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Title: URBAN GLOWSCAPES - An Alternative Vision for Illumination of Trees

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Frederikskaj 12,

DK-2450 Copenhagen SV

Semester Coordinator:

Secretary:

Supervisor(s):

Ellen K Hansen
Claus B Madsen

Project group no.: N/A

Members:
Divya Tahlani

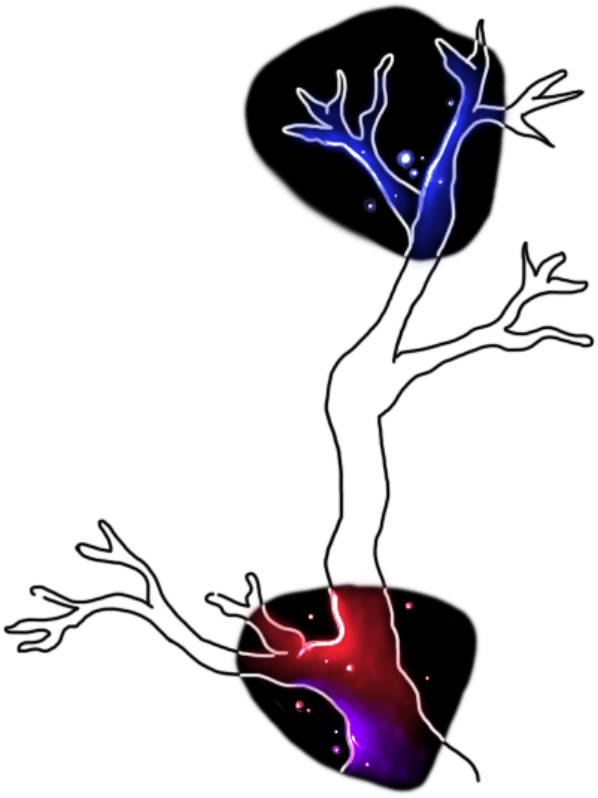
Abstract:

A conclusion from several studies confirms that illumination of trees and plants at dark hours disrupts their circadian rhythm and increasing light levels in urban landscapes contribute significantly to light pollution. Such practises have led to us losing the experience of darkness and of viewing a sky full of stars. This thesis explores the conceptualisation and visualisation of an alternative typology in illumination of trees in urban parks. A new concept is proposed after observing and understanding of existing lighting practises on trees and its effect on their growth cycle. The proposed illumination strategy uses different spectrums from daylight that are beneficial for leaves to conduct the process of photosynthesis which can lead to improvement in their growth. The use of red light (500-600 nm), Blue light (400-500 nm) and UV light (100-400 nm) in specific quantities can help in improvement in growth of trees. This light recipe is used artistically to create an experiential landscape with the intention to encourage urban inhabitants to interact with their natural surroundings at dark hours and to provide a lighting strategy that is beneficial to trees and minimizes light pollution.

The design is validated with a user experience test, that allows us to understand the acceptability and adaptability of urban inhabitants to a volumetric lighting strategy in urban public parks. Most of the users support the proposed design, encouraging the vision of luminous volumes as a source of illumination in urban landscapes.

URBAN GLOWSCAPES

An Alternative Vision for
Illumination of Trees



BY DIVYA TAHLANI

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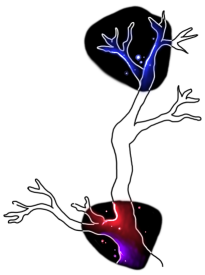


01 INTRODUCTION

This chapter discusses the existing lighting practices and introduces the motivation to this thesis project. It brings out awarenesses on various aspects of landscape lighting, and envisions the future of lighting in urban landscape connecting to user's needs to the needs of biodiversity.

01 Introduction

1.1 Foreword

This Master's Thesis project has been developed as a continuation of the study and research from a project undertaken with fortheloveoflight, Copenhagen. I completed an internship for a period of 6 months at the studio fortheloveoflight based in Copenhagen in the year 2020. The project at Postbyen was to develop a streetlamp that provided a multifunctional quality to illuminate the horizontal path, directionally adjustable illumination of trees and create a warm lantern effect acting as wayfinding guide for the visitors in the site of PostByen in central Copenhagen. My involvement in the project was to study the spatial surroundings of the site, draw inspiration from the new and old age architecture of central copenhagen and iterate in product development of the street lamp to be delivered for this project. It also included understanding and specifying the specs of the lamp, the effect of its illumination on trees and walking paths and to design an overall experience of the inhabitants and visitors in the space.

My involvement in this project and the process undertaken made me question the effect of illumination on trees. And upon further research I discovered the adverse effects of illumination on trees in dark hours with our existing practises. I took this thesis research to be an opportunity to explore an alternative solution for our illumination needs of urban cities at night which could minimize the damage to our biodiversity.

One of the essential goals of this project is to use the knowledge and learnings I have acquired in the past two years as a masters in lighting design student at AAU and during my internship at fortheloveoflight and demonstrate a new vision of lighting urban landscapes. This thesis project develops its own version of design process and thinking model inspired from the design experiment model introduced to us by Ellen K Hansen and Mette Hvass. The project discusses in-depth about the analysis of theories using urbanistic and anthropological tools, visualises and conceptualises light through illustrations, sketches, renderings and VR simulations using various softwares and techniques, conducts a user experience test and evaluates the design concept.

It has been a privilege and a great opportunity to have been able to work on this topic and emphasize the growing need of lighting for biodiversity in our urban landscapes. It is a crucial and essential step towards discovering myself as a lighting designer by utilising my skills, interests, knowledge in a transdisciplinary approach.

Acknowledgements

This chapter of my life would have been incomplete without the unconditional support of my family and my partner. Covid 19 pandemic has been hard on the entire world. Working in isolation has been the most difficult thing I have ever had to do. With the support of my professors and supervisors Ellen K Hansen and Claus B Madsen who have guided and encouraged me to be more pragmatic I was able to trust my instincts and achieve my best. I would also like to give my acknowledgement to Aalborg University, who have managed the administrative aspects of our study plan and the entire lighting design faculty who have provided us with their valuable time and feedback. A warm thank you to the company fortheloveoflight in Copenhagen, which provided me a practical experience and exposure to lighting practises in the industry through my internship in the previous semester. A gratitude of thanks to all the users who participated in my test to validate the design concept. And last but not the least, thank you to all my friends across the world who cheered me up with breaks in between and supported my process with their invaluable suggestions and inputs.

1.2 Importance of Landscape lighting

Outdoor lighting is now an essential and inseparable element of urban nightscapes. It creates visibility, meets the functional needs of the people and provides the possibility to extend the day according to the needs and desires of new urban civilizations. Although as night becomes brighter it develops many other problems as well such as light pollution, which leads to waste of enormous amounts of energy, generates millions of tons of greenhouse gases, disrupts ecosystems, threatens wildlife and puts public health and safety at risk. Since, life in pure darkness is not an option for the survival of the current lifestyles in urban cities, street and landscape lighting plays a very essential role in creating a balance between providing illumination and respecting darkness in public spaces. This has led to an evolution in lighting of public spaces as current redevelopment projects have gradually moved to creating cities that are more respectful to the environment and biodiversity. (Narboni R, 2020)

"The project management teams were able to respond to these new demands by integrating more systematically, in addition to the usual urban architects, landscape architects and engineers, lighting designers (who are more in charge of the nocturnal aspects of the public spaces and not only their simple lighting), but also and according to the projects, ecologists, designers, artists, sociologists and even sometimes philosophers or night geographers" (Narboni R, 2020, p.07). Landscape Lighting design today is a balance between technical, normative, environmental, energy, budget constraints and attractive and varied luminous ambiances that encourage social interactions in public spaces.

1.3 Existing practices

This chapter indicates existing practices in the field of lighting design in public spaces that have been able to create social engagements, minimize pollution and create a new experience of urban cities today. Some of the examples are as follows,

Pedestrian Lighting Poles, the design of street lamps for pedestrian walkways have evolved enormously over the past decade in terms of range of lighting effects, multifunctional optics, minimizing energy consumption, reduced glare as well as increment in decorative and aesthetic effects of light. Smart Luminous Columns, with the purpose to minimize the number of masts as well as create multifunctional and adjustable luminaires led to the creation of cylindrical modular luminous columns with various functions at different heights. High Lighting Masts, Spatial illumination created from multiple projectors mounted at different heights on high masts. They create the possibility of light graphics visible in perspective of the architecture it illuminates as well as create general ambiance illumination for pedestrian walkways. Coloured illumination, use of Coloured LEDS and adjustable and tunable white LEDs have increased in the past few years in urban public spaces. Coloured lights creating dynamic installations in public spaces have been greatly accepted by city dwellers. As it helps in transformation of the space and create a special ambiance of identity and a unique experience encouraging them to interact. (Narboni R, 2020)

Figure 1.1 Lüdenscheid, Erco, n.d

Figure 1.2 Bank of China, Beijing, Erco, n.d

Illumination of trees acts as one of the essential elements in highlighting a landscape. The current strategy of illuminating trees using fixtures varies according to the tree species and shape and size. The most common practice that has been observed whilst illuminating trees is the use of spot or flood lights to achieve a wide beam and uplighting to create a three-dimensional effect. Other practices include using multiple floodlights from sides and front with uneven distribution to uplight its voluminous foliage. (Erco. n.d)

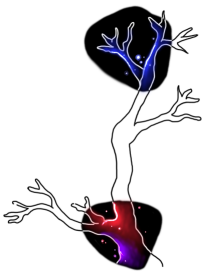
The use of floodlights in the background creates a back lighting and makes the crown of the tree appear like a silhouette. Using uplighting on tree trunks accentuates its length and linearity creating a visual connection between the crown and the earth. Downlighting of trees essentially emphasizes the contour of its crown and is used to create a canopy-like experience for the pedestrian walkways. The lighting remains unchanged with changing seasons, creating different effects through the year. Illuminating trees and surrounding landscape help in highlighting the natural environment of urban cities and encourage public interactions. However, the current practises are biologically harmful for the trees and contribute greatly to light pollution. This thesis research intends to discover methods and strategies for illuminating trees sustainably and create an enriching and intimate experience with nature for urban inhabitants. (Erco. n.d)

1.4 Future of Urban Lighting

Urban lighting master plans featuring illuminated landmarks, lighting for traffic and circulation areas are due to be complemented by lighting designed for human scale and well being at dark hours. Besides the need for safety, new strategies include designing public spaces to encourage social life, attract the public in the urban realm. However, the future includes interactivity, technologically driven and most importantly sustainable both in terms of human and environmental wellbeing. Gradually with street lighting poles becoming obsolete, public lighting will eventually transform and evolve into modular lighting structures with the capability of creating luminous volumes and design different experiences of night with varied dimensions. These user-friendly environments with volumetric lighting approach would be able to cater to community well being by developing anti stress environments, rhythms, light therapy, chromotherapy, dark therapy and encourage interactions and encounters. It will have the ability to transform its form and shape its surrounding illuminated environment to interact visually with the space and people to enhance, highlight and multiply its purpose and functionality. (Narboni R, 2020)

“In the long run, it is a real democratization of the public spaces’ lighting that can be offered to users so that they regain control over their nocturnal environment as well as the luminous ambiances they desire, and finally free themselves from the control of technicians and operators of the lighting sector who have always decided, studied and designed functionally the lighting of the world’s cities without real contradiction or citizen debate.” (Narboni R, 2020, p.13)

The research on using phosphorescent materials capable of being integrated into our landscapes by genetic modification of bioluminescent bacteria could revolutionize a new non-energy consuming urban lighting. Such futuristic light sources with untapped potential can help in creation of nocturnal landscapes, in nature or urban, completely complementing the biodiversity and develop a new irreversible trend of denaturation of cities. (Narboni R, 2020)



02 BACKGROUND

This chapter discusses the existing knowledge that helps derive the vision for this thesis proejct. It discusses the problems in existing lighting solutions and its effect on humans and biodiversity.

02 Background/Motivation

2.1 Development of streetlamp for Postbyen

The vision is to continue study and research from a project undertaken with fortheloveoflight, Copenhagen. This project led me to an investigation of landscape and the technical knowledge of illumination with flexibility and adjustability to harmonize with the growth and seasonal change in plants and trees through the year. However, from a more sustainable perspective, the negative biological effects of illuminating plants and trees are a bigger concern in landscape lighting today. Plants and trees require dark hours to complete their circadian clock, just as us humans. To balance the rhythm, urban cities needed to create adaptability to darker nights again and truly appreciate the night sky and the nature that surrounds them. With the discovery of a problem within the existing practices, I found there to be a need for a typology of illumination that does not harm the biodiversity, helps in creating darker nights and creates a user experience for people to engage with the nature that surrounds them. This chapter further discusses the existing practises of illumination of trees and its biological effect on them. Followed by the importance of having a darker night as a part of our culture and biodiversity to develop a design vision for this thesis project.

Figure 2.1 Posten Parklight prototype, Ankerstjerne.C, Fortheloveoflight, 2020

2.2 Effect of illumination on trees

The advancement and development of artificial lighting has transformed human civilization and lifestyle enormously, increasing the time available for both work and pleasure. Whilst it has functional benefits it has also impacted and altered the natural nighttime environment. Large areas on earth are exposed to differing illumination from natural regimes in timing, intensity and spectral distribution. Artificial illumination at night creates a significant anthropogenic pressure on natural biological systems as such systems are usually organized foremost by light and change of light on a daily and seasonal basis. One of the most observed impacts of artificial illumination of trees is delayed retention of leaves and attraction of birds and insects, which alter their natural biological cycle. (Sanders.D, 2020)

Photoperiodism is the physiological reaction of organisms to the length of night or a dark period. Different species of trees have varying responses to length of the day, some can be categorised as short day, long day or day-neutral. TIn response to shortening of day length in late summer, short day trees flower and enter dormancy. However, trees of the long day category flower during the early summer and continue their vegetative growth until fall. Day neutral trees do not respond to the length of the day at all. The photoperiod not only influences the shedding of leaves and blooming of flowers but can also influence various other factors such as the shape of the leaf, hairiness of the surface, formation of pigments, root development as well as onset and breaking of bud dormancy. Certain Illumination strategies on trees at night can alter their natural photoperiod and upset their growth and developmental processes. (Chaney. W, 2002) Illumination techniques especially from a source that emits in the red to infrared range of the spectrum, extends the day length and can affect the flowering

patterns and encourage continued growth preventing the trees from developing dormancy which is an essential process to survive the rigors of the winter season. Younger trees tend to be affected more as they grow longer than their natural cycle due to extended illumination exposing them to higher risk of cold injuries as compared to matured trees. (Chaney. W, 2002)

Continuous illumination of tree foliage can help it to grow bigger in size, although it also makes it more susceptible to air pollution and water stress as it exposes its stomatal pores for a longer duration during the growth season. Using illumination strategies of intensity adjustability during the day, modified spectral distribution according to the species sensitivity will cause less or minimal damage to the growth and development of trees. (Chaney. W, 2002)

2.3 Importance of a dark night

A tradition of many centuries, humans have used astronomy in their everyday lives. They related to constellations on their farming strategies and stars as a means of communication. The night sky is a sight to behold, with billions of stars being seen on a clear night sky, to the arc of nebulous light that rises across the sky which is the Milky way galaxy. Night is a part of our life cycle, documented in our history and engraved in our cultures. However, developments and advancement in human civilization in the last few centuries has given us the opportunity to enjoy the night but has also resulted in light pollution, having created a “ceaseless twilight”. Light pollution has not only diminished the view and experience of the night sky but also has an enormous impact on quality of life and energy consumption. (Serapion. J, 2018)

The end of the night a book by Paul Bogard discusses his search for natural darkness. He entails that darkness has been diminished from the night and how humans have not experienced what darkness truly is. And hence, sets on a mission to find the darkest places on earth by measuring through the Bortle scale of darkness that ranges between 1 to 9. An astronomer John E Bortle designed this scale in the year 2001 to determine and compare the darkness of the sky in an observing site. The lowest end of the scale at 1, represents darkness at its absolute extreme, completely undisturbed by artificial light and casts shadows from the illumination from the Milky Way galaxy. (Bogard, 2013)

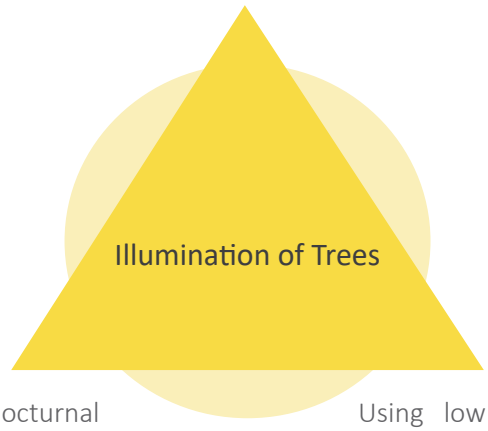
Figure 2.2 Borten Scale, Ref: Modified after “Conserving Dark Skies,” n.d., Bortle. J, 2001

Scale 1 is technically brighter than 2, due to natural light from the celestial sky. The highest end of the scale at level 9, indicates the inner parts of the city where it's impossible to see the stars due to enormous artificial light exposure.
"When being presented with the Bortle scale, we become aware of new levels of darkness. A darkness that is very rare and that many humans never felt or experienced'' (Bogard, 2013).

Absence of darkness and exposure to continuous illumination at night can disrupt the circadian and neuroendocrine physiology in both humans and wildlife. The 24-hour day/night cycle, known as the circadian clock, affects physiologic processes in almost all organisms. These processes include brain wave patterns, hormone production, cell regulation, and other biologic activities. Disruption of the circadian clock is linked to several medical disorders in humans, including depression, insomnia, cardiovascular disease, and cancer, says Paolo Sassone-Corsi, chairman of the Pharmacology Department at the University of California, Irvine, who has done extensive research on the circadian clock. *"Studies show that the circadian cycle controls from ten to fifteen percent of our genes," he explains. "So, the disruption of the circadian cycle can cause a lot of health problems."* (Chepesiuk.R, 2009)

2.4 Vision

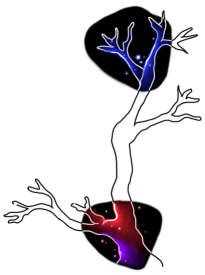
The vision of this research is to study and design illumination of our landscapes, trees in specific which may improve its growth and development and minimize the dramatic drastic effects of light pollution to help create a natural built environment for communities in urban public spaces. To fulfill this vision a triangulation circulation method has been adopted to help achieve three stated criteria.



Triangulation and Circulation Method
(three interdisciplinary fields that combine together to create an interdependent system)

This method further helped in derivation of the initial research question,

How can landscape lighting be designed to help trees **grow**, **avoid light pollution** and **harmonize with nature's-built environment**?



03 METHODOLOGY

This chapter illustrates the design process model that helps develop this thesis project. It is a model inspired from the design experiment model by Ellen K Hansen and Mette Hvass and Double Diamond model, a process model created by Design Council, a British organization, in 2005.

