levels increase cancer risks.

Another hypothesis about the connection between cancer risks and artificial light exposure during night is the disruption of the circadian rhythm (IDA 2012, p. 22). As mentioned, the circadian circle requires being regular for normal biochemical and physiological functions. IDA stated that these light-cued functions are controlling most of the body's organs and must be well synchronized with each other to optimize their functions. Shift-workers alter the relationship between these internal rhythms and therefore show higher rates of cancer initiation and progression (IDA 2012, p. 22).

3.1.4 Psychical Effects of Artificial Lighting

> *We might love the light, but we need the dark.* (The City Dark 2011)

This quote sum up the development of lighting used in the globalization of the world. Scientists in the documentary The City Dark (2011) show great respect for the need of darkness. This fascination of lighting is deeply rooted in human beings, but the scientists are worried that our dependency on, and some times addiction to, light is unhealthy. Some scientists in The City Dark (2011) even reached to the level of saying that the future loss of darkness might be dangerous.

For the first time in history more people live in urban areas than on the countryside. The global urbanization has lead to larger and more spread out cities, which has increased the sky glow. IDA (2012) claimed that many children of today are growing up without a clear view of the stars. The limited view contributes to a disconnection between imagination and science. Children are inspired by what they see and experience but few children will, according to IDA, ever see a truly starry night sky. IDA (2012, p VII) proclaimed that children and future generations are therefore denied one of the grandest spectacles of the universe – the Universe itself.

Scientists in the documentary The City Dark (2011) mean that the evolution of mankind is characterized by the presence of the starry sky. A starry night sky can evoke evolutionary questions, whimsies and wonders that are important for human beings. The absence of a truly dark starry sky can have unknown influence on the further evolution of mankind. IDA (2012) predicts that when the view eventually fades, the interest to preserve the dark night is likely to dim as well. Few people will then realize the magnificence of what is lost.

Picture 4.The constellation Orion: To the left from dark skies and to the right within the urban area of Utah, USA. Wikipedia.

3.2. Light Pollution's Consequences on Wildlife

A growing amount of data, presented by IDA (2012, p. 25) is asserting that artificial lighting at night has negative or deadly effects on wildlife. Birds, amphibi-

ans, mammals, insects and plants depend on regular interval of daylight and darkness for proper functions of reproductive, behavioral and immune systems. The dark night of the evolutionary past is an integral part of thousands of species and the disappearance of darkness may signify grave consequences for these creatures (IDA 2012, p. 25). The documentary film The City Dark (2011) showed that artificial lighting during night affects not only nocturnal animals but also diurnal species, active during the day. Even crepuscular species that are active at dawn and dusk are affected by light at night. The artificial light triggers unnatural periods of repulsion and attraction that leads to disturbances in reproductive cycles (IDA 2012, p. 25). The light disorients and fixates animals and interferes with sustenance and feeding (IDA 2012, p. 25). Studies have shown that artificial light at night disrupts mating and reproductive behavior in fireflies and frogs as well as interferes with the communication between numerous of species, from coyotes to glowworms (IDA 2012, p. 25). Other studies have shown that artificial light at night affects the movements of migratory birds and hatchling turtles (The City Dark 2011).

The recurring cycle of light and dark during a twenty-four-hour span, the circadian rhythm, has been a dependably consistent element in the natural environment during the evolution (IDA 2012, p. 26). Since climate seasons vary from one year to the other, many species of plants and animals rely on the length of the day to indicate the proper season for molting, mating and other activities. IDA (2012, p. 26) described light sensitivity as so exact that many species have the capacity to detect discrepancies in the length of the day as short as one minute. IDA continued that artificial light at night interferes with the light-detection system of plants and animals and are disrupting the reproduction cycles. Trees fail to lose their leaves or bud prematurely when given false cues from outdoor artificial night lighting (IDA 2012, p. 27). Migration paths of birds and bats are timed to coincide with the blossom of edible trees and flowers along the migration routes (IDA 2012, p. 27). These symbioses, IDA wrote, feed animals and pollinate plants, but if a tree is budding prematurely it is no longer a viable food source and is less liable to become pollinated. Artificial lighting can, according to IDA, directly displace animal and plant activity and therefore indirectly affect other organisms that interact with them.