This thesis explores the conceptualisation of a new typology in landscape lighting through dynamic illumination of trees that supports its growth, minimizes light pollution and encourages the importance of darkness. The design process is constructed by declaring a vision supported by research on existing theories and case studies to derive a research question. The process continues with designing a concept built on inspiration and exploration to a proposal that is validated through a user experience test that informs the potential of the designed concept and evaluates it. This design process has been inspired by the transdisciplinary process model for designing lighting developed by Michael Mullins and Ellen Kathrine Hansen (Hansen & Mullins 2014) and from The Design Experiment model by (Hansen & Hvass 2019) and Double Diamond model, a process model created by Design Council, a British organization, in 2005. These models extract knowledge from different fields to combine and develop a design process. Figure 3.1 illustrates a modified version of a design process and thinking model inspired from the above.

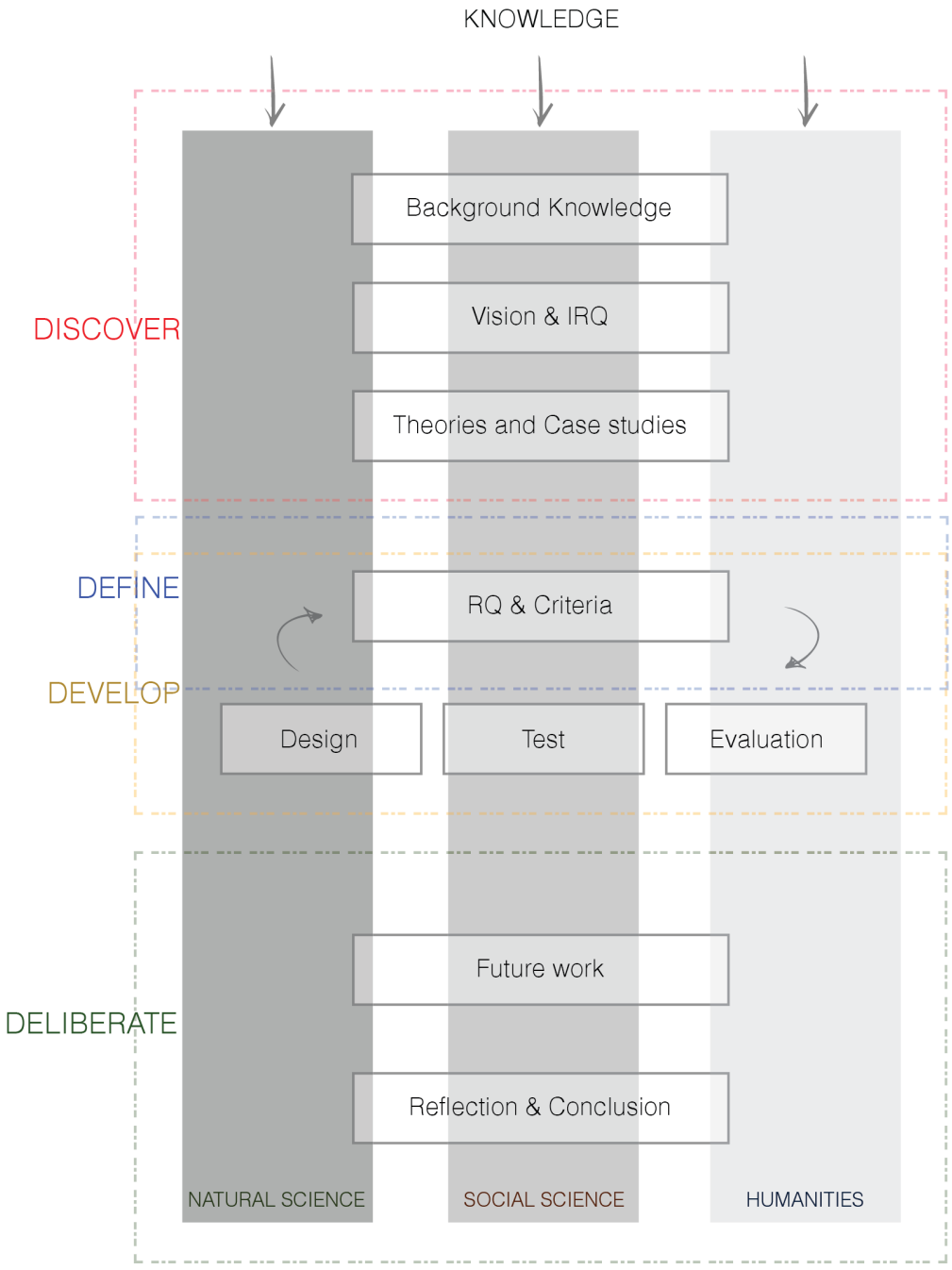


Figure 3.1 Modified Design Process Model, Tahlani.D, 2021

DISCOVER

This is the preliminary step of gathering the background knowledge and identifying a problem to discover the vision and form an initial research question. The vision defines the potential and problems and functions as a catalysator for the whole process. And the initial research question further helps in guiding the direction of the new knowledge to be researched in the transdisciplinary fields of natural science, social science and humanities through scientific theories and case studies.

DELIBERATE

This step is a consideration and reflection of the data and analysis achieved through design development. It discusses the possibilities of improvement and further in depth development and implementation in the near future. To finally conclude if the design criteria and research question were fulfilled.

DEFINE

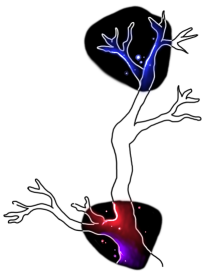
The new knowledge gained brings clarity and creates the definition of the research question. This step uses the triangulation and circulation method that combines the three fields to create an interdependent system that formulates the success criteria, which hereafter act as guidelines for the entire design process.

DEVELOP

An overlapping step in an iterative loop that uses the defined research question and criteria to conceptualise a design concept. Which is validated using a user experience test and evaluated with the criteria to define the design solution. This thesis report uses Virtual Reality as a medium to conduct the user experience test, through a comparative analysis using both qualitative and quantitative data to analyse user response.

LIMITATIONS

The experimental work of this thesis has been limited due to the Covid-19 pandemic. Consequently, it was not possible to conduct experiments physically and hence, this report uses Virtual Reality headset to evaluate user perception. The limitation of the physical experiment is not only due to covid 19 restrictions but also due to absence of time and scope of this project. To create conclusive data, if the specific proposed light spectrums for the illumination of trees are able to help in growth improvement cannot be scientifically proven as it would require extensive resources and a minimum observation period of two years. The access to the university was also restricted, making the light laboratory and lighting equipment inaccessible, which delayed the test. Additionally, Covid 19 pandemic also led to research being constricted to online resources only. An essential limitation to the test conducted for validation of the designed concept is the absence of a large user database. Due to current pandemic restrictions this thesis is only able to investigate a total number of 11 users, as the test has to be conducted physically. There are further aspects of the design concept that need to be researched on and developed in the future. The technical aspect of which source of illumination and its specs have not been discussed in this report and is considered to be a part of a discussion for the future hopeful of advancement in technologies.



04 CASE STUDIES

Based on the vision of this thesis research, this chapter discusses four case studies that inspire and share the vision of developing illumination techniques and concepts that are established in harmony with our natural environment. They are developed concepts and designs by eminent lighting artists and architects who have created a new vision of lighting in urban cities for the future. They share the principles of respecting biodiversity, reducing light pollution and creating a dark night again. Each of these case studies have been chosen and highlighted with the following attributes,

- Grow- use of different spectrum of illumination on plants to improve its growth.
- AIUIa- preservation of darkness through use of portable illumination
- BioLED - vision of using bioluminescence with emerging technologies to illuminate cities
- Glowing Plant- use of bioluminescence enzymes to create a new generation of glowing plants

04 Case Studies

4.1 Grow by Studio Roosegaarde

GROW is an installation project with a design-based light recipe which vertically illuminates across 20,000 m2 of farmland with leek (Allium porrum). The users experience the artwork in the form of 'dancing lights' across the huge agricultural field. The design of the installation makes the light poetic and makes it come alive. The project is inspired by photobiology light science technologies which have shown that certain recipes of blue(400-500 nm), red (600-700 nm), and ultraviolet light (100-400 nm) can enhance plant growth and reduce the use of pesticides by up to 50%. (Roosegaarde.D, 2021)

The project GROW shows how the beauty of light can help plants. It highlights the importance of farmers and the plants which are the basic ingredient for the food we consume. It is also a call for enlightenment during these dark times. The concept is based on principles of sustainability and delivers a message of hope to the people across the world. It adds a new meaning to the word 'Agri-culture' by reframing the landscape as a living cultural artwork.The project is implemented by installing the 20,000m2 agricultural field with four systems of programmed lights of the specific spectrums powered on solar batteries for exhibitions worldwide. It is a set up of precision lighting, projected horizontally in a controlled area, which can act as an extension of sunlight for a short period of time and can only be seen from nearby to avoid light pollution. This way the project GROW is able to achieve a harmonious balance with the environment. (Roosegaarde.D, 2021)

This project inspires the research and design towards segregation of the colours of the spectrum and creates a dynamic experience for the users. It also provides validation of using such light recipes for improvement in growth and providing a better solution for illumination plants and vegetation.

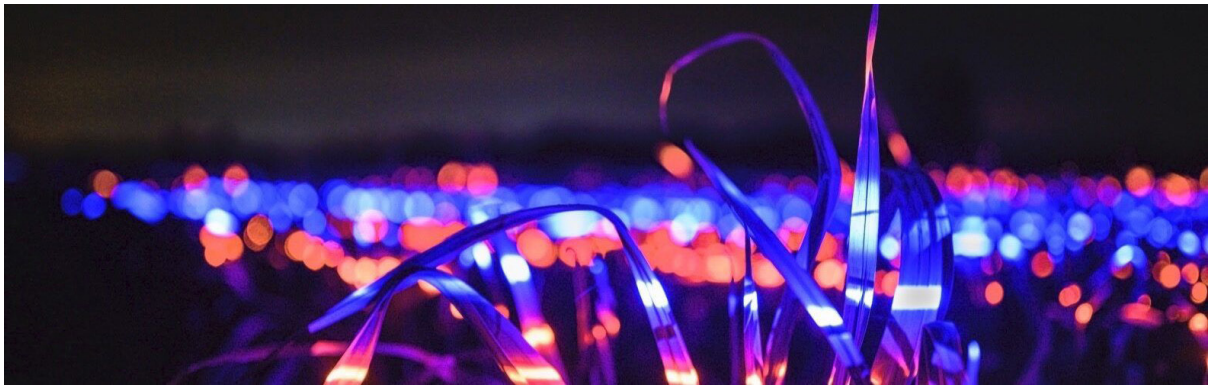


Figure 4.1 Grow spectrum, Studio Roosegaarde, 2021

Figure 4.2 Grow Overall view, Studio Roosegaarde, 2021

4.2 AlUla, a light strategy to preserve darkness by Concepto

This is a project designed by Concepto, a lighting design studio in Paris. It was a concept submitted for a competition. The focus of the project is a starry sky and its preservation, a major issue for the masterplan to be designed for this upcoming tourist site in Saudi Arabia, both in terms of protecting biodiversity and celebrating the sky. In order to still be able to develop a specific, poetic and attractive night experience, the proposed lighting strategy aims to illuminate and enhance the landscape without distorting the landscape, by involving innovative processes, a reflection on temporalities, to promote the beauty of natural darkness. By including portable lighting solutions that create a perceptive unique experience for each visitor and using illumination that blends into the natural night light creating an enchanting atmosphere. (Concepto,2020)

This project acts as an inspiration for the goals of this research and design study. Sharing common values of protecting biodiversity and celebrating the night sky. Concepto, very beautifully creates a unique and customized experience for each user by providing them with portable illumination. This strategy along with using bioluminescence inspired lighting in the water body in the landscape creates a very natural experience, which not only protects the biodiversity at night but also creates room for people to explore the darkness of the night and view a starry night.

Figure 4.3 AlUla, Lantern dessert, Gaia.L, Concepto, 2020

Figure 4.4 AlUla, Lantern structure, Gaia.L, Concepto, 2020

4.3 Future of lighting using bioluminescence in urban landscapes

This project discusses the use of BioLEDs in the near future as a replacement of the current lighting strategy in urban nightscapes. LEDs are gradually and systematically replacing lighting's legacy sources, and by 2030 they will be installed everywhere. But there are also other important areas of research such as optoelectronic and bionic discovery of new and even more powerful illumination sources, as in the case of BioLEDs, which is the product of hybridizing LED technology and genetically modified bioluminescent bacteria, with energy efficiency. It is hoped that this technology can achieve 400 lumens per watt and will make way for a revolution in non-energy-consuming urban lighting that will adapt automatically, in real time, to new uses of urban space (analyzing the ambient light and urban form, flows and density of users, lighting needs, temporary conditions) and will operate for city dwellers on demand.(Narboni R, 2020)

"These futuristic sources, whose characteristics and potential are still undefined today, will lead to the creation of new nocturnal landscapes, both natural and urban, that are totally synchronized with and exist in symbiosis with the environment." (Narboni R, 2020)

This project inspires the design and research to re-invent the outlook of urban street lighting and create a design intention for the future. To transform the design strategy towards a nocturnal landscape that helps communities become closer to nature and appreciate the biodiversity that surrounds them and create an experience that is in harmony with preserving the natural environment.

Figure 4.5 Lighting Master Plan for Banks of the Huangpu River, Shanghai, Concepto, 2017

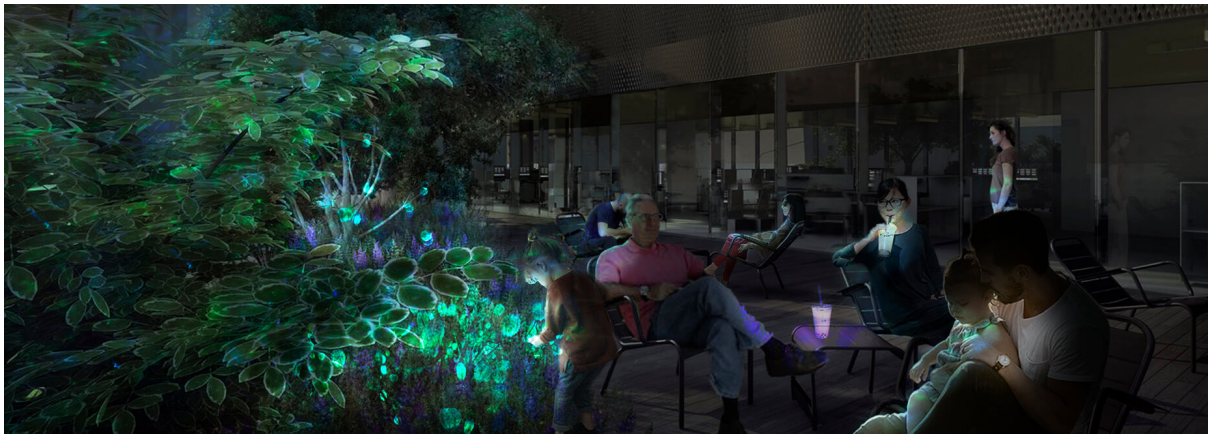


Figure 4.6 Bioluminescence Exhibition, Concepto, Infography Noémie RIOU, 2020

4.4 Glowing Plant

This project is an ongoing research by Studio Roosegaarde and a laboratory at Stony Brook University who have successfully been able to develop a glowing plant by merging a chemical that allows fireflies to glow commonly known as luciferin with an ordinary plant. Resulting in a naturally glowing plant. This research has been conducted on Dan Roosegaarde's concept of "merging worlds of nature and technology" which is to learn from nature and incorporate into our urban built environment, in this case illumination of landscapes. (Dezeen,2014)

It is a marriage alliance between the super and sans natural environment which will evolve the perception of technology to not be limited to screens for gain of information and utility. Today urban illumination in the United States of America accounts for more than 1/5th of commercial energy consumption. To reduce the consumption of energy and use a technology that powers itself autonomously, a concept that is energy neutral and creates a dynamic poetic landscape. (Dezeen,2014)

Figure 4.7 Images above and below are visualisation of Bioglow plants, Studio Roosegaarde, 2014

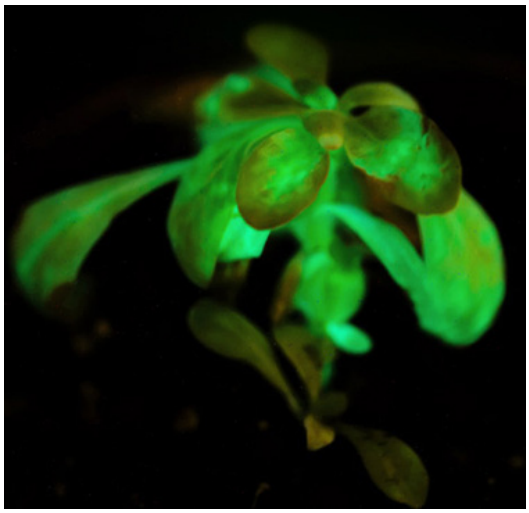
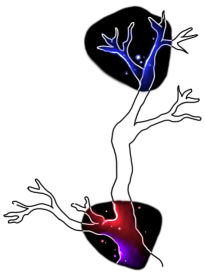


Figure 4.8 Genetically modified glow in the dark plant, Studio Roosegaarde, 2014

4.5 Summary

These case studies help in establishing lighting strategies that benefit biodiversity, preserve the darkness of the night, and introduce futuristic lighting developments that can illuminate trees and plants in urban landscapes. The project Grow by Studio Roosegaarde creates a fine balance between illuminating plants to help them grow and creating a dynamic experience to celebrate the hard work of the farmers that grow the food we eat. It uses specific light spectrums to illuminate the crops that have proven to improve growth, which provides a direction to research theories to develop the design vision. AlUla, a project by Concepto establishes the importance of darkness and implementation of lighting strategies that creates a unique experience for each visitor with respect to the biodiversity that surrounds the site. Followed with two case studies of ongoing research about futuristic lighting strategies that can be developed to illuminate our cities through biodiversity using BioLEDs and artificially induce bioluminescence enzymes to make plants and trees glow.



05 THEORIES

The following chapter discusses the theories that will help define the criteria and concept guidelines for this thesis project. They have been broadly classified into three categories, Illumination for Biodiversity - Trees, Impacts of illuminating the environment at night and Urban Nightscapes. Each of these classifications have further been discussed in subcategories followed by a summary of the knowledge acquired.

05 Theories

5.1 Illumination for Biodiversity - Trees

5.1.1 Introduction

Trees play an essential role in landscaping as they help in zoning of areas and creating space within a space. The species of the trees is chosen based on the climate and region they are grown in, and its seasonal transformations. The shape and size of its trunk and crown vary with every species, growth stage and season. In practice, illumination of trees has been a more ornamental and highlighting contributor. It has been commonly observed that trees are illuminated by up lighting to emphasize the grandeur of its structure and ease of installation. This chapter discusses various factors to be considered to illuminate trees as a sustainable practise.

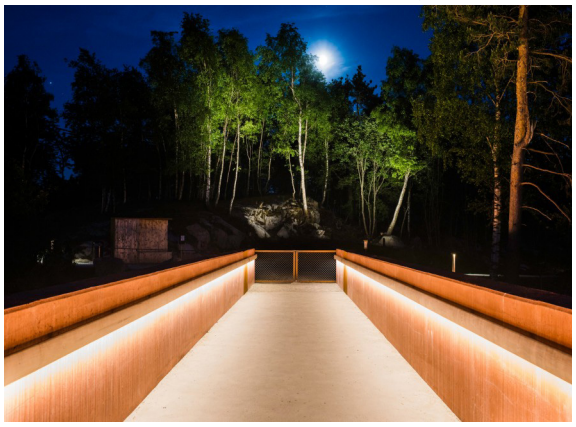


Figure 5.1 Light-Bureau-JØRPELAND, Norway, 2018

Figure 5.2 Lighting Design Collective, OAKS Development, Prague, 2019

5.1.2 Spectrum of light ideal for growth of plants and trees

Light plays a key role in plants and trees to conduct the process of photosynthesis and photomorphogenesis. Photosynthesis is a process by which plants convert the light they receive from the sun into chemical energy and in response to the light they receive, plants have the ability to modify its growth which is known as photomorphogenesis. The spectral range of light that plants predominantly use to conduct photosynthesis ranges between 400-700 nm. This range is termed as Photosynthetically Active Radiation (PAR). Plants use red and blue light most efficiently to allow the chlorophyll to absorb the maximum amount of light to carry out the process of photosynthesis and allow the plants to grow. Other colours in the spectrum such as greens, yellows and oranges are relatively less useful for photosynthesis, as chlorophyll a is absorbed largely from both red and blue light and chlorophyll b is absorbed mostly from blue light. Blue light essentially helps in early vegetative growth stages of the plants, as it helps the plants produce healthy stems, increase in density and establish its roots. The growth is further enhanced with increased red light absorption, resulting in longer stems, increased foliage of leaf and fruit/flowering therefore, playing a dominating role in plant maturity and size. (Ouzounis.T, 2015), (Naznin.M,2019)

Red Light Spectrum (600–700 nm)

Red colour as a part of the light spectral range is considered to be the most effective spectrum of light to enhance photosynthesis as it is largely absorbed by chlorophyll pigments, as it is at the highest peak among other spectrums. At a wavelength of around 660nm red light enhances leaf, stem and general vegetative growth, and is particularly responsible for stretching of leaves and flowers. Red light when paired with blue is an essential balance required to avoid disfiguration and overstretching of stems. Even though red light is essentially the most responsive spectrum for plants, its efficiency enhances when balanced in combination with other spectrums from the PAR wavelengths. (Ouzounis.T, 2015), (Naznin.M,2019)

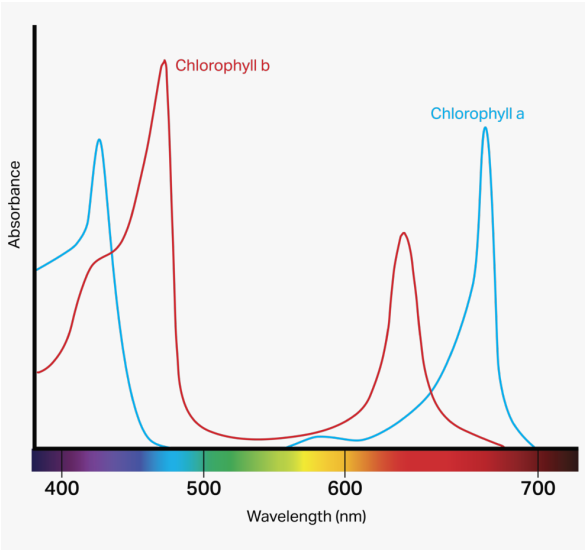


Figure 5.3 BIOS, 2020, Chlorophyll Absorbtion

UV Light Spectrum (100–400 nm)

UV light which is technically outside the PAR range is between 100-400nm, and is not visible to the human eye. Ultraviolet comprises 10% of the light we receive from the sun, and similar to humans plants and trees can be harmed through overexposure of UV light. It can be categorized into three types, UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (100-280 nm). The advantages of exposure to UV is an ongoing research in the horticulture industry, the purple colour of the light in balanced small quantities can be beneficial to plants by providing them nutritional value, enhancement of colour, taste and aroma. Studies have shown that with the use of controlled amounts of UV factors such as environmental stress, pests and fungus can be reduced significantly in plants and trees. (Ouzounis.T, 2015), (Naznin.M,2019)

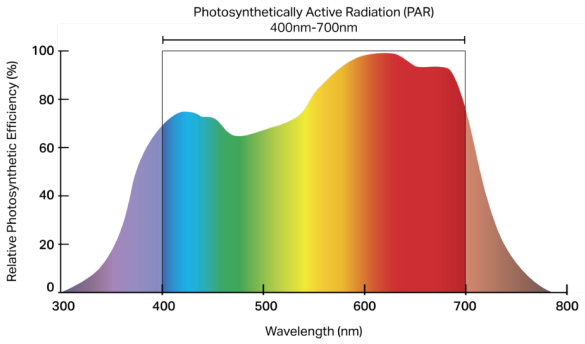


Figure 5.4 BIOS, 2020, Photosynthetically Active Radiation,

Blue Light Spectrum (400–500 nm)

Blue light as a component of the PAR range between 400-500nm is essentially responsible for enhancing quality especially in leafy crops, by encouraging stomatal openings which allow greater absorption of CO2 in the leaves. Blue light drives peak chlorophyll pigment absorption which is required for photosynthesis. It is proven to be advantageous for seedlings and plants and trees at a young vegetative growth stage as they establish a healthy root and stem structure which can be essential when stem stretching has to be balanced. (Ouzounis.T, 2015), (Naznin.M,2019)

5.1.3 Directionality of illumination on trees and their effects

This research discusses the existing directionality of illumination on trees and its adverse effects, whilst also providing suggestive theories of the suitable direction which can be a more sustainable approach. It has been observed that uplighting trees has been the most common directionality used in practice. Uplight illumination of the tree crown particularly brings out the beauty of the outermost blossom in the springtime. In the summer, the dense foliage makes the crown appear as a solid mass. Coloured leaves are characteristic of autumn. In the winter, the lighting effect is reduced to the filigree branch work. However, it is essential for fixtures to be shielded so that the light is directed more towards the ground and does not create direct illumination on trees to reduce light pollution and potentially harm the trees biologically. Uplighting and illuminating over great horizontal distances should be avoided. Dimming of lights during off peak hours to avoid continuous illumination of trees, as it has the greatest potential for upsetting its normal growth patterns (Liscum. E, 2014). An example of a project studied and designed as an intern under the company fortheloveoflight in Copenhagen. (Urban Glowscapes, Chapter 1.1) A play of angles and narrow beam of light adjusting with the seasonal changes was the ideology of this project. The seasonal change also accounts for intensity manipulation and probably a directional adjustability depending on the different species.

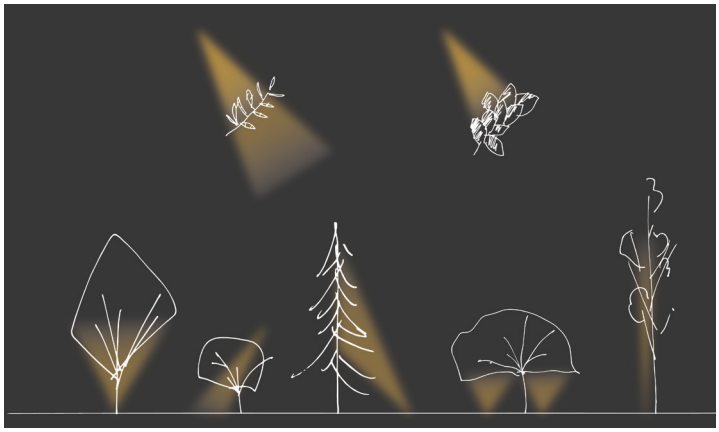


Figure 5.5 Light Adaptation to different species, Ankerstjerne.C, Fortheloveoflight, 2020

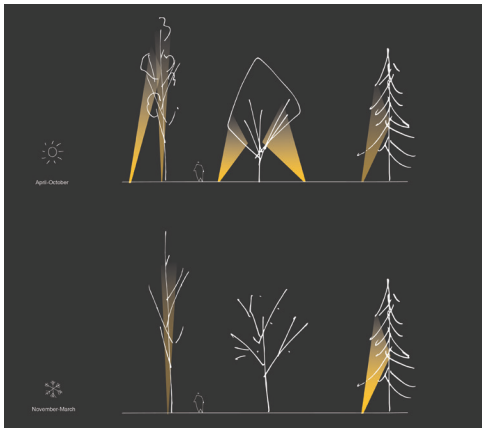


Figure 5.6 Light Adaptation based on Annual Cycle,Ankerstjerne.C,Fortheloveoflight, 2020

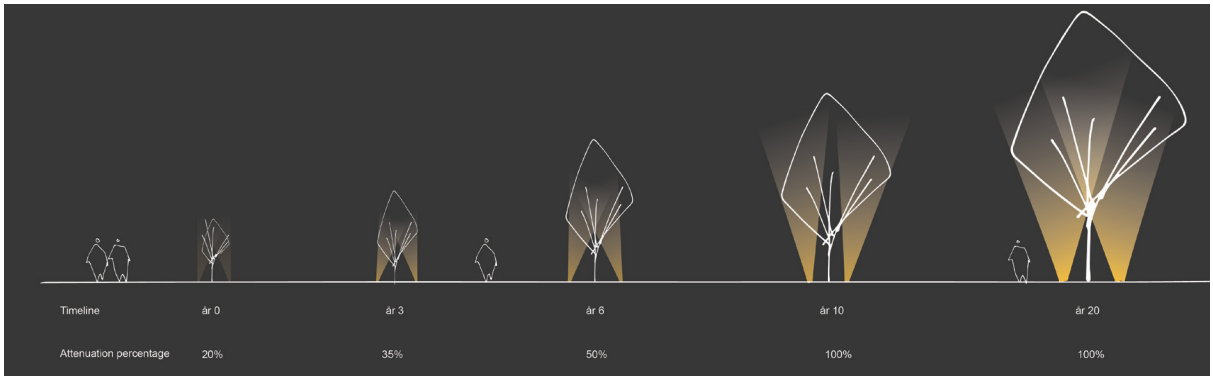


Figure 5.6 Light Adaptation based on Growth, Ankerstjerne.C, Fortheloveoflight, 2020

To further understand and evaluate the ideal direction to be used for illumination of trees it is essential to understand their behavior and patterns towards light.

"Phototropism, or the differential cell elongation exhibited by a plant organ in response to directional blue light, provides the plant with a means to optimize photosynthetic light capture in the aerial portion and water and nutrient acquisition in the roots." (Liscum. E, 2014)

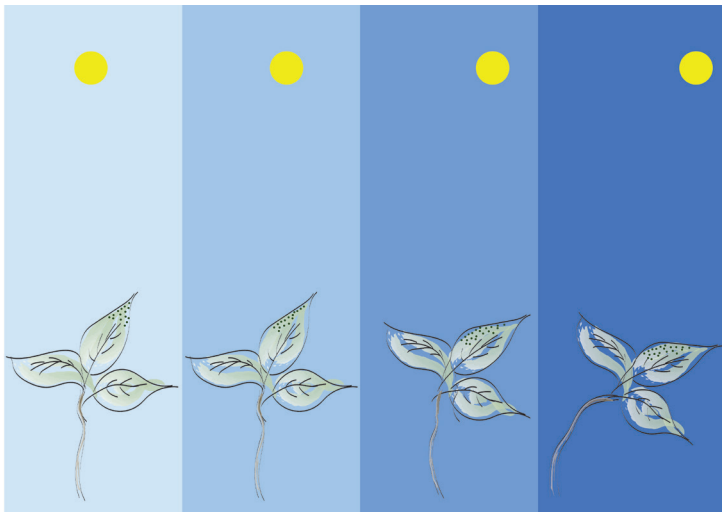


Figure 5.7 Tahlani.D, 2021, Phototropism (self produced)

This implies that the direction of light acts as a signal pathway for photosynthesis. It is essential for the source to downlight the plant to be able to accelerate growth.

Up lighting from below can shock the plant and change its growth directionality. One of the most phototropic plants are sunflowers as they not only respond to growth stimulation with light but also movement stimulus by rotating with the movement of the sun. (Liscum. E, 2014)

5.1.4 Distribution of light to avoid light spill and pollution

Light trespass is a common phenomenon in the city and describes lighting trespassing inside the illuminated objects or parcels of real estate. It involves the “leak” of intrusive artificial light beyond the property or area that is illuminated. Before designing external illumination, careful analysis of the environment is required so as not to cause residents sleepless nights. To minimize this negative effect, it is mandatory to control light by appropriate selection of light optics, the correct location of luminaires and analysis of the overall level of illumination. (Zielinska.K , 2014)

One of the very essential factors in determining the distribution of light is to study the landscape, identify the different species that grow in the region/site. And create illumination flexibility and adjustability accordingly. This study was conducted with fortheloveoflight during an internship, to understand the role of growth and seasonal change in light distribution and adjusting intensity in order to avoid light trespass and further light pollution.

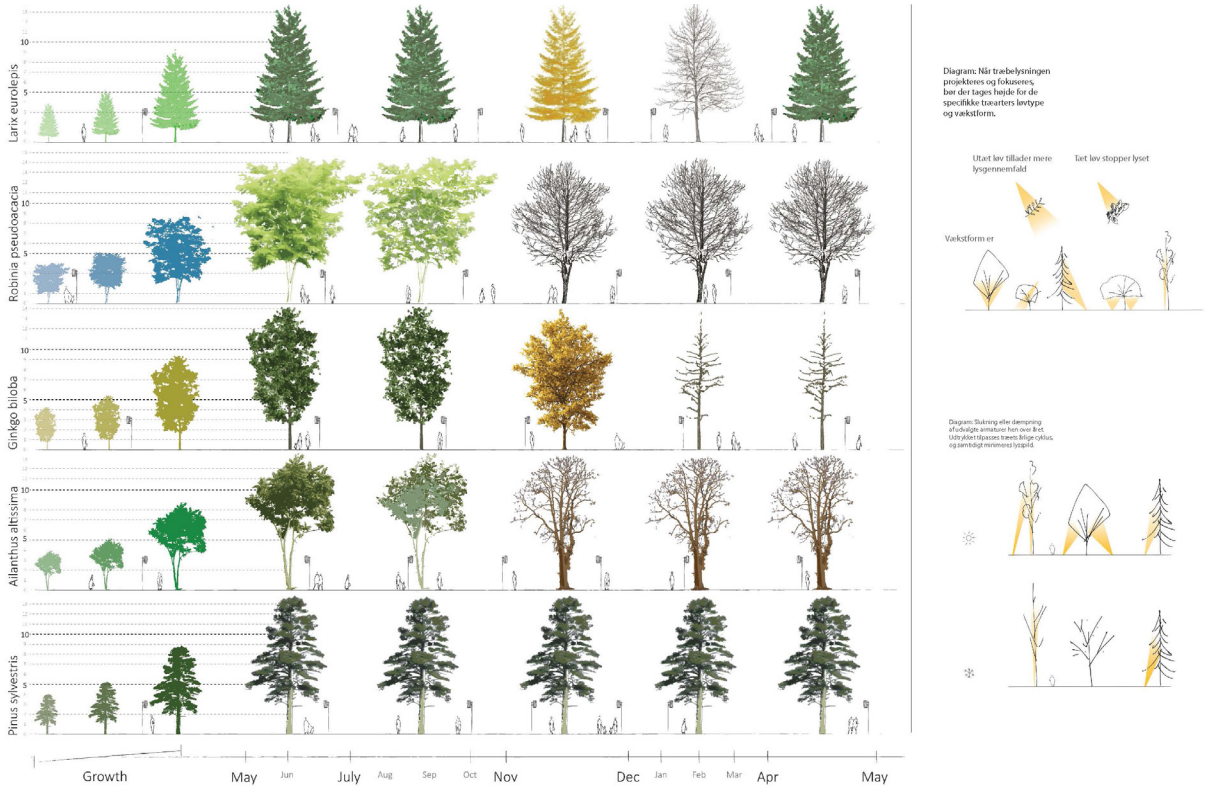


Figure 5.7 Fortheloveoflight, 2020, Light distribution based on seasonal and growth eveolution of trees.

5.2 Impacts of illuminating the environment at night

5.2.1 Introduction

The environment affects the complete set of physiological and psychological reactions of the living organisms. Pollution of the basic and essential components of the environment, i.e., soil, water and air threaten our everyday life. Human urban civilizations with increasing demand for intensive illumination at night disturbs the environment and influences the circadian rhythm of all living organisms. Worldwide artificial lighting has been rapidly increasing at the rate of 2.2 % per year (Kyba et al., 2017). The International Dark-Sky Association (IDA) defines light pollution as: *“any undesirable impact of artificial lighting causing excessive sky brightness, radiance, infiltration of excessive light into houses, reduced*

visibility on roads and wasteful energy consumption" (IDA, 2013). When light is directed towards the sky, it reflects from the atmospheric particles such as dust and water vapor and spreads far beyond the source of origin. Resulting in a visibly brighter sky at night even at great distances from its source, commonly observed in densely populated urban areas. Natural darkness is essential for all living organisms that are active during the day and to ensure the correct course of their circadian rhythm. The lack of darkness disrupts their natural life cycle which has been developed and evolved over a million years.

Plant growth and development is critically influenced by the light spectral quality, quantity and duration. The plant photoreceptors, i.e., phytochromes, cryptochromes, phototropins and FkF1 photoreceptor – mediate physiological and developmental responses in plants (Briggs, 2006). The phytochrome is blue-green plant pigment which regulates plant development, seed germination, flowering and leaf expansion. The phytochrome system allows plants to grow towards light. Sometimes photoreceptors act independently, sometimes redundantly, sometimes cooperatively, sometimes antagonistically, sometimes at the same stage of development, and sometimes at different stages of development. Moreover, some of these responses are incredibly sensitive (Briggs, 2006).