3.2.1 Effects on Amphibians, Marine Animals and Insects

Amphibians are currently suffering population decline around the world and these species are especially disposed to reproduction disruption (IDA 2012, p. 27). Many pond-breeding salamanders show a strong fidelity to their home ponds and studies, presented by IDA, have shown that artificial light and illumination can disrupt salamanders' ability to return to home ponds to breed.

Firefly populations are also decreasing noticeably and IDA (2012, p. 27) stated that artificial light at night interferes with several firefly behavioral mechanisms. IDA (2012) continued that fireflies depend on light cues for flash pattern and flight altitude since these mechanisms are linked to feeding and reproduction. Artificial light cause some behavior to be artificially triggered and others to stop, diminishing the time an adult spends attracting a mate, but also decreases the effectiveness of flash patterns by making mating behavior less visible (IDA 2012, p. 27). Artificial light can paralyze the night-flying insects and make them more visible to predators. IDA (2012, p. 28) showed that moths, for example, have an incessant attraction toward artificial points of light. This disrupts the nocturnal

pattern of predator species by creating an unnatural concentration of food. IDA (2012, p. 28) continued that some predators, such as bats and birds, are not repelled by light and this disruption create a dramatic change in quantity and location of their food. These imbalances in predator-to-pray relationship have negative consequences for both species. Chepesiuk (2009) showed that some researchers blame light pollution for the decline of population of many spices of moths.

Like moths, some fish species can be dangerously drawn to artificial light sources (IDA 2012, p. 29). According to IDA (2012) artificial light is used by large night-fishing enterprises to attract fish and squid species. Even anthropological salmon ladders or other facilities to help fish species reproduce are disrupted by artificial light (The City Dark 2011). Lighting along rivers and waters has therefore consequences that should be considered during the designing phase of a place. IDA (2012, p. 29) verified that other ocean dwellers could be temporary blinded and left vulnerable by artificial light that restrain anti-predation behavior such as schooling. Fry are, according to IDA, especially sensitive to artificial light since it disrupts their migratory patterns.

3.2.2 Effects on Birds

Most migratory birds are diurnal, active during the day, but hundreds of species do migrate at night (IDA 2012, p. 29). Fatal Light Awareness Program, FLAP (2012) wrote that millions of birds make seasonal journeys and in part guided by the moon and the stars. This behavior naturally draws the night-migrating individuals towards the light of urban centers. IDA (2012, p. 29) wrote that clear and moonlit skies make migrating birds fly at high altitudes but fog, rain or low clouds bring the birds closer to the ground. Birds naturally fly low preparing to land to rest or feed. IDA also wrote that birds flying at low altitudes are particularly vulnerable for dangers posed by light at night. Especially during fog, birds often fly directly into the lit windows of skyscrapers (The City Dark 2011). The City Dark (2011) also described that many birds are killed outright but others are shocked and dazed for hours before recovering. Birds that survive a nighttime collision are still in danger during the day as they try to escape the city. Many birds collide with buildings during the day or become trapped in a maze of bright, reflective buildings and therefore fall victims to gulls, raccoons, crows or cats (IDA 2012, p. 30). Shiny building exteriors reflect the surrounding trees, sky and clouds and give the migratory birds an illusion of a safe passage. According to FLAP (2012) bird-biologists estimate that, only in North America, one to ten birds are killed per building each year. In a city such as Toronto, Canada, with over 940 000 high buildings, that amounts between one to ten million birds lost every year. FLAP (2012) also estimated that the number of migrating birds killed annually by collisions with buildings across North America ranges from a hundred million to one billion individuals. According to FLAP (2011) ornithologists claim that collisions with human built structures are the leading cause of migratory birds mortality in North America.

IDA (2012, p. 30) stated that birds are crucial for a healthy environment since they pollinate plants, disperse seeds and eat billions of insects every year. They are also important for their song, beauty and intimate connection with wilderness.

IDA showed that centuries of anecdotal evidence have proven how fatal the combination of bad weather and artificial night lighting can be to birds. Lighthouses, emission stacks, tall monuments and other high structures can be devas-

tating to a huge flock of birds in the vicinity at a foggy, cloudy or rainy night. IDA also presented reports on extreme weather conditions, which show that more than five thousand warblers and other birds were killed during two nights in September 1968, by collision with a television tower in Nashville, USA. Another extreme report estimate that fifty thousand birds were killed during two nights in October 1954 at Robins Air Force Base, Georgia, USA.

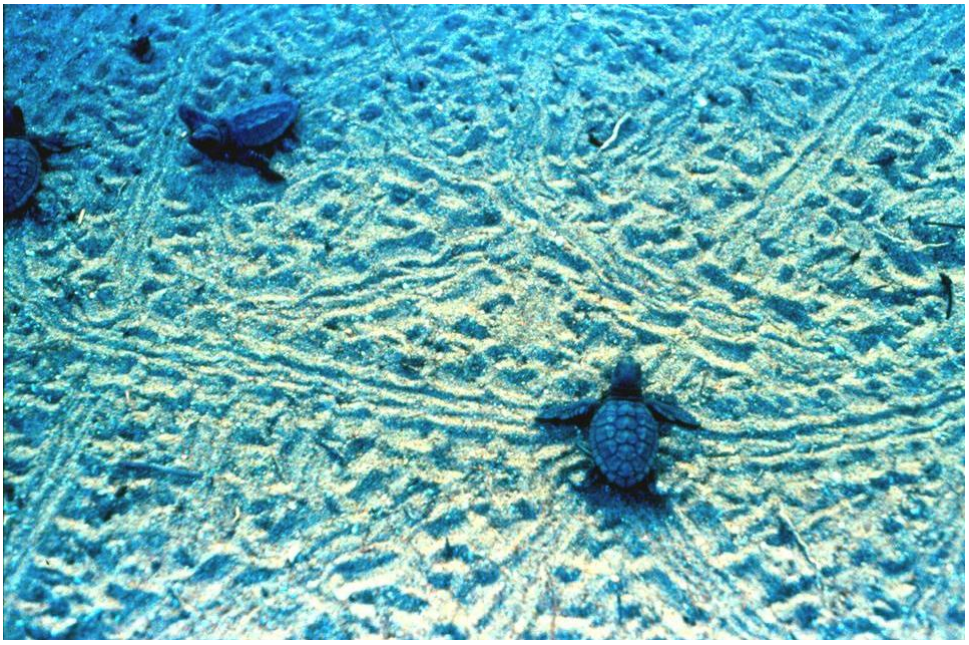
Picture 2. Birds killed by collision with buildings in Toronto, Ontario. Collected by volunteers in 2009. Kenneth Herdy. Used with permission from Susan Krajnc/FLAP.

3.2.3 Effects on Turtles

Like migratory birds, sea turtles provide a dramatic example of how artificial light can disrupt behavior (Chepesiuk 2009). Many species of sea turtles lay their eggs on beaches. IDA (2012) wrote that a female turtle is returning to nest for decades on the beaches where it was born. This biological event has taken place for millions of years. According to IDA, the hatchlings point themselves seaward by orientating toward the center of a broad and bright horizon. Hatchlings therefore, IDA continued, crawl on precise direction toward the bright seaward if the beaches are lit only by the twinkle of stars or glowing moon. Beaches lit by the glare of electric light deceive hatchlings who often attempt to reach the over lit artificial brightness instead of crawl towards the subtitle cues from nocturnal light (IDA 2012, p. 32). IDA stated that these hatchlings are unlikely to ever reach the water.

IDA (2012) described that on beaches with no visible artificial light, it takes only a few minutes for the hatchlings to reach the safety of the ocean. Furthermore IDA (2012, p. 32) showed that the tracks from the nest spread out about 45 degrees – all showing more or less straight path toward the water. Hatchlings on beaches exposed to artificial lighting show tracks that span from 90 to 360 degrees from the nest (picture 3). According to IDA many hatchlings crawl parallel to the shore or turn around in circles. These hatchlings are often orientated towards the artificial lit horizon that contributes to exhaustion, dehydration or death by crossing roads (Chepesiuk 2009).

Beaches that are brightly lit at night may also discourage female turtles from nesting in them (Chepesiuk 2009). In most species the reproductive activities take place only at night, mostly at the darkest areas of beaches. Chepesiuk (2009) continued that the bright light disorientates the turtles that often wander onto nearby roads where they encounter several dangers.



Picture 3. Hatchlings disoriented by light are turning around in circles in search of the ocean. Used with permission from Florida Fish and Wildlife Commission.