"Some plants and tree species also react to strong light sources and to changes in the day/night length. Approximately 80% of flowering plants are sensitive to photo-periodism" (Samach and Gover, 2001; Searle and Coupland, 2004). Naturally, their blossom, budburst and leaf fall occur in appropriate seasons. Within less than 10 minutes after changing the radiation intensity, the plant reacts by altering its transpiration (Klimešová and Středa, 2016). The change in photoperiod can influence flowering response, as well as their entrance into bud dormancy, or their initiation of leaf senescence. Artificial light in the night-time environment is sufficiently bright to induce a physiological response in plants, affecting their phenology, growth form and resource allocation (Briggs, 2006; Bennie et al., 2016). (ŠKVARENINOVÁ. J, 2017)

5.2.2 Circadian Rhythm in Plants

A single rotation of earth on its axis takes 24 hours, creating a result that in either of its positions the earth's surface alternatively faces toward or away from the sun – day and night. The physiology, behavior and metabolism of most organisms experience profound changes between day and night. Most of these organisms have the innate ability to measure time, they not only respond to the movement of the sun but, rather, anticipate and calculate its movement to adjust their biology accordingly. (McClung.C, 2006)

The circadian clock of plants is an internal timekeeper that anticipates environmental cues such as light, temperature and regulates photoperiodic rhythmicity essential for its growth. Term "circadian" was coined by Franz Halberg in the late 1950s and consists of two Latin words i.e., circa, meaning "around", and diem or dies, meaning "day". The circadian rhythm in plants enables signals for flowering to facilitate pollination, leaf movement, germination, stomatal gas exchange, growth, enzyme activity, fragrance emission and photosynthetic activity. A well-functioning circadian clock is a critical aspect during the beginning of flowering and the general viability of the plants. Studies have shown that plants with impaired circadian clocks have dramatic shifts in flowering time, either they bloom too early or too late and have low viability phenotypes under certain photoperiods. Moreover, research and experiments have demonstrated that plants with clocks that are in sync with the environmental light and dark changes have increased chlorophyll contents and an enhanced photosynthetic capacity, leading to accumulation of higher biomass and resulting in a better survival of plants. It has also been observed that ideal circadian rhythms result in an optimized rate of starch degradation at night which ensures optimal carbon utilization and continued growth during dark hours. Circadian rhythm being the internal molecular timekeeper in plants measures periodic changes in the environment including daily as well as seasonal changes or fluctuations and adjusts their biology accordingly. (Srivastava.D, 2019)

"The diversity of circadian photoreceptors in plants demonstrates the potential importance of perceiving a wide wavelength range in order to run the daily timekeepers." (Srivastava.D, 2019)

5.2.3 Impact of Artificial light on plants

Plants have the capability of perceiving and processing data and information it receives from its abiotic and biotic surroundings for its optimal growth and development. Light acts as one of the most essential environmental cues that help in the development of plants and regulate its behavior. Research has shown dark and light cycles imitating natural cycles gave the best result compared to continuous light in development of seedling growth. Plants' response to light entail sensing of its quantity (fluence rate), quality (wavelength), direction and duration through photoreceptors. (Ouzounis.T, 2015)

Plants use light as a cue for seasonal changes and changes in the time of the day, adjusting their biological clocks accordingly. The circadian rhythm in plants regulates the timing of its output responses. The length of the day affects the growth of the plant drastically but also its intensity and spectral distribution plays an essential role in its growth patterns. Artificial light can shift or delay seasonal events causing growth abnormalities or even cause trees to bloom early. (Singhal, Kumar, & Bose, 2019; Bennie et al., 2016)

Plants respond to artificial light depending on their species. Some species tend to be sensitive to any amount of illumination at night and some show sensitivity towards intensity of direct illumination at night. Besides the direct effects on plants, artificial light at night also indirectly affects plants and has a significantly complex influence on the interaction between plants and animals. When plants are exposed to artificial light at night, the timing for the flower opening for nocturnal pollinators can be shifted, resulting in less nocturnal pollinators, which have detrimental consequences for plant reproductive success (Inoue et al., 2018; Knop et al., 2017; Bennie et al., 2016).

However, there is a massive lack of evidential research on how artificial light affects plants, which leads us to believe that maintaining the natural circadian rhythm is proven to be the most effective way of ensuring healthy plant growth and development.

5.3 Urban Nightscapes

5.3.1 Light Urbanism

The idea of "light urbanism" was introduced in France during the late 1980's, commonly now referred to as Lighting Master Plans which supposedly at that time meant to prioritize and differentiate the systems and types of lighting according to the infrastructure of the city that includes, roads to fulfil the separation between automobile and pedestrian pathways. (Narboni.R, 2016)

The focus of lighting plans then was to create dramatic distinction regarding technical visibility in the city at night, which was partial and biased. It essentially focused on functional lighting such as illuminating architectural heritage of importance, urban lighting of pathways and public spaces and luminous ambiances for pedestrians. (Narboni.R, 2016)

However, light urbanism today enables one to think about the creation of night silhouettes and urban nightscapes, gradually creating spaces with distinctive identity, hierarchy, characteristics and luminous ambiances. The focus of lighting master plans has changed over the years, the current strategy involves focusing on city wide scale and placing luminous hierarchy onto the city center instead of taking the concept of neighborhood, leading to neglected suburbs. For an increasing number of residents in the cities, the dramatization of a city at night, enhancement of architectural heritage often come at the expense of luminous atmospheres considered important in their daily perception and therefore their

own assessment of the quality of life in their neighborhoods. (Narboni.R, 2016)

5.3.2 The 24th City

The 24TH city is referred to as a phenomenon that designs and shapes urban nightscape experiences. An increasing percentage of social and economic life takes place at dark hours. Current trends on development of the 24th city has led to blurring the human perception of day and night. Recent studies have shown great importance of different and distinctive shades of night. Identification of everchanging luminous environments from dusk to dawn will help us shift away from seeing light as a functional requirement. This can create a new typology of nighttime illumination that is more meaningful and relevant for the communities and city inhabitants. Such practices include bus shelter lighting that creates the possibility to improve the health and well being of its users, interactive lighting installations that initiate community and social interactions, functional yet adjustable streetlights that can create different levels of illumination according to the time of the day. (Schwendinger, 2015)

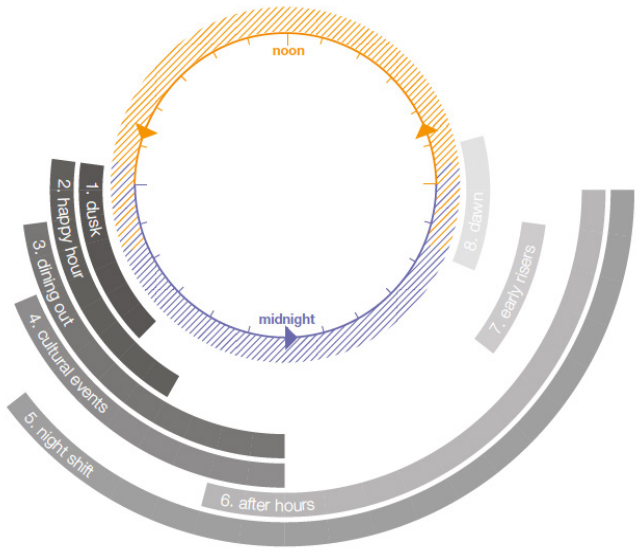


Figure 5.7 Arup, 2015, Cities Alive, 8 shades of night.

The holistic approach that can be taken to create a 24th city true to its meaning that designs a nighttime experience for people in coordination with the natural rhythms of the environment and the dynamic needs and requirements of the public. Traditionally cities have been designed to recreate the daytime experience, the nighttime is much of an afterthought to how our cities have been designed. This daytime bias can be linked to our work culture in historic times which was limited to the presence of daylight. However, with the invention of electricity and lighting, and with the use of our current fast developing technologies a new wave of innovation has the potential to transform human experience and utility of the dark hours. (Schwendinger, 2015)

Shades of Night – Public Space during the Darkened Hours is a framework that identifies activity shades, or zones, within districts of a city. It helps match future illumination according to changing street life and commercial and institutional opening/closing hours.

1. Dusk: As the sun sets, depending on season, either the workday extends into the night, or daylight extends into the post work hours
2. Happy hour: the social extension of the workday, decompression time
3. Dining out: the date, the business meeting, the special event, window shopping, strolling, meeting friends
4. Cultural events: going to the movies, theater, the ballet, concert or opera
5. Night shift: factory workers, cleaning crews, around-the-clock services, such as transit, and emergency repairs and services begin
6. After hours: nightclubbing and after-hours clubs
7. Early risers: the first shift arrives, outdoor markets set up, newspapers arrive
8. Dawn: the commuters begin to arrive, school starts
(Schwendinger, 2015)

5.3.3 Perception of safety for urban nightscapes

The “broken window theory” by Wilson and Kelling illustrates the importance of creating a balanced urban environment for combating anti-social behavior amongst the inhabitants of a city. They enhance a connection between physical conditions and crime in a neighbourhood. The more physical vandalism and disrepair is seen in a neighbourhood, the more likely it is for its inhabitants and communities to perceive a feeling of lack of safety and make them care even less about their surroundings. Researchers at Eindhoven University have found that interactive lighting in public spaces can help in de-escalating aggression and anti-social behaviour. Varying light intensities, distribution, colour temperature, and dynamism can initiate social interactions and influence people’s perception of safety. Studies have shown that such lighting scenarios can encourage positive behavior amongst inhabitants for instance by lowering of arousal levels, shifting and broadening attention or triggering a positive mood amongst its users. This can help in reversing the broken window effect and nudge and direct people towards desired social responses and behaviours. (Schwendinger, 2015)

Studies in home offices in the UK on interrelation and connection between improved street lighting and crime levels have been documented to a decrease in crime by an average of 20% across experimented areas. This reduced percentage was observed during day and night, with improved lighting supporting social control and community interactions instead of increased surveillance through higher illumination. However, the perception of safety amongst people can differ from the actual risks in an environment. Commonly observed, illuminated spaces are safer than dark spaces with no illumination; however, if the higher level of illumination further increases safety is unclear and not a proven theory. Factually, over illumination of spaces can lead to reduction in adaptivity of the eyes to darkness and see the visible danger, especially in areas with high contrasting levels of illumination across adjacent spaces could increase the risk of crime. Enhanced illumination should be used as means to attract more people, increase social activity and hereby create safety through physical presence. (Schwendinger, 2015)

5.3.4 Nocturnal Urbanism

Nocturnal Urbanism can be referred to as a systematic interdisciplinary approach to urban planning that takes 24 hours of the day into account while illuminating cities. Illumination of cities will transform in the future as a new discipline devoted to dark hours, of which methods, approaches and research is yet to be determined. *“The city of tomorrow could just as well be initially thought in terms of urban night instead of sole daytime occupation. Diverse sectors, the city’s layers, would then be differently imagined according to the predominance of the periods of nighttime uses“* (Narboni R, 2016).

The materials we use to create our cities such as the floors and facades will evolve to provide new opportunities and typology to build volumes and luminous architectures that will illuminate its immediate surroundings, offering an entirely new perception to public spaces at night, moving away from traditional practices of using street light poles. (Narboni R, 2020)

“It is the whole physiognomy of cities and streets that we have always known that would be completely and definitely changed” (Narboni R, 2016)

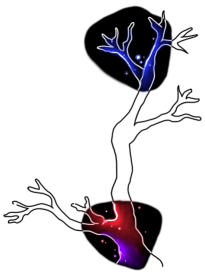
In the early 2010’s, new lighting strategies were studied, and research developed to initiate dark infrastructures to reduce consumption of energy, minimize light pollution, and preserve biodiversity at night. This dark based approach theorized the role of public lighting and importance of darkness in urban nightscapes in response to the needs and demands of its inhabitants who expressed their observation of over illumination of their cities and desire to preserve darkness in natural spaces. *“When darkness is no longer systematically synonymous of irrational fears or feelings of insecurity, new urban*

scenarios could be imagined in response to energy crises, the global will to fight climate change and reduce air pollution, in order to experience a rediscovery of the night in the city and the invention of new ways of illuminating that respect the darkness." (Narboni R, 2020, p.16). The gradual and ongoing development of implementing dark infrastructure and abandonment of systematic and continuous public illumination can pave a path for night therapies and create human adaptability and pleasure of being in natural darkness and shades of night. Urban nighttime represents 50% of a city life, with transformation in lighting public spaces can revolutionize the lifestyle of urban dwellers in the not-so-distant future. (Narboni R, 2020)

5.4 Summary

This chapter discusses and reviews how artificial light with specified qualities in terms of spectral light distribution, directionality of illumination and intensity can affect plants and trees. It directs towards an approach that with certain considerations illumination techniques can be developed for trees with minimal impact on its biological health and the environment. To conclude the obvious from the stated research; artificial illumination with any technique or strategy affects all living organisms at night by disturbing their natural circadian rhythm and creating disruptive consequences for the ecosystem. Trees, in particular face alteration of their circadian cycle and timing of their photoperiod response which can lead to overgrowth, and worse in time kill the plant. From these theories it can be definitely concluded that all living organisms would benefit the most if they were not exposed to any artificial illumination at night. However, the reality of human civilization today is of night urbanism, and using illumination at night to extend the activities of the daytime hours. It is impossible to reverse this progression of life and go back to primitive ways. Although, we can take measures to ensure that our environment is illuminated with minimal intensity and reduce the adverse effects it creates on our biodiversity.

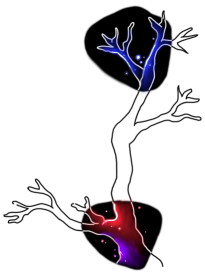
The research indicates theories of using separate spectral colours from the PAR wavelength in specific quantities to promote growth of trees, use of low intensity illumination to avoid light trespass into the atmosphere, directionality of illumination that can avoid both pollution and complement the biological clock of the trees. And most importantly it also suggests to make illumination in direct correlation to the time of the stay, seasonal changes and activities that city inhabitants conduct during the day in order to avoid over illumination, waste of energy and light pollution. These theories also create a certain sense of awareness towards appreciating darkness of the night, with suggestive theories of *"light urbanism"* that encourages use of luminous atmospheres in urban cities to create a sense of identity and community in different neighbourhoods. With the theory of Nocturnal Urbanism, Roger Narboni promotes creating dark infrastructures in cities to rediscover night in urban cities and pave a path for night therapies and create human adaptability and pleasure of being in natural darkness and shades of night.



06 RESEARCH QUESTION & HYPOTHESIS

How can illumination of trees be designed to be **biologically beneficial**, **reduce light pollution** as well as contribute to creating **natural night light**?

Success Criterias	Analysis from Theories
● Biologically Beneficial Illuminating trees with specific colour temperatures from the light spectrum can be used as a strategy to evolve urban lighting to be biologically and aesthetically efficient.	Lighting for Biodiversity - Trees ● *Meeting the needs of light required by trees to conduct photosynthesis and help in improving growth*
● Reduce Light Pollution If illuminating systems for urban public spaces are programmed to be adjusted in intensity as per the time of the day, seasonal and growth evolutions in trees, it can help minimize light pollution.	Impacts of illuminating the environment at night ● *Changing directionality and providing flexibility in illumination intensity can reduce light trespass.*
● Natural Night Light Majority of urban inhabitants prefer volumetric lighting of public parks and are able to adapt to low levels of illumination.	Urban Nightscapes ● *Respecting the darkness, designing with low illumination levels can contribute to viewing a natural night sky and light.*



07 DESIGN CONCEPT

The following chapter discusses constructed design criterias developed using the design process model and correlates it to the research theories discussed in chapter 5 as illustrated in the previous chapter. It further guides the reader into the development of the design concept through inspiration, ideation, design experience using a persona study followed by design intentions of the proposed concept.

07 Design Concept

7.1 Concept Guidelines

The aspect captured in the set design criterias of Biological beneficial, Reduce light pollution, Natural Night light form the guidelines for development of the concept. These criterias are essential to fulfill the project research question based on the scientific theories stated in the discovery phase of this thesis (illumination for biodiversity- trees, impacts of illuminating the environment at night and Urban Nightscapes). The methodology of derivation of criteria has been shown in figxxx.

The success criteria and concept iterations and development will be supported by knowledge obtained from scientific papers and theories as stated in chapters 2 and 5 and case studies based on these criterias as discussed in chapter 4.

The following proceedings will help us define the guidelines for the design concept and help evaluate the fulfillment of the success criterias declared. These guidelines are an interconnective loop between the Define and Development phase of our design process methodology model as shown in figurexxx. Which will further guide the project in need of a user test, which will help validate the concept designed based on researched theories.

Biologically Beneficial **Illumination for Biodiversity - Trees**

Illuminating trees with specific colour temperatures from the light spectrum can be used as a strategy to evolve urban lighting to be biologically and aesthetically efficient.

Keywords : specific colour spectrum, biologically, aesthetically, efficient, evolve

"Lighting designer's work is not limited to the realm of aesthetics, but also responds to functional, technical, spatial, and experiential necessities of a project. Lighting design necessitates a deep, meditative exchange of knowledge, and therefore it must be understood not as an interdisciplinary field but as a transdisciplinary one that traverses the boundaries of conventional thought." - (Herve Descotte, 2011)

Conclusion for concept based on Research Theories and Case studies :

Theory from scientific paper (Ouzounis.T, 2015), (Naznin.M,2019) help the in deriving the specific colour spectrums at Red (500-600nm), Blue (400-500nm) and controlled amounts of UV (100-400nm) are successful in initiating the process of photosynthesis as the chlorophyll absorbs these spectrums to convert to chemical energy and initiate growth. The project GROW by Studio Roosegaarde, provides a platform of practically executed installation of these coloured spectrums on a leek plantation which have proven to improve their growth and reduce the use of pesticide by 50%. (Refer to Chapter 4.1) Use of these spectrum colours of light in required proportions to specific species according to their growth stage, season and time of the day is an aspect carried forward to the concept ideation.

Reduce Light Pollution **Impact of illumination on environment at night**

If illuminating systems for urban public spaces are programmed to be adjusted in intensity as per the time of the day, seasonal and growth evolutions in trees, it can help minimize light pollution.

Keywords : adjusted, intensity, time of the day, seasonal change, growth, minimize, light pollution

"Simply put, light pollution is excessive and inappropriate artificial light at night. Light pollution is not all outdoor lighting, and important distinctions are made depending on the ecological sensitivity of an area. Artificial lighting is an essential part of modern culture and possibly the most obvious demonstration of technological progress. The problem arises when "progress" cross the line to become wasted energy, wasted resources, and a negative alteration of the environment." - (IDA, 2013)

Conclusion for concept based on Research Theories and Case studies :

Based on theories of (Samach and Gover, 2001; Searle and Coupland, 2004); (ŠKVARENINOVÁ. J, 2017); (McClung.C, 2006); (Ouzounis.T, 2015), (Naznin.M,2019), it can be concluded that high and continuous illumination of trees at night can cause adverse biological effects on their circadian rhythm. The techniques used to illuminate trees also contribute greatly towards light trespass and causing light pollution in the night sky. By creating an illumination strategy where the direction of illumination is towards the earth and not the sky along with controlled intensity and duration of illumination can contribute greatly towards reducing light pollution. The case study of AIUIa, a concept proposal by Roger Narboni as discussed in Chapter 4.2, also highlights the possibility of providing illumination for users with the use of unconventional sources. His concept proposes use of portable lights given to the user, rather than subjecting the entire environment to be constructively illuminated. It provides an opportunity to the user to have his own unique experience inspiring this design concept to move away from conventional light sources for urban parks and use volumetric sources to indirectly provide path illumination.