According to IDA (2012, p. 33) research on sea turtle reproduction has been performed for over a century, but only about fifty years ago did the connection between light cues and hatchling orientation become clear. Hatchlings are also sensitive to light spectra, which means that some wavelengths of light are more attractive than others. New studies, according to IDA, showed that some wavelengths have little or even no effect on the orientation of newly hatched turtles. This information is helpful in determining what type of lighting should be used in order to have the least impact on hatchlings (IDA 2012, p. 35).

3.3 Conversations with Skilled People Working with Lighting

The interest for lighting design has increased and several universities offer a bachelor in lighting design. Since lighting designing is complex, many architect offices have lighting designers who handle all the architectural lighting. Conversations and discussions with a small group of skilled people working with lighting contributed to a broader point of view on light pollution. These conversations also gave some aspects to consider while choosing electric fittings to reduce light pollution. These aspects are easy to consider as a landscape architect while designing and planning with lighting.

3.3.1 Considering the Effects of Light Pollution while Designing with Lighting

The substance of the conversations with a few lighting designers were that designing with lighting is complex. The lighting design process is as much a design with darkness. They all agreed that to be able to design with lighting, darkness has to be present. Darkness is crucial to accomplish contrast.

Lighting designer Andreas Milsta[1] said that the negative aspects of light pollution are briefly discussed through the lighting design education in Jönköping. Professional lighting designers are therefore often aware of the existence of light pollution but few are actively working to prevent it.[2] The use of sustainable lighting is often an indirect consideration of the negative aspects of lighting pollution. Milsta[1] also described that cities are bright and old lighting is competing with new lighting. Milsta therefore often have to reduce old lighting before he starts the new design.

According to Lena Hildeman[4], leaking lights and glare are not considered as sustainable lighting design. Lighting designers and landscape architects sometimes choose these light sources as part of a conceptual design. It is difficult to state universal guidelines since every project has to be evaluated from its special conditions and requirements. The lighting designers often have to consider wishes and guidelines from the municipality during the design of new lighting. [4]

Hildeman[4] continued that the selection of light sources is constantly developing but the designs of electric fittings are sometimes contrary to the sustainable functions of lighting. Landscape architects and lighting designers may therefore choose between good design and preventing light pollution. New technologies combining design with sustainable light are important elements to prevent light pollution. [4] Electric fittings are often considered partly by the aspects of design partly in the aspects of light trespass and glare. According to Andreas Milsta[1], it is not difficult to combine sustainable lighting with good design, safety and regulations. But lighting designer Mikaela Pärsdotter Andersson[2] describes that the aspects of safety or design are sometimes considered more important then saving nocturnal insects living on the site of the designing. It is rather a question about *how* the lighting is used, not *if* lighting should be used at all.[1] The awareness to prevent over-lighting and glare are working-routines for many lighting designers but also a condition to create sustainable lighting.[1 & 4] The knowledge about how light reflects by different surfaces is also a crucial aspect to create good and sustainable urban lighting.[1] City lighting can therefore be exciting and enjoyable through designing with contrasts between light and dark.[3]

The knowledge about light pollution among landscape architects is varying. Many are familiar with the phenomenon of light pollution but fewer seems to know of its consequences.[3 & 5]

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[1] Andreas Milsta, architectural lighting designer, White. Conversation in Uppsala the 12 of April 2012.

[2] Mikaela Pärsdotter Andersson, architectural lighting designer, Tengbom. Conversation over telephone the 4 of May 2012.

[3] Lars Johansson, landscape architect and city gardener at Uppsala Municipality. Conversation in Uppsala the 7 May 2012.

[4] Lena Hildeman, industrial- and architectural lighting designer, Bjerking. Conversation in Stockholm the 8 May 2012.

[5] Disa Löfvendahl, landscape architect, Bjerking. Conversation in Stockholm the 8 May 2012.

[6] Maria Handberg, landscape architect, Bjerking. Conversation in Stockholm the 8 May 2012.

According to several lighting designers, every project and place are treated individually and light pollution is often considered while choosing the electric fittings. Landscape architect Disa Löfvendahl[5] said that it is difficult to feel engaged in the consequences of light pollution in a national or even global context while designing smaller areas. Knowledge about light pollution is often present during the design process but few landscape architects are working to prevent its consequences. Löfvendahl[5] continued that it seems difficult to feel obligated to prevent the effects of light pollution for example in Stockholm while designing a smaller area in town. Light pollution seems like a global problem out of reach, but there are definitely possibilities to work preventive.[5]

Many people see light as a statement of security and are therefore afraid of dark places in towns.[6] Fear often restrain these citizens to visit darker places even though these places are not, statistically, more unsafe that up-lit places.[4 & 5] A big power failure in Gothenburg 2006 darkened around half of the city. The fire department expected increased crimes and warned the public for unsafe condition in town. But the night was calm. Lars Johansson[6], who at that time was the city gardener in Gothenburg, later revised e-mail from a woman who wished for a moonlight-park. She enjoyed the darkness during the power failure since she could see the bright moonshine and the stars in the city of Gothenburg. This park was never established but the suggestion of a moonlight-park was a good idea since the darkness in cities is vanishing.[3]

3.3.2 Design Restrictions to Reduce Light Pollution

Many countries have restrictions and even laws regulating what lighting designers have to consider while designing with lighting. It could, for example, be laws regarding electric fittings or type of light source used in an urbanized area. These restrictions might have good intentions to prevent light pollution but, according to lighting designer Lena Hildeman[4], these restrictions are not likely a resolution to this problem. To create sustainable lighting design every place has to be considered by its own qualities. All kinds of restrictions are therefore limiting the design process. Hildeman also pointed out that knowledge and information often are better ways to decrease light pollution. Lighting designers are consciously choosing sustainable electric fittings or light sources and are therefore indirectly preventing light pollution.[1 & 4]

Many Swedish municipalities have guiding principles and achievements considering safety, economy and sustainable environment regarding lighting. Uppsala municipality has a strategy for planning the future lighting but also guiding principles for maintenance and replacement of old electric fittings.[3] Light pollution was also mentioned as an aspect to consider while planning the future lighting in Uppsala (Uppsala Kommun 2010).

To plan the future lighting is an important guideline in the globalized world where more and bigger cities are using lighting to demonstrate their wealth. The rapid development of new and economically sustainable light sources, like LED, may increase the use of lighting. The escalating use of lighting may trigger new lighting to be brighter since cities are getting more lit up and light cluttered.[1]

3.4 What to Consider while Designing with Lighting

Awareness of the consequences of light pollution is important to reduce the negative effects of the phenomenon. A conclusion of the conversations with skilled lighting designers and landscape architects were that all places are different and should therefore be designed in consideration to this. Different projects are evaluated individually and various aspects are always considered. Some projects are more sustainable in the aspects of light pollution then others, but there is always a thoughtful design behind it.[4]

There is no easy way to reduce light pollution in a globalized world were darkness mostly is experienced as a threat. Some aspects are though easy to consider while choosing electric fittings:

- *Avoid glare* – use light and fittings that are shielded and aim these thoughtfully.
- *Avoid reflections* – unnecessary reflections can create unwanted glare and light trespass. Examine the surface were the light reflects.
- *Use top-down spotlights* – the trespass of up-aimed spotlights is easily avoided by pointing the spotlights downward.
- *Do not over-light* – good lighting is not strong light. Try different kind of light sources to find a harmoniously light.
- *Use flat-lens luminaire* – these luminaries reflect light less than drop-lens luminaries.
- *Avoid lighting on trees* – this type of light is often beautiful but point the light straight upwards.
- *Use timer or dimmer* – in the right context, like the private garden, dimmers and timers are useful energy savers but also help to reduce light pollution.

The substance of the conversations with skilled people working with lighting developed these aspects together with IDA's (2012, pp. 91-95) recommendations for reducing light pollution.

4. Discussion

The purpose of this essay was to answer the question: What are the negative consequences of light pollution? The results of the literature study showed some serious negative effects of light pollution on both humans and wildlife. Through this essay I have shown that knowledge about this phenomenon has great significance for the future profession of landscape architects designing and planning with lighting.