Natural Night Light **Urban Nightscapes**

Majority of urban inhabitants prefer volumetric lighting of public parks and are able to adapt to low levels of illumination.

Keywords: volumetric lighting, majority, adapt, low levels of illumination

"I saw the sky that night in three dimensions- the sky had depth, some stars seemingly close and some much farther away, the Milky Way so well defined it had what astronomers call "structure", that sense of its twisting depths. I remember stars from one horizon to another, making a night sky so plush it still seems like a dream." - (Bogard.P, 2013)

Conclusion for concept based on Research Theories and Case studies :

Based on the theories of Narboni.R, 2016; Schwendinger, 2015; Narboni.R, 2020 the concept is directed towards the creation of night silhouettes and urban nightscapes, gradually creating spaces with distinctive identity, hierarchy, characteristics and luminous ambiances. With respect to 24 hours in the day, and influencing technology to be flexible to occupancy and time of the day making room for darkness and nocturnal landscapes. The case study of Glowing plants by Studio Roosegaarde and Advent of Bio-LEDs by Roger Narboni as discussed in chapter 4.4 and 4.3 inspire the concept to visualise natural sources of low level illumination, contributing and enhancing the natural night light.

7.2 Introduction to Design Concept

Illumination of trees and plants have increasingly become an essential component of urban landscapes. It is one of the elements that contribute to keeping the cities alive at dark hours. Scandinavian countries like Denmark experience more dark hours through the year, creating the need for urban lighting to simulate the daytime activities. This design discussion is specifically going to introduce and suggest concepts and ideas to illuminate trees in urban public parks. A park in one's neighbourhood is one of the closest interactions with nature urban inhabitants have in their daily lives. This proposal discusses lighting strategies that can be developed to enhance this experience in our natural surroundings and encourage people to be outside. As the research above has discussed elaborately on scientific theories supporting and developing the three criterias. There is a need to change our strategy from functional lighting to illumination in harmony with biodiversity, that not only protects the flora and fauna but also caters to the functional needs of daily human activity. The proposal is based on the belief that we are headed towards a future where the implementation of this strategy can influence illumination strategies of urban cities as a whole. However, this proposal is entirely based on a conceptualised theory that can possibly be achieved with future technological advances.

7.3 Initial ideas and Inspiration

Below is a collection of images forming a mood board that inspired the concept in its aesthetical, functional and experiential values.

Figure 7.1 Moodboard for design concept. Reference from left to right; Obon, Miya. A, 2012; Scenes, Underwood.B, 2014; Grow, Roosegaarde. D, 2021; Chikuraku festival, 2019; Longwood Gardens, Munro.B, 2012; Swan Song, Börsch.C, 2019; Tokyo Hotaru festival, 2012; Grow, Roosegaarde. D, 2021.

These images are installations with light that interact with our natural surroundings appreciating and enhancing the beauty of nature on earth. Something common that ties all the projects together is the low intensity of illumination and allowing room for darkness to truly appreciate the illuminated landscapes. It helped inspire questions and a general mood for the design concept. How can we use light to enhance the beauty of nature? Can we use light to create sustainable practices in harmony with our biodiversity and built environment? Can we create an experience in urban cities appreciating darkness and different shades of night?

"The sky grew darker, painted blue on blue, one stroke at a time, into deeper and deeper shades of night." - (Murakami.H, 2006)

To encourage **human interaction with nature and design an experience of the natural night light** , the concept draws its inspiration from the idea of an enchanted forest. An environment that brings the community together and closer to nature. Creating an urban public space, appreciative of the nature that surrounds us amidst the concrete jungle is a therapeutic experience for the community as a whole. The illustration as shown in figxxx is a visual key image that has been used as an inspiration of the desired visual experience, composition and emotional response to the concept.

Figure 7.2 Inspiration image - Cameron.J, 2013, Na'vi River Journey, Inside the Magic.

The following sketch is an exaggerated representation of the reality, depicting the mood and intention behind using the ideal spectral composition for trees biologically, using low intensity luminaires to reduce light pollution and creating a different positioning and placement possibility for the source of illumination. Designing an atmosphere, composed and balanced with specific colours and intensity in harmony with the different shades of the night to deliver the experience of an enchanted forest and a dark night.

Summary :

The visual image of the enchanted forest constructed with a composition of colours and intensity made to balance with the natural night light is the key inspiration drawn to the concept of Urban Glowscapes. Supporting the design with the knowledge from the discovery phase and defining guidelines from the criterias develop the design experience that will be discussed elaborately in the following chapter.

Figure 7.3 Initial Concept, Tahlani.D, Self produced, 2021

7.4 Design Experience

To help visualise the concept better, the design experience of a user walking through a park has been illustrated and described through a storyboard in this chapter. It guides the reader to visualise the experience through a persona simulated storyboard as shown below,

Figure 7.4 Story Board A
Tahlani.D, self produced, 2021

Figure 7.5 Story Board B
Tahlani.D, self produced, 2021

Figure 7.6 Story Board C
Tahlani.D, self produced, 2021

Lucy Anderson, 25

Student at CBS, Copenhagen

Figure 7.7 Persona Character, Tahlani.D, self produced, 2021

Let's take this persona character Lucy Anderson as our persona character in the story taking a walk through the park. She is walking home from school on a late winter afternoon at around 6pm, and crosses the Kings Garden on her way home. (assuming that the design concept has been implemented at Kings Garden, Copenhagen) She enters the park and is taken aback by the magical land before her. She couldn't believe it was real, feeling captivated by the colours and the environment she starts to walk on the path as shown in Story scene A. She observes the trees around as the colours make the atmosphere come alive and seek all her attention. This was an unusual day for her, usually she bikes home through the main street, but as it had gone for repair she decided to take a walk home after a long exhausted day at school. The park looked so inviting she was glad she chose to walk through it. It was a good break by taking a walk and fresh air in. Even though it was chilly outside, she decided to stay longer and see things around. As she finds a bench to sit and looks around she finds the light of colours red, blue and purple almost crawling onto the trees as seen in Story scene B.

She is truly amazed by the landscape and how different it appeared to be. She had been to this park several times with her friends before, but almost couldn't recognise it with the change in lighting now. The experience makes her observe, stay in the moment and appreciate the nature around her in this unique landscape. It gives her a therapeutic experience, a break from her usual environment, and makes her appreciate the park with such beautiful trees and plants around that she never really paid attention to earlier. She recalls the walk she took here before, as shown in Story scene C, and remembers not realising what was around her. She rather focussed on her travel while listening to music on her way home. Today her focus was entirely on the surroundings, even though it was a bit darker than before the lighting seemed sufficient to walk and see, and she strangely discovered it to be a more lively environment. The low light levels make her look up at the sky, as though everything around her is connected to it. As she reaches home her mood is uplifted, it was a refreshing and magical experience that she excitedly shares with her roommate and is determined to take this route everyday from now on.

This experience of Lucy walking through the park points out the essential components of the design experience and concept. It correlates the criterias defined to integrate into the desired experience. To create an environment that helps people connect to the natural environment and appreciate their surroundings while providing illumination sensitive to biodiversity. This is a step towards lighting design not just for humans but also for the nature that surrounds us. To encourage in designing and creating opportunities in balance with our biodiversity.

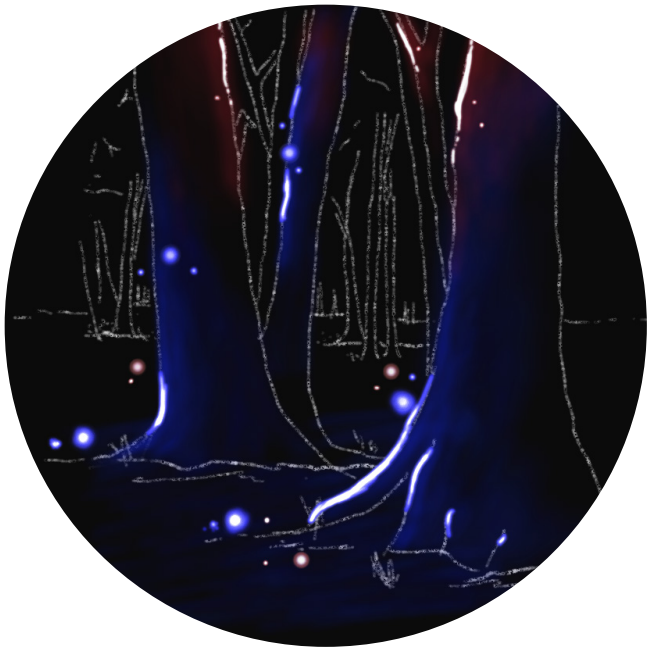


Figure 7.8 Design Experience, Concept sketch, Tahlani.D, Self produced, 2021

7.5 Concept Lighting Intention

The proposed concept has been named Urban Glowscapes as it creates illumination through urban landscapes respecting biodiversity and in harmony with different shades of night. Following the guidelines of the defined criteria of creating illumination strategy that is biologically beneficial, minimizes light pollution and contributes to a natural night light, the designed concept is categorised into lighting intentions, which help in deriving the design experience as stated in chapter 7.3.

1. Placement, Distribution and Color Temperature

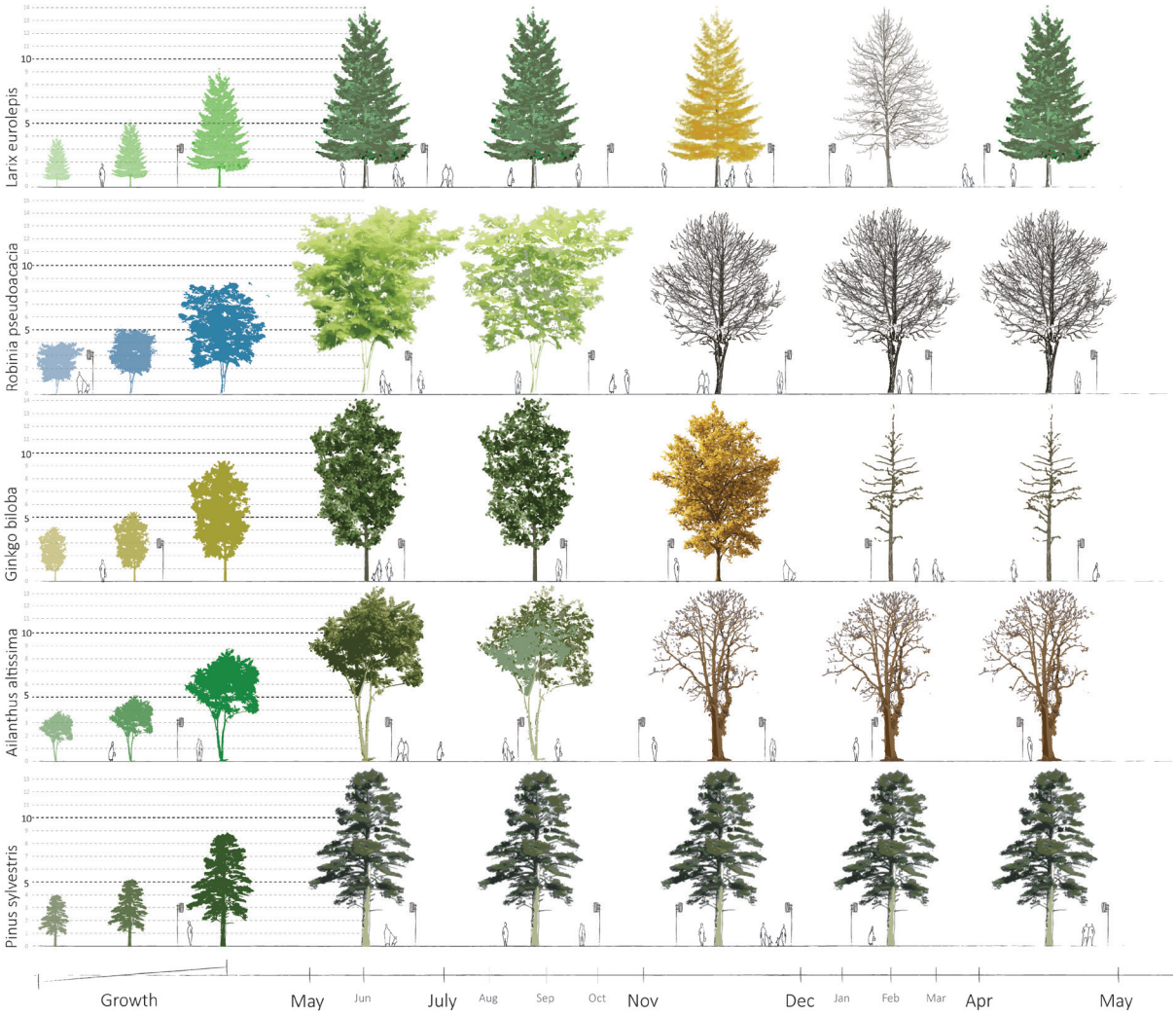


Figure 7.9 Seasonal and Growth eveolution of trees, Fortheloveoflight, 2020

To create a more realistic solution, there are five species of trees taken into consideration while describing and designing the lighting intentions for the concept. These species are currently being planted in Postbyen, a project in Copenhagen, a part of a study during my internship at fortheloveoflight in Copenhagen. This illustration describes their growth and seasonal changes through the year.

The lighting distribution strategy takes the seasonal changes into account as many trees lose their leaves half of the year. Static and non- adjustable lighting solutions create excessive light pollution during these months and the foliage density protects the light from escaping into the sky. And absence of leaves allows tremendous amounts of light trespass causing light pollution. (IDA, 2013)

The distribution and placement of the source of illumination and adjustability plays an essential role in avoiding light pollution and respecting the biological clock of trees. This also adds a certain sense of

dynamism to the experience of the inhabitants. To cater to these qualities urban Glowscapes is a concept that places the source of illumination on branches and trunks of the trees illuminating the dense foliage through a combination of soft indirect and direct illumination. This is possible by providing an omnidirectional, glowing low intensity source to be placed on the structure of the trees. These luminaires are visualized to be Bio-LEDs, that are sustainable and not harmful for the trees or the environment and create a soft natural glow within the vegetation of the urban landscapes. The invention of Bio-LED's is yet an ongoing study, with hope of this technological advancement, urban nightscapes can be transformed magnificently. (Narboni R, 2020)

To elaborate on how we can use a source of illumination that can improve the growth of trees and plants, data from multiple research papers and study have been used to derive the spectral distribution of light to be used in the concept of Urban Glowscapes as mentioned in chapter 5 (Ouzounis.T, 2015), (Naznin.M,2019). Following are assumed spectral peak graphs based on the understanding of the above stated studies. The 5 species in focus of this study are further categorized based on their features i.e., whether they are flowering, fruit, evergreen, deciduous, coniferous trees. As these qualities are drivers in deciding the spectral peaks the tree requires for its optimal growth. Through a case study Grow by Daan Roosegaarde (Urban Glowscapes, Chapter 4.1), research and experiment has proven that spectral colour peaks of red, blue and UV in a certain light recipe has improved the growth of leek crops and reduced the need for pesticides by 50%. This existing installation and study are one of the key driving inspirations behind the spectral distribution of light in the concept of Urban Glowscapes. Hence, the design proposes the use of Red (500-600nm), Blue (400-500nm) and moderate amount of UV (100-400nm) for illumination of trees to improve growth of trees. (Ouzounis.T, 2015)

2. Light spectral distribution based on different species

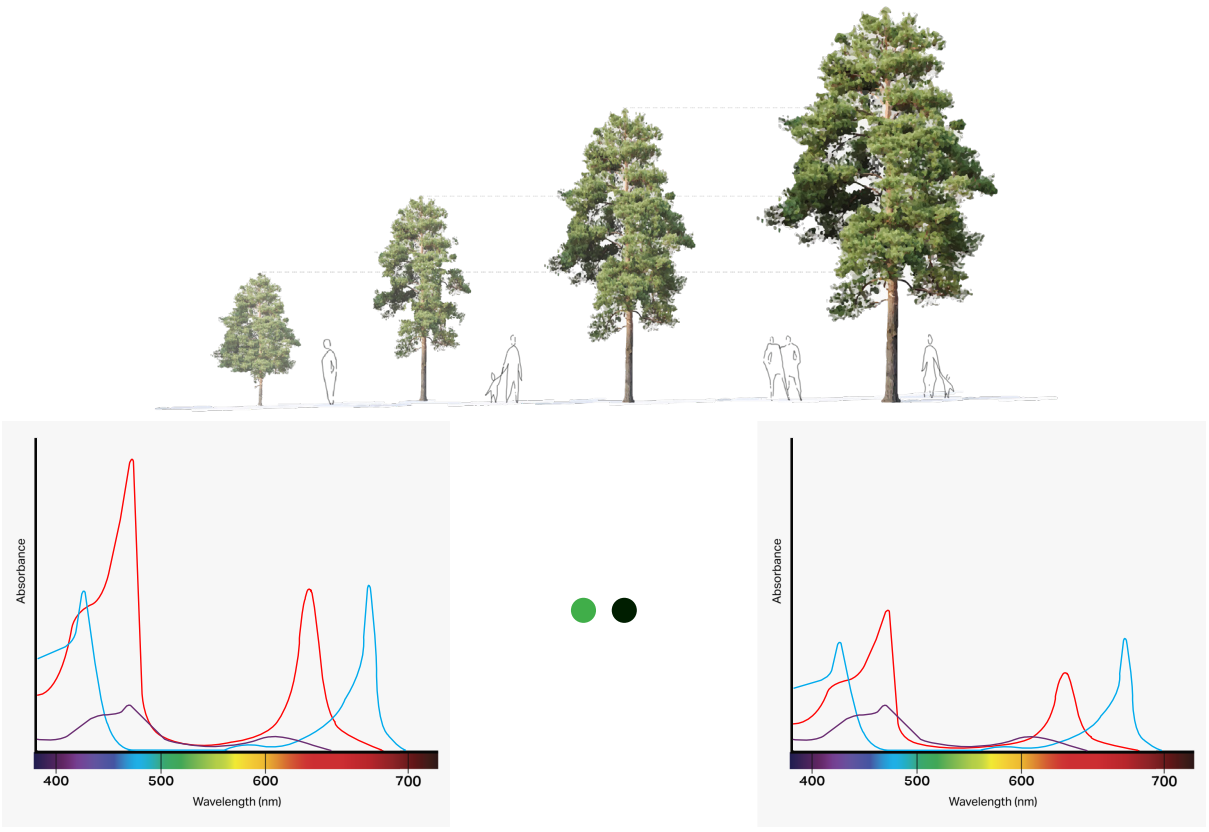
Name	Larix Eurolepis	Robina Pseudoacacia	Ginkgo Biloba	Ailanthus Altissima	Pinus Sylvestris
Type	Conifer, deciduous, needle like leaf, no flowers, has cones	Black locust, deciduous, pale pink white flowers	Broad leaf, Dense foliage, Deciduous, no flowers	Large leaves, Dense foliage, Deciduous, small flowers	Needle leaves, Dense foliage, Evergreen coniferous, no flowers, has cones
Light spectrum distribution by type at growth stage					

Figure 7.10 Light spectral distribution graph based on different tree species, Tahlani.D, Self Produced, 2021

The light spectrum distribution graph has been created for each of the species based on the knowledge from the research and case studies. However, it requires an experiment to test and evaluate if these peaks can actually show improvement in growth, which will not be discussed or proven through this paper. Early growth stages of trees require more Blue light (400-500nm), as it helps in development of root and stem structure and overall growth of the plants. Higher red peaks are created for flowering trees as compared to non-flowering trees, as it encourages growth of flowers and fruits. Red spectrum (500-600nm) helps in growth of leaves and denser foliage. Red light when paired with blue is an essential balance required to avoid disfiguration and overstretching of stems. UV (100-400nm) light is provided to each of the trees in low intensity and quantity as it is absolutely essential for growth, but overexposure may lead to harming its growth. (Ouzounis.T, 2015), (Naznin.M,2019). The light spectral distribution also varies with the growth stages of the trees as over exposure of illumination to full grown trees can cause abnormal elongation. Hence, below are two different spectral distribution graphs adapting to the growth stages with higher peaks at early growth to lower peak and intensity at full growth.

Light spectral distribution adaptability to growth stages of the tree

It is understood through research of Nocturnal Urbanism by Roger Narboni, and the 24th City (Schwendinger,2015), that illumination spectrum and intensity require adjustments based on the biological clock of the trees to ensure improvement in its growth and to respect the needs of biodiversity. The concept of Urban Glowscapes provides illumination to the trees as an extension of daylight and an environment of glowing landscapes for its inhabitants to experience nature during dark hours.



Growth stage spectral peaks to encourage and regulate growth

Full grown stage spectral peak reduces to avoid over elongation and stretching of stems and leaves.

Figure 7.11 Light spectral distribution graph based on growth evolution of trees, Tahlani.D, Self Produced, 2021

3. Light Intensity adjustment based on seasonal changes and time of the day.

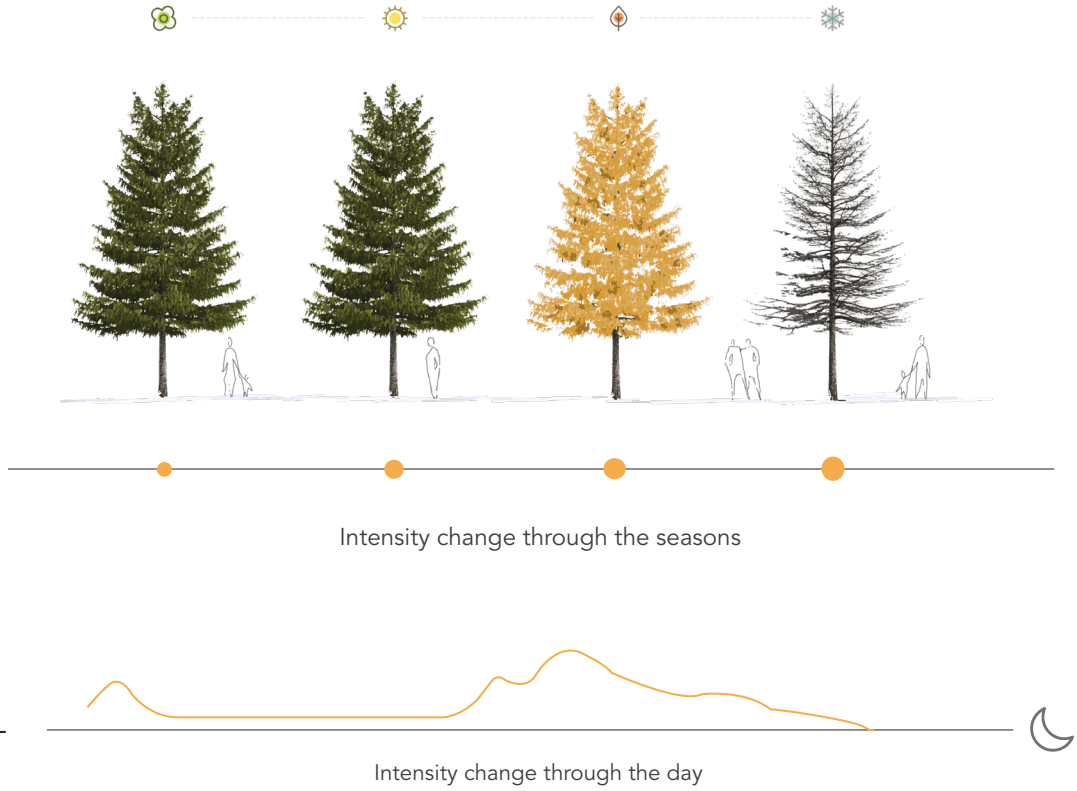


Figure 7.12 Light intensity adjustment graph based on time of the day and year, Tahlani.D, Self Produced, 2021

Intensity adjustment through the seasonal changes of the trees and through the day provide us with the ability to minimise light pollution, reduce energy consumption, respect the biological needs of trees and plants and also create room for complete darkness as it is also an essential component of circadian rhythm of both humans and its surrounding biodiversity. Fig.12 illustrates the desired intensity adjustment Urban Glowscapes propose for illuminating the trees. Through the seasonal change from summer to winter it is seen that the intensity fluctuates from low to high. As summer has longer daylight hours it reduces the need for illumination and winter with shorter days has higher intensity and duration to substitute the absence of daylight. The Fig.12 also illustrate the change of intensity with the day which is directly proportional to period of daylight hours, occupancy rate of inhabitants, circadian rhythm of biodiversity.

4. Distribution and directionality of illumination

The concept also takes the distribution of illumination along the vertical length of the tree into consideration by providing sparse to dense distribution from crown to canopy.

The distribution of illumination varies across the vertical height, as the crown receives more light during the day, the bottom canopy elongates itself to receive more sunlight, the reason why we observe a triangular growth very often among trees in colder regions. (Liscum. E, 2014)

This phenomenon suggests the design solution to provide a denser illumination in the canopy and reduce as it crawls above to the crown. This also creates a dynamic visual as the light is scattered more organically and not placed evenly in a geometry.

Figure 7.13 Light intensity adjustment based on the structure of the tree, Tahlani.D, Self Produced, 2021

The distribution of illumination varies across the vertical height, as the crown receives more light during the day, the bottom canopy elongates itself to receive more sunlight, the reason why we observe a triangular growth very often among trees in colder regions. (Liscum. E, 2014)

This phenomenon suggests the design solution to provide a denser illumination in the canopy and reduce as it crawls above to the crown. This also creates a dynamic visual as the light is scattered more organically and not placed evenly in a geometry. The directionality of illumination of the source is omnidirectional, however the intensity is extremely low which does not allow a lot of light to emit into the atmosphere. Phototropism, the behavior of trees and plants to grow towards the direction of the light, led the design to position the luminaire from within the structure of the tree itself.

Current practices illuminate trees from the ground which shocks the trees due to a change in directionality of illumination between day and night causing abnormal changes in its circadian rhythm. Use of an omnidirectional glowing source of illumination from the structure of the tree allows to minimize the shock to its circadian clock. (Liscum. E, 2014). This concludes the design to accomodate the illumination to be adaptable, adjustable and flexible to the evolution of the tree, helping in improvement of its growth. It is also to be understood that light is one of the factors that essentially help in tree growth. Other factors such as wind, water, soil have been considered to be at a constant. With changes and adjustment in the quality of illumination, replicating certain qualities of sunlight that help in the process of photosynthesis can provide a sufficient improvement in its growth. In the following renderings, the source of illumination has been visualized as a glowing algae and moss on the structure of the trees with emissive properties. (Inspired from the research of bioluminescent glowing plants by Daan Roosegaard from chapter 5.7.) This visual allows the light to blend in with the natural environment more organically and create a homogeneous experience.

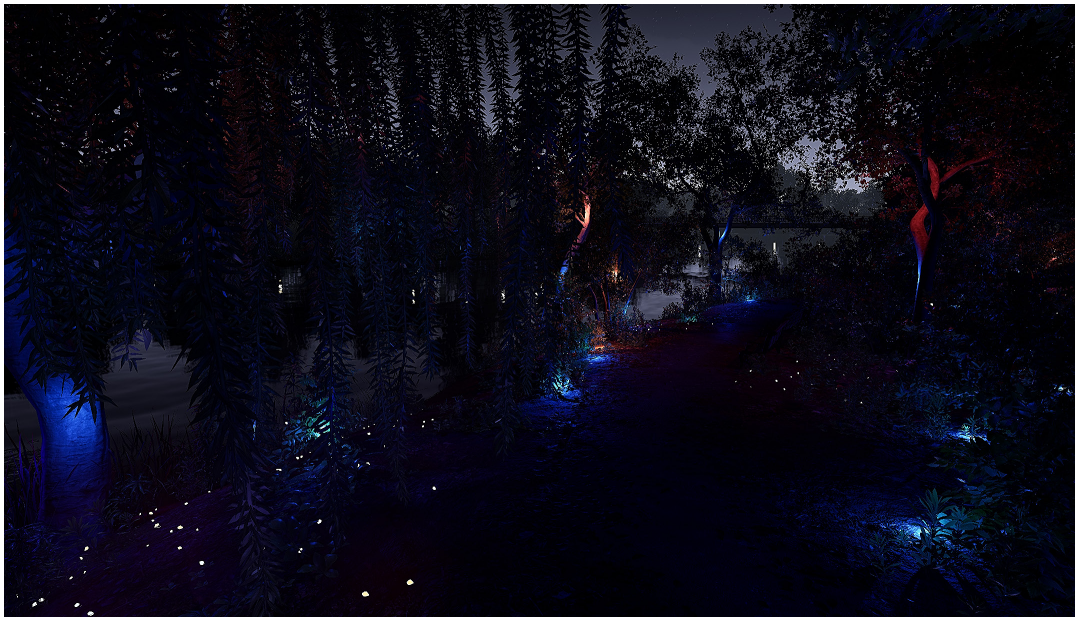


Figure 7.14 Concept render, illumination of trees, Unreal Engine 4.2, Tahlani.D, Self produced, 2021

Look and feel with the use of three different spectral distribution to illuminate the trees. The source of illumination has been placed along the structure of the trees.

The position and placement of the source of illumination creates a play of shadows and a dramtic effect in the landscape. And the emissive rocks makes the scene come alive representing the bioluminescence in nature.

Figure 7.15 Concept rendered on Unreal Engine 4.2, Tahlani.D, Self produced, 2021

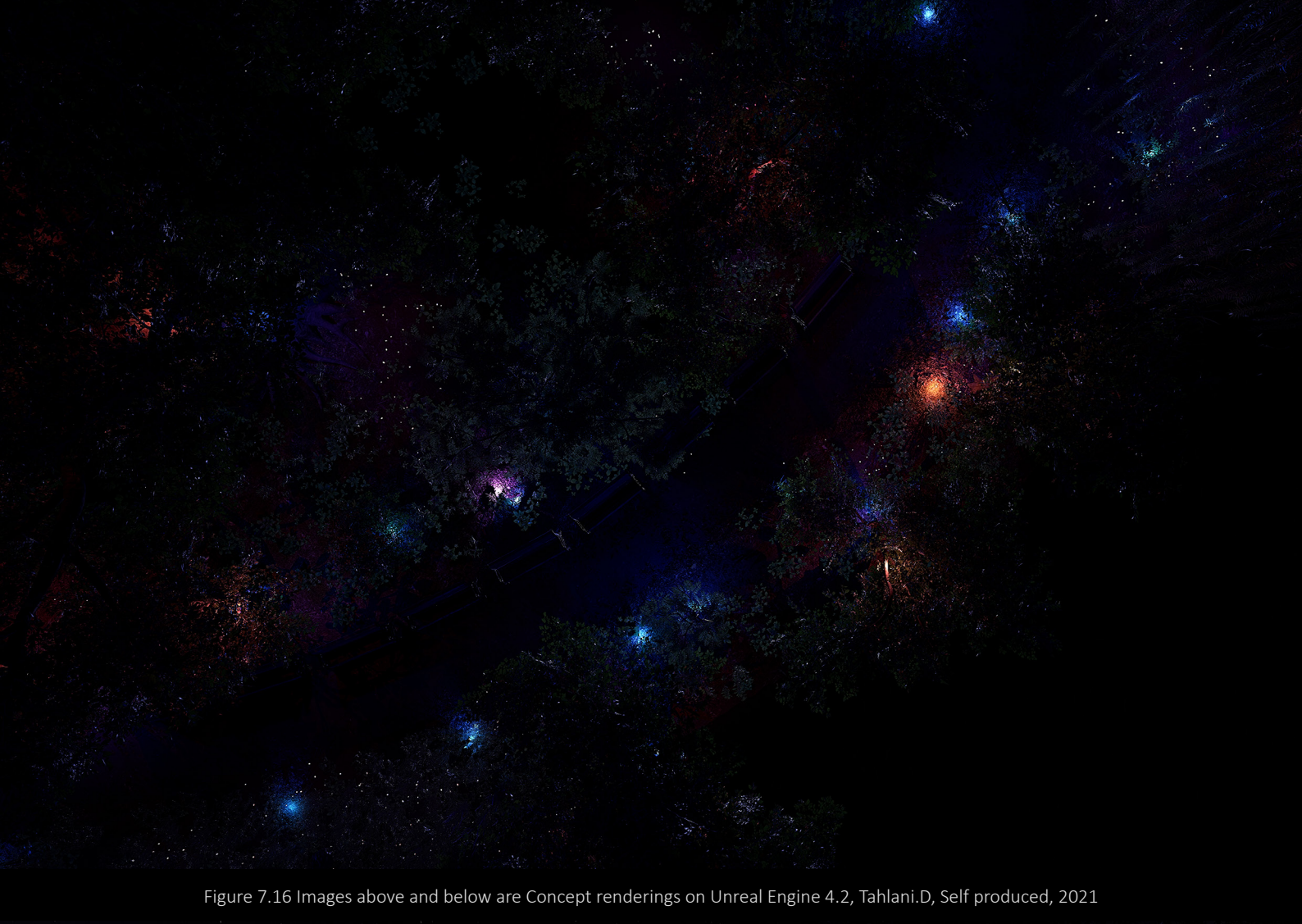
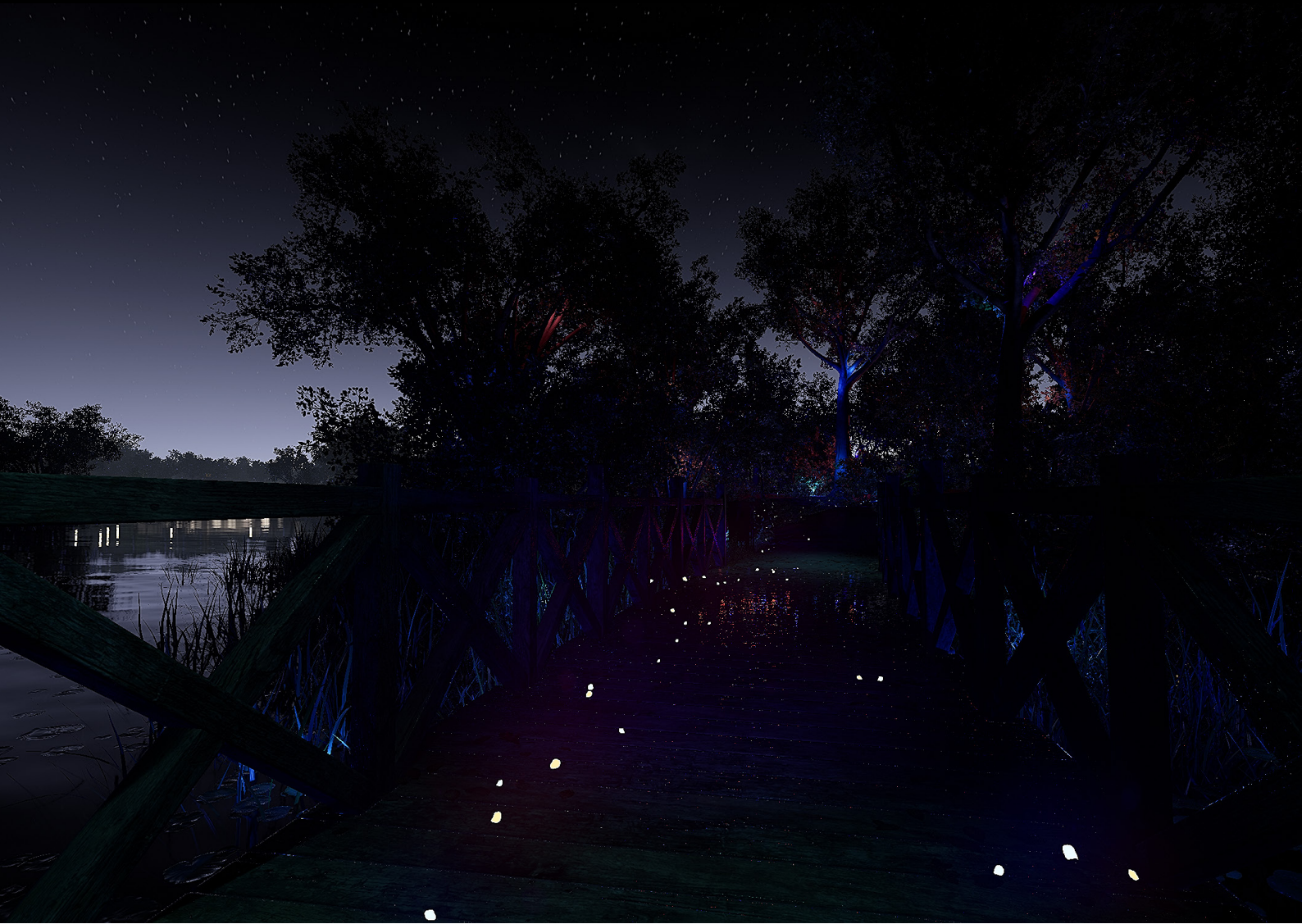


Figure 7.16 Images above and below are Concept renderings on Unreal Engine 4.2, Tahlani.D, Self produced, 2021