The aim of this essay was to map out these negative consequences and discuss the question: How can landscape architects reduce light pollution while designing with light? The conversations with lighting designers and landscape architects gave some aspects to consider but according to me, this question has two answers. The first answer is simple but not realistic: Do not design or use lighting at all. The second answer is more complicated: Our globalized cities are dependent on light and probably always will be. Since the designing of lighting is complex, skilled people who know the consequences of light pollution should perform all public and commercial lighting. By knowledge and new scientific results on the matter, landscape architects have a responsibility to consider the

negative effects of light pollution in the design process of every new site of design/planning. It is also important to remember that every site should be considered by its own qualities and needs. Some light pollution might be acceptable if the aspects of aesthetics and safety are valued higher on a particular site. This is always a balance between the conditions and qualities of the planning site.

This bachelor essay has shown that light pollution is a growing global potential threat, which we do not know the long-term consequences of. Scientific results have presented dramatic effects on both wildlife and humans caused by constant artificial lighting. Ecological systems, animals and human beings are depending on a dark-light rhythm. A functional circadian cycle controls the fundamental and evolutionary rhythms in most living organisms. These biological and biochemical systems might therefore be disrupted and can potentially lead to cancer and other diseases. Knowledge about light pollution and its consequences are therefore important for landscape architects, while planning and designing lighting. Without knowing the effects of over-lighting, the escalating urban brightness and the overuse of lighting might therefore eliminate the darkness.

I think it is important for landscape architects to have these negative effects in mind while designing with lighting since all lighting designing naturally is contributing to light pollution. Even though some landscape architects experience a difficulty to feel motivated to prevent light pollution on a national or global scale, it is significant to know that even small considerate choices make a difference.

4.1 Methods and Sources of Errors

The results from the literature studies demonstrate a pessimistic future development of light pollution. It is important to observe that The International Dark Sky Association presented most of these scientific results. Even though they do not have a financial interest in this matter, they still have an interest of preserving a dark night sky. All effects of light pollution are therefore presented as negative.

It would have been interesting to investigate if there are any positive effects of light pollution. The potential positive effects of light pollution seem unlikely since scientists around the world support many of the negative effects. Throughout the research for this essay all information presenting the effects of light pollution were negative. It would have been of great value to have a second opinion from scientists who do not believe in these negative consequences of light pollution.

The results from the conversations with lighting designers and landscape architects displayed their view on the phenomenon light pollution. Their knowledge contributed to a wider perspective upon the issue of light pollution but also the aspects of how to preserve the darkness throughout the design process. The few numbers of skilled people to whom I talked might have been a source of errors. All of the skilled people I talked to were working in Sweden and had quite the same opinion of how to prevent light pollution. To get more realistic results, it would have been interesting to interview several more lighting designers and landscape architects. Conversations with engineers working with lighting might have brought an even broader perspective and more reliability upon the results.

4.2 Future Development of Light Pollution

I think light pollution should be treated as any other global environmental pollution. Today, many people only see the good sides of lighting – the twinkling light in big cities, the feeling of safety and the hypnotic lighting in modern metropolitans. To work, shop or eat at any hours are also some of the fantastic possibilities that lighting has contributed with. The fundamental human fascination for light is sometimes even considered as a human right. A human in the modern society expect to do what she want, when she want to do it. Lighting is therefore a question of freedom. That is why new high up-lit buildings often are seen as a prof of economical growth, wealth and success.

The importance of light seems inevitable and the modern society is built on it. It is difficult to argue against the feeling of safety, excitement and exhilaration that people feel when they visit *cities that never sleep.* But is it important to have cities that never sleep? Could it be possible to switch of any of the commercial or non-functional lighting during some hours at night? Many new questions were evoked during the research of this essay and the answers are hidden in the future.

Lighting has gone from a practical necessity to an everyday dependency – from the first manmade fire to today's overuse of lighting. Most of the new everyday devices that we are depending on are using electricity. Many electric appliances also have a screen or are up-lit. Today, the human fundamental fascination of light is shown everywhere. Lighting should therefore be considered as pollution to handle with care. Lighting is fantastic and inevitable in a modern society, but we should learn how to appreciate the darkness as well.

I hope future lighting designers and landscape architects can contribute to a sustainable lighting design and at the same time protect the darkness. The human safety and commercial interests should not be more important than dark nights and a sustainable urban environment. I think the modern human will have to learn how to appreciate darkness. It should not be seen as a threat that inhibits peoples freedom of moving. Darkness should rather be seen as a biological necessity and a privilege to embrace.

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