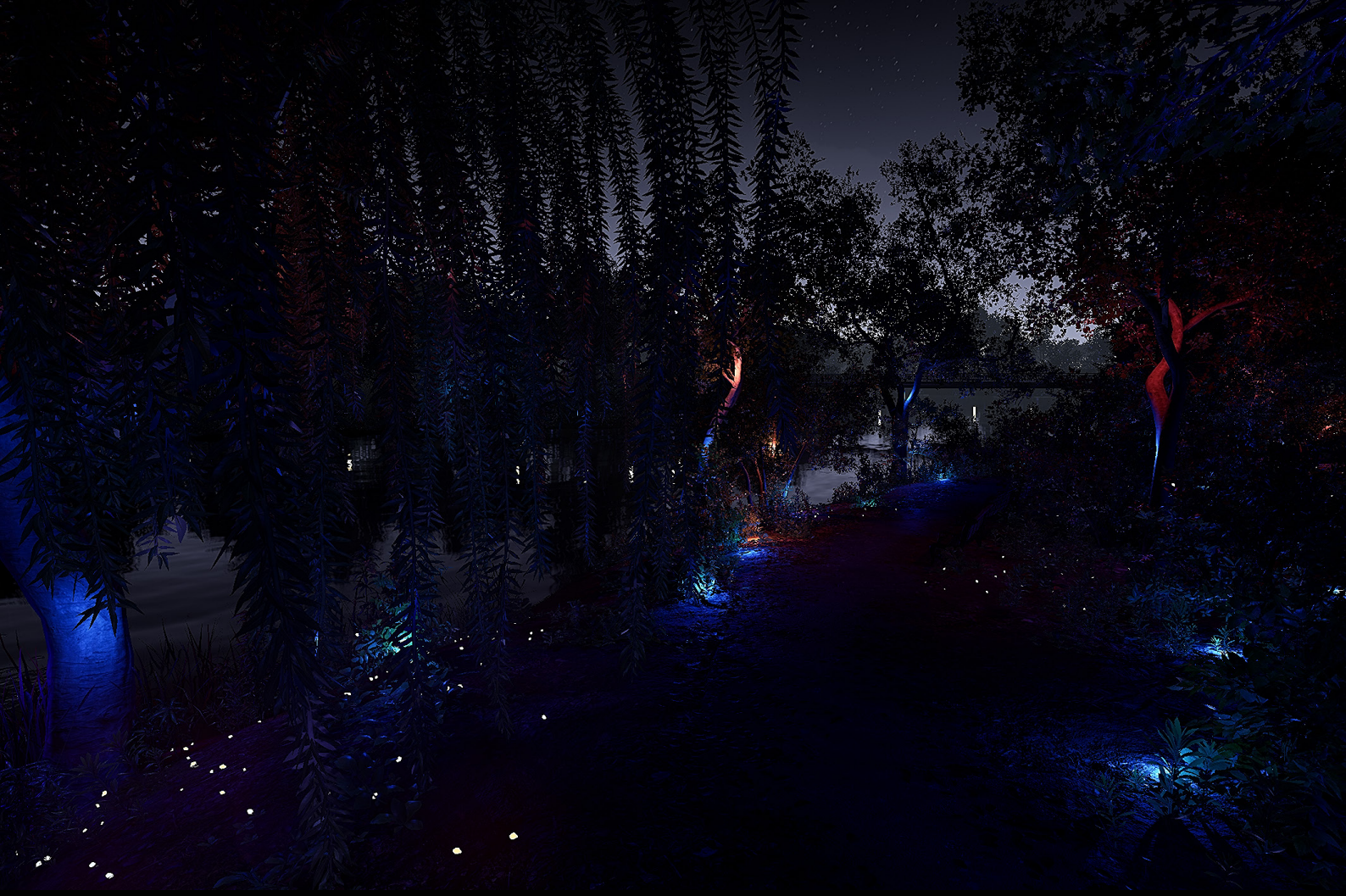
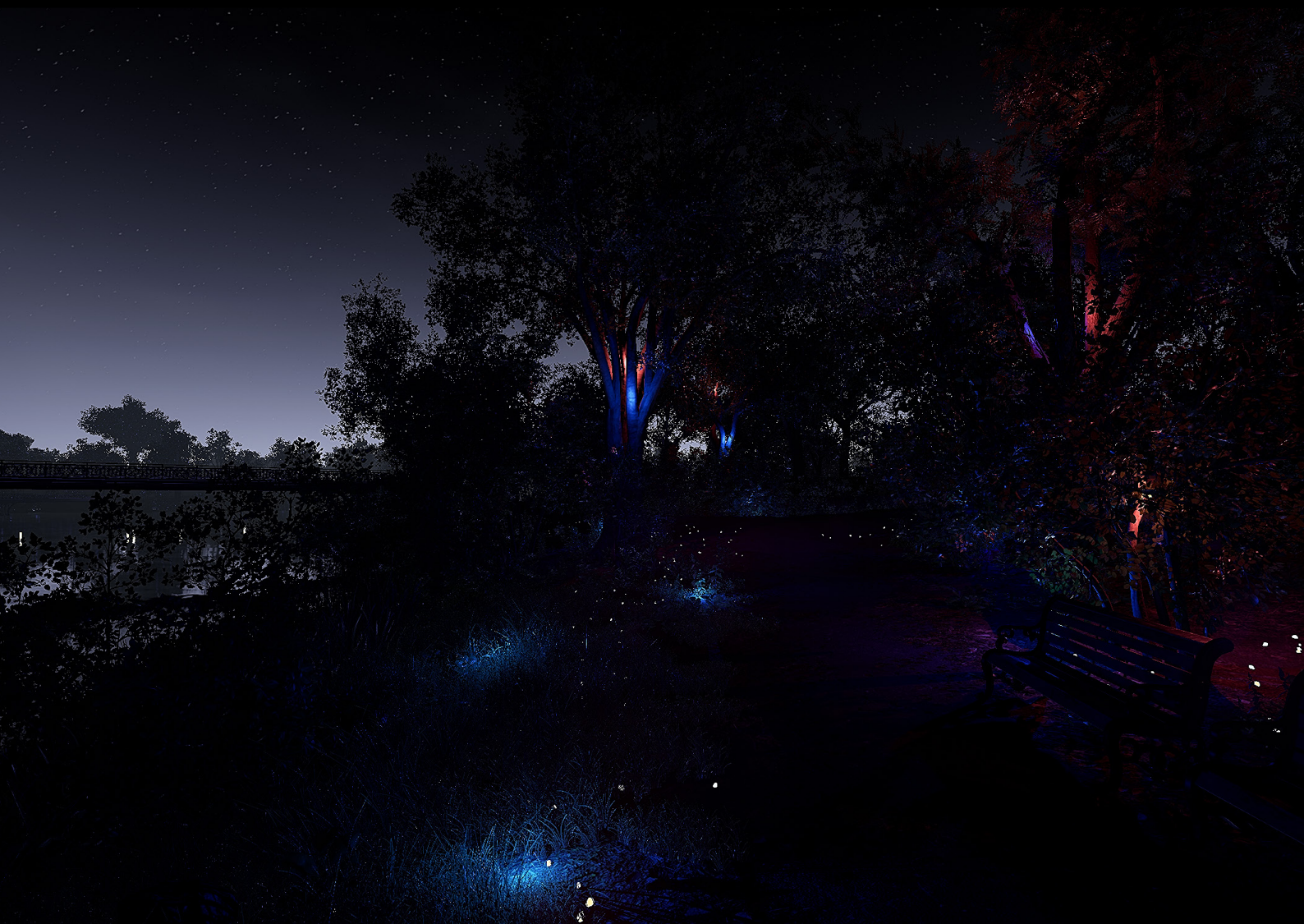
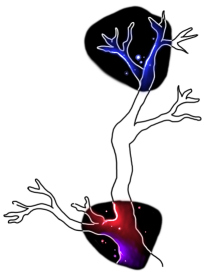


Figure 7.17 Images above and below are Concept renderings on Unreal Engine 4.2, Tahlani.D, Self produced, 2021





08 TEST

The following chapter discusses the user experience test conducted through virtual reality. It elaborates on the intention and methodology for the test conducted followed by the survey process and the results analysed to understand the user preference.

08 Test

8.1 Introduction

To elaborate and validate the initial design concept that has been introduced in the previous chapter, a user validation research was conducted to test the user perception. Due to the limitations of time, covid19 restrictions and this study does not validate scientifically but is entirely based on perceived value of volumetric lighting in public spaces. Given the restrictions, the experiment is conducted through Virtual reality experience amongst users. The experiment contains two scenarios for a comparative analysis. Each of the scenarios represent a different typology in illumination of public parks in urban cities. Scenario A illustrates existing lighting practices through street lamp poles for path illumination, floodlights and spots for trees and landscape. Whereas Scenario B illustrates volumetric lighting through illuminating trees from within its structure, using different colour temperatures as described in detail in chapter 7.5 Design concept for Urban Glowscapes.

This test will enable us to understand the perception of darkness and how much light users actually need while walking in a park in a natural landscape. It will give us a quantitative and qualitative perspective on the experience of the atmosphere in both scenarios and help in achieving a design validation that represents the qualitative attributes and emotions of a human experience. It will also indicate the preferences of people, as they go through a comparative analysis and make their own choice which helps us achieve a relatively unbiased result. Using the exact same space with only the illumination typography changing allows a fair comparative study of a better solution.

8.2 Methodology

This survey uses Virtual Reality as a tool to conduct the test. Virtual Reality is a simulated experience that can be similar to or completely different from the real world. This test uses the headset Rift S by Oculus. Virtual reality headset displays are based on technology developed for smartphones including: gyroscopes and motion sensors for tracking head, body, and hand positions; small HD screens for stereoscopic displays; and small, lightweight and fast computer processors. The user wears the headset, which uses visual simulation through a lens on the eyes strapped across their head. It is an immersive experience through a 360 degree camera function that creates the feeling of being projected into a virtual space. The motion of walking through the space is controlled by the joystick on the left controller of Oculus Rift S, which has been programmed in unreal engine 4.

The test will use VR experience followed by an online survey that will ensure the test to be conducted from anywhere keeping in mind the Covid19 restrictions. The user group would be a mix of students from various fields, lighting designers, of varying age groups between 20-30 years, in order to attain a wide spectrum of responses. The test is conducted by asking the user to wear the VR headset and experience Scenario A, then answer the questions on the survey, then move to Scenario B followed by the survey for the same. The survey questions are both qualitative and quantitative in nature and are undertaken through a Google forms survey. (please refer to the appendix for survey questions)

The users do not follow the same pattern of viewing scenarios, it is done on an alternative basis to ensure unbiased answers. The survey includes answer options in the form of rating scale which allows them to be more flexible in their responses, multiple choice reaction cards that help them place emotions to their experience and end with an open-ended question to give them an opportunity to express with their own words and provide a review. After conducting the test, the responses are calculated and represented in a tabular format of bar graphs representing the majority responses.

Description of creating the VR Scenes,

The scene has been created on unreal engine 4 for this thesis project. The structure of the park has been

derived as an asset from Epic games and adjustments have been made onto the scene to create the desired experience for both the scenes developed. They both use a motion controller pawn for creating the VR experience. The following section is a description of each of these scenes in detail,

Methodology for Scene A

This scene has been created as a representation of the existing lighting scenario in urban parks. The lighting on the bridge uses a led strip light along its structure which has been created using rectangular planes with emissive property and 12 spotlights all with 3500 K as their colour temperature and intensity to be 0,05 c/d, outer cone radius to be 80 degrees as seen in figxx. The rest of the walkway uses bollards commonly seen in Copenhagen, Denmark designed by company PVD concept, model named simply brass 90 as seen in figxx. The light source cube has been made emissive with the same colour temperature as the spotlight placed on it. The specs of these spotlights are, intensity- 0,2 c/d and outer cone radius to be 80 degrees. Additionally multiple spotlights have been used to illuminate some trees along the path as seen in figxx. Their specs are, intensity- 2 c/d, colour temperature 3500 K, And cone radius of each of them have been adjusted according to the size and species of the tree it illuminates.

The sky sphere has been adjusted to appear light glow from the transition hour of dusk to night sky. Where the sun brightness is at a 0, cloud opacity at 0.4 and cloud movement at 2, and sky brightness at 0.005 which is level 8-9 from the bortle scale of darkness (refer to Fig 8.2). As a common element the scene is added with finishing touches of volumetric atmosphere fog and an adding some emissive light poles in the surrounding environment to give the appearance of being in a city and not a forest. No further spot lights or any other sources of illumination have been added to the scene. For the smooth transition and movements while in VR experience a Nav mesh Volume bound has been added along the walkway of the scene. The user also experiences sound of the water in the surroundings, which has been added as an audio element depending on the user's proximity to the water. To create a more realistic environment, the scene's atmosphere is enhanced by using wind as an element in the material editor of the trees, vegetation and water to create a slight movement or sway.

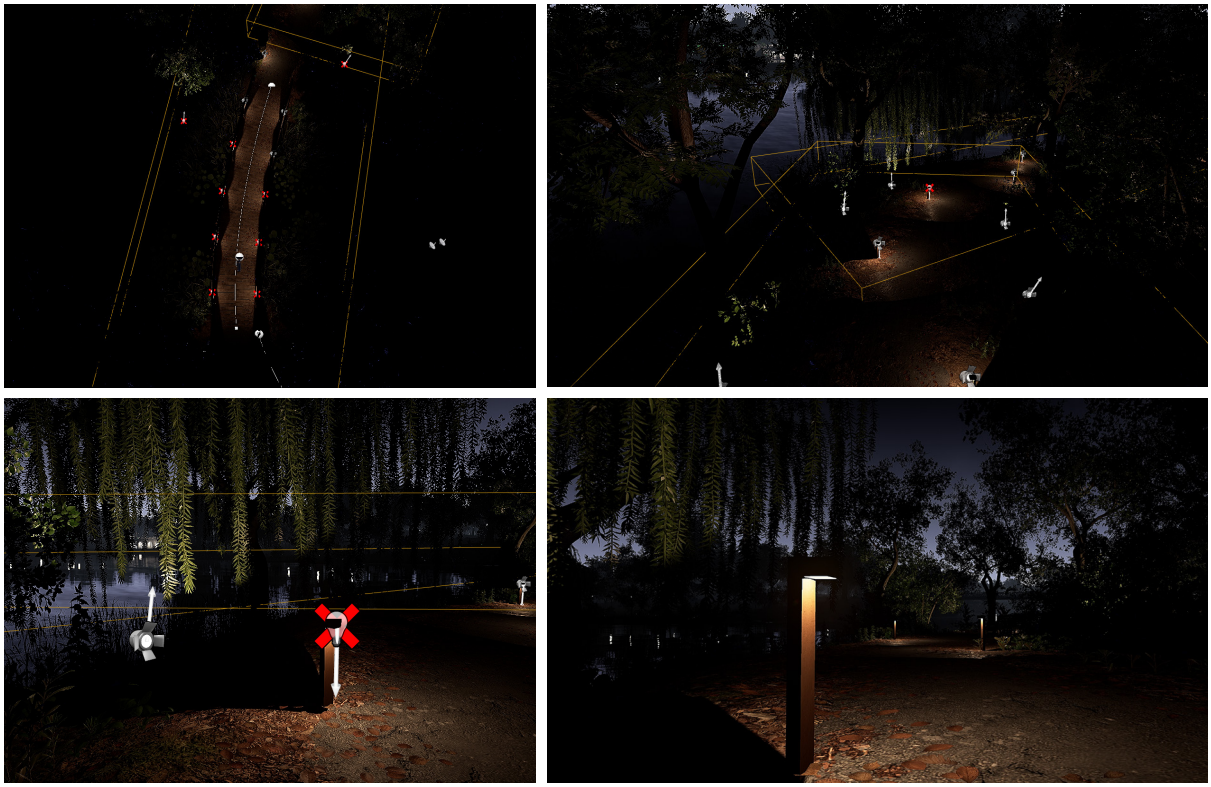


Figure 8.1 From left to right; Plan view, perspective view, Zoom view to bollard, Rendered Images from unreal engine 4.2, technical luminaire data, Tahlani.D, Self produced, 2021

Methodology for scene B

It is a scene of a visualised urban park, with the proposed lighting set up. The environment has been adjusted to a transition hour period, appearing similar to a late winter afternoon in Copenhagen, Denmark. To create the following lighting scene, multiple point lights have been used at 0,1 c/d intensity very close to the structure of the tree i.e, bark and branches as seen in figxxx. The colours of light that have been used represent the three different coloured spectrums of light Red(500-600nm), Blue (400-500nm) and UV(100-400nm) are red, blue and purple. (HEX sRGB: BLUE = 004DFFFF, RED = FF6180FF, PURPLE = 914DFFFF)

Apart from point lights, there are emissive rocks used on the ground representing the bioluminescence in nature and add to the mystic effect of the scene. They are made by adding low intensity emission property to a low poly rock object. As a common element the scene is added with finishing touches of volumetric atmosphere fog and an adding some emissive light poles in the surrounding environment to give the appearance of being in a city and not a forest. No further spot lights or any other sources of illumination have been added to the scene. For the smooth transition and movements while in VR experience a Nav mesh Volume bound has been added along the walkway of the scene. The user also experiences sound of the water in the surroundings, which has been added as an audio element depending on the user's proximity to the water. To create a more realistic environment, the scene's atmosphere is enhanced by using wind as an element in the material editor of the trees, vegetation and water to create a slight movement or sway.

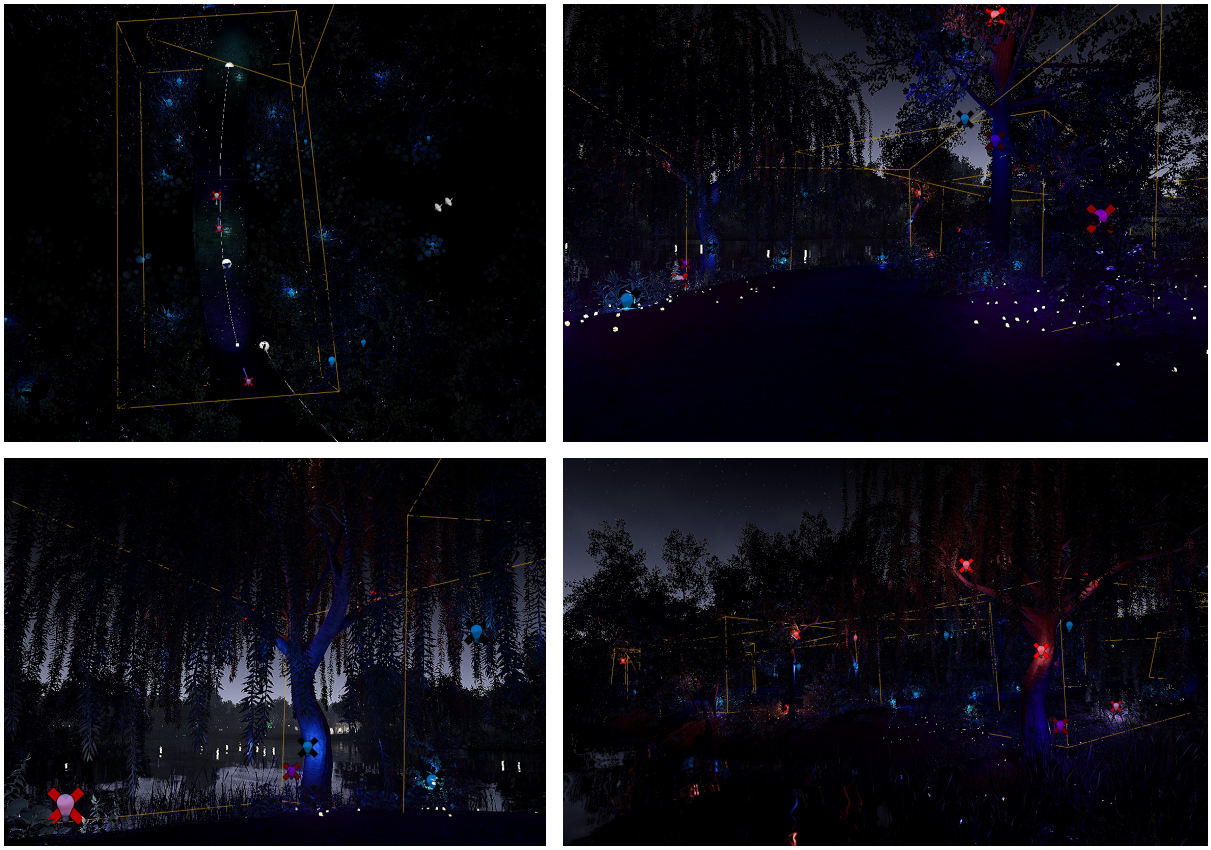


Figure 8.2 From left to right; Plan view, perspective view, Illumination of trees, perspective view, Rendered Images from unreal engine 4.2, technical luminaire data, Tahlani.D, Self produced, 2021

Survey Questions

Each individual user, experiences each of the scenarios in VR and answers the survey questions as mentioned in the appendix. The sequence of the survey is to experience a scenario and answer questions and then repeat with the second scenario, to ensure an unbiased and clear opinion of each experience one has.

Scene A Scene B

Figure 8.3 From left to right; Images above are renderings of the existing lighting scenario and proposed concept through Unreal Engine 4.2, Tahlani.D, Self produced, 2021

8.3 Test Results

The user survey was conducted through an online survey on google forms. The results of the test are displayed in the form of bar graphs and compared between both the scenarios as follows,

1. Visibility

Out of the total of 11 users for this test, the users rated their visibility within a linear scale of 10 points. Scene A observes the mode (scale point with the highest response) to be scale point 8 which is towards the higher side indicating most users did not have any discomfort in visibility to walk in the scene. However, it is also seen that a total of 18.2 % of the users felt the visibility was >/= 4 scale point which indicates that certain users did not find sufficient comfort in visibility to walk. It is analysed to be due to non uniform illumination and high contrast environments which may create highly illuminated and intensely dark zones which can create a certain sense of discomfort for people to see clearly.

Scene B observes the mode to be scale point 10 with a 36.4% response that they had no discomfort of visibility at all. Furthermore this graph also indicates that the majority range lies between scale point 8-10 with a total of 63.7% and the rest 27.3% of the users felt a moderate level of visibility by choosing scales between 5-6. It is analysed to be due to absence of focal illumination on paths, and using the idea of indirect lighting from volumetric sources in the surroundings can provide sufficient to moderate visibility of path. This comparison concludes that users had more comfort in visibility in Scene B when compared to Scene A, where the sky conditions, time of the day, location and technology of conducting the test all remain constant, with only illumination strategy as a variable.

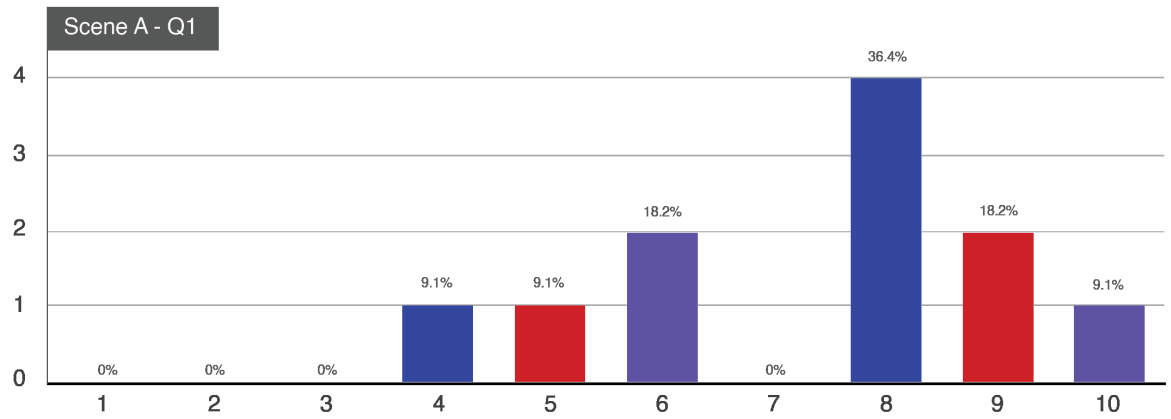


Figure 8.4 Visibility, Scene A, User response bar graph, Tahlani.D, self produced, 2021

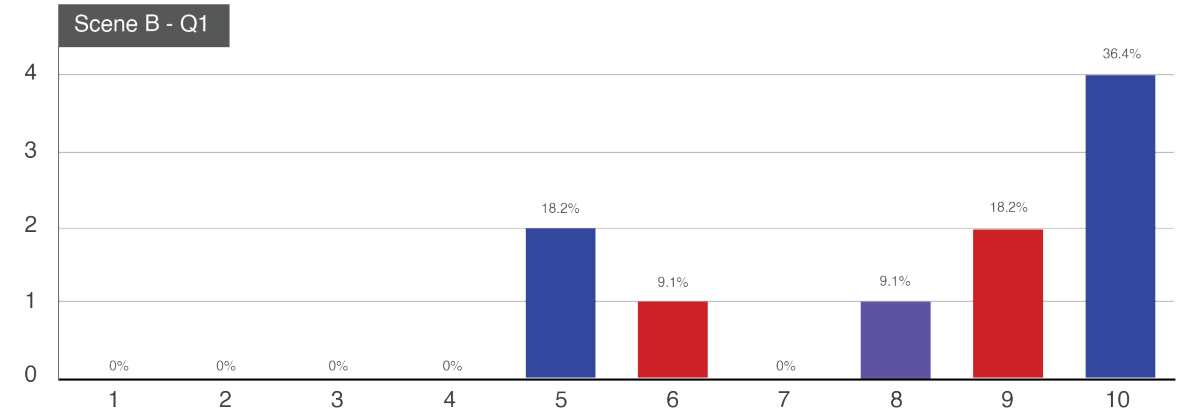


Figure 8.5 Visibility, Scene B, User response bar graph, Tahlani.D, self produced, 2021

2. Safety

Scene A shows a large varying degree of responses where one user did not feel safe to walk on a later winter afternoon by placing their perception at scale point 1 to 27.3 % users feeling completely safe to walk and rating their scale at point 9. Even though 72.8 % of the user responses scales between moderate to sufficient feeling of safety ranging between 5-10, 27.2% of the users felt unsafe concluding the need for more illumination of the surroundings.

Scene B shows a clear response of 90.9% of users choosing between scale point 8-10 and stating their sense of safety in the experienced environment with one user feeling radically unsafe possibly due to the unusual surroundings and possibly a feeling of detachment from the environment of an urban city. This comparison shows more users felt safe in Scene B as compared to Scene A.

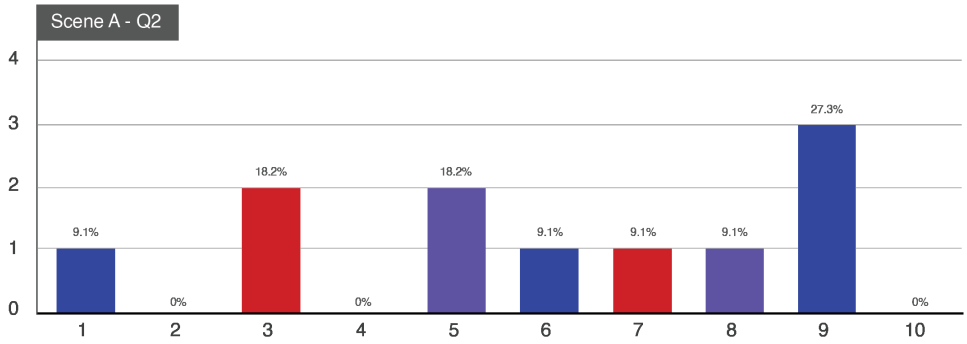


Figure 8.6 Safety, Scene A, User response bar graph, Tahlani.D, self produced, 2021

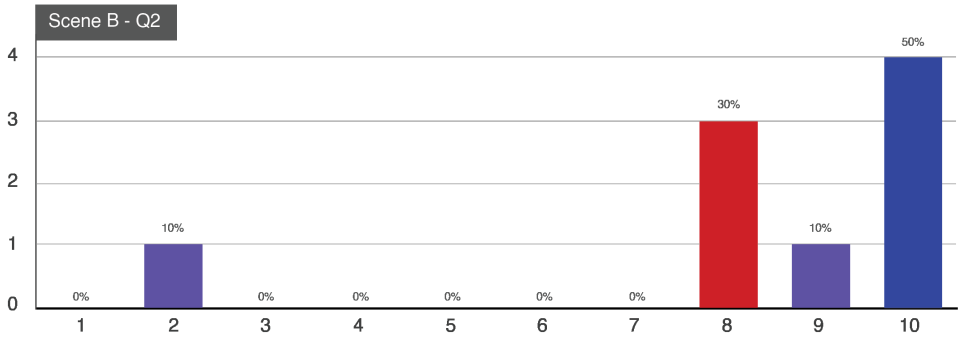


Figure 8.7 Safety, Scene B, User response bar graph, Tahlani.D, self produced, 2021

3. Feeling close to natural surroundings

Scene A shows a clear majority response of all users feeling close to their natural surroundings as they all chose the scale point between 7-10. However, Scene B has a varied response. While 63.7% of the users felt close to their natural surroundings rating between scale point 8-10, 27.3% of the users rated between 4-5 rating their feelings were moderate. It is analysed to be due to the fantasy element of scene B, that makes the environment feel more alien as compared to scene a which is a more usual setting, where they see the surroundings as they are. This concludes that more users feel close to their natural surroundings in Scene A as compared to Scene B.

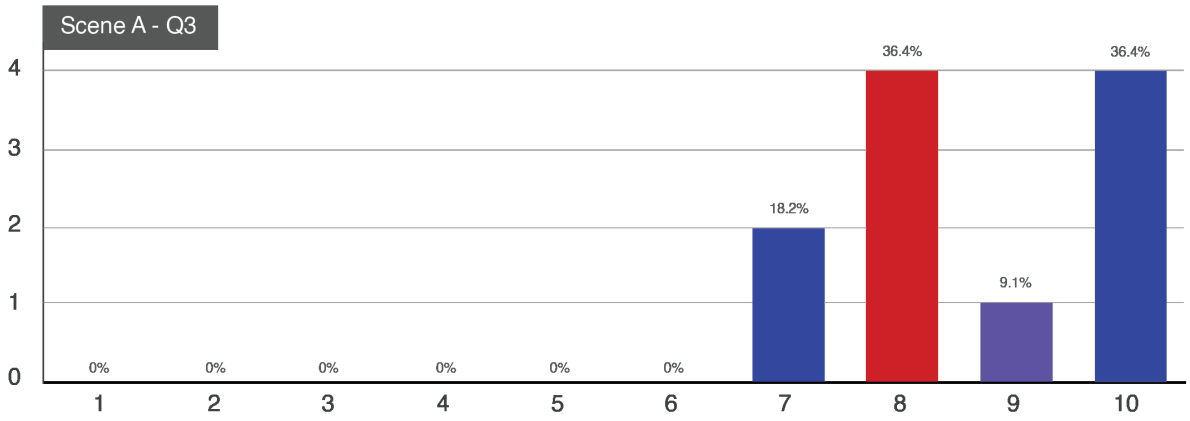


Figure 8.8 Natural Surroundings, Scene A, User response bar graph, Tahlani.D, self produced, 2021

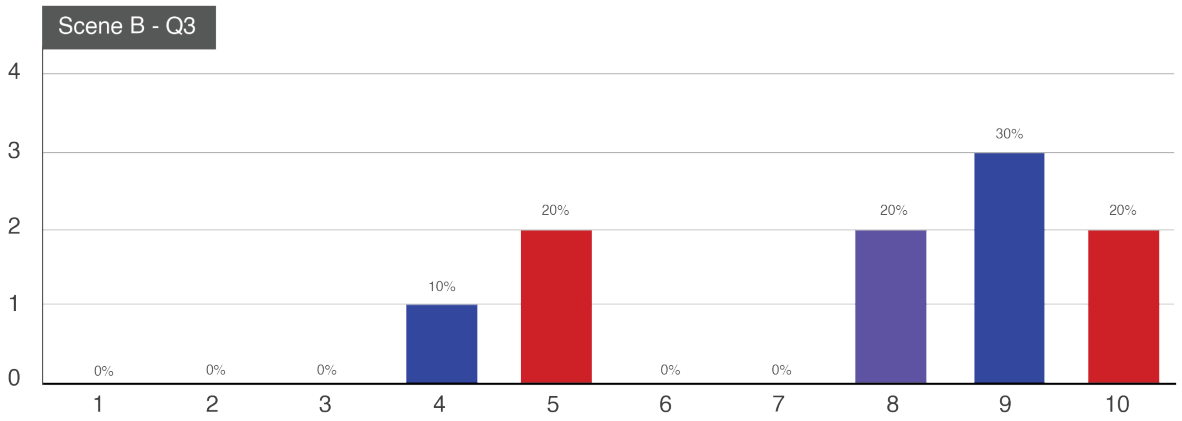


Figure 8.9 Natural Surroundings, Scene B, User response bar graph, Tahlani.D, self produced, 2021

4. Comfort and cozy

Scene A shows with a majority of 81.9% users agreeing or strongly agree to feeling cozy and comfortable in the environment. And two users felt neutral about their sense of comfort. Whereas, Scene B shows a larger majority of 90% users strongly agreeing or agreeing to the degree of comfort and coziness they feel in the atmosphere. With one user strongly disagreeing with the feeling of comfort which is assumed to be due to the uniqueness and alien nature of the environment which could make one uncomfortable as a drastic change. With the larger majority of 90% users, Scene B is concluded to be a more comfortable environment as compared to Scene A.

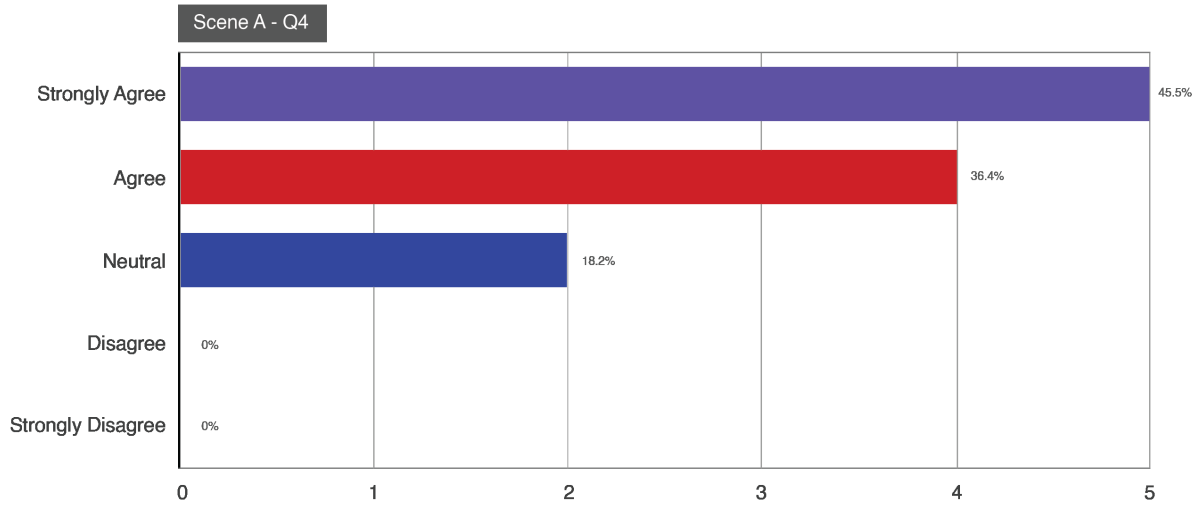


Figure 8.10 Comfort and Cozy, Scene A, User response bar graph, Tahlani.D, self produced, 2021

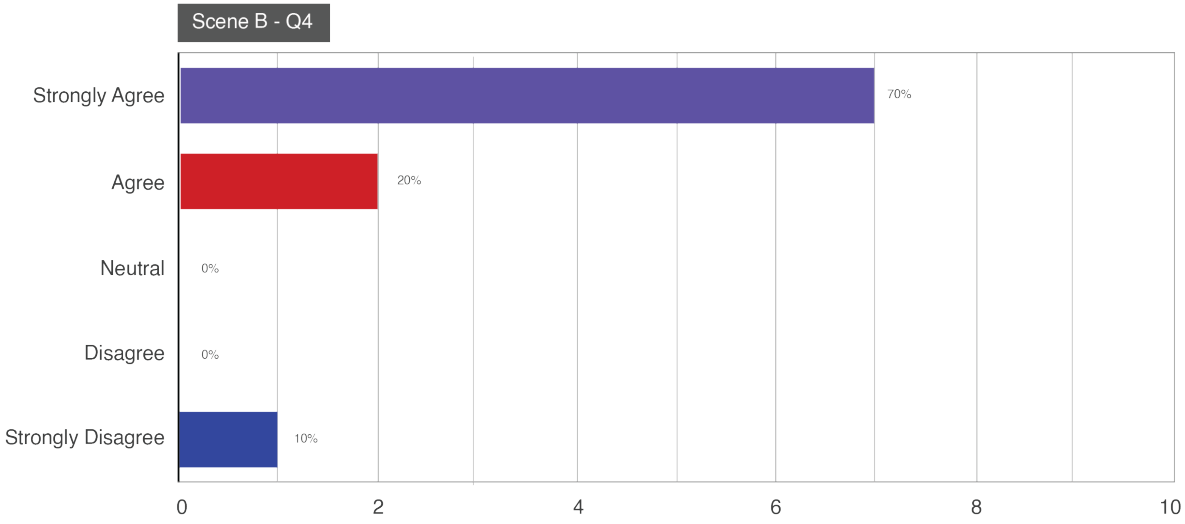


Figure 8.11 Comfort and Cozy, Scene B, User response bar graph, Tahlani.D, self produced, 2021

5. Emotions and reactions

The reaction cards help users put words to their experiences and define them through guided options. Scene A has been perceived and described by the users to be comfortable, cozy, natural, fantasy, pleasant, intimate, dim, lively, relaxed, personal and depressing. Majority of the users indicate a pleasant and positive response to their experience as scene A. Scene B is described through emotions of comfort, coziness, natural, fantasy, static, pleasant, intimacy, dim, bright, lively, relaxed, detached, personal, enriching, uncomfortable, unpleasant and tense. This experience of users seems more contradicting and varying in scene B, with some users finding it to be comfortable yet detached, intimate yet lively and definitely the majority agrees to experience a sense of fantasy. These reaction cards help in understanding the users emotions and feelings of the atmosphere and validate it to the design intention.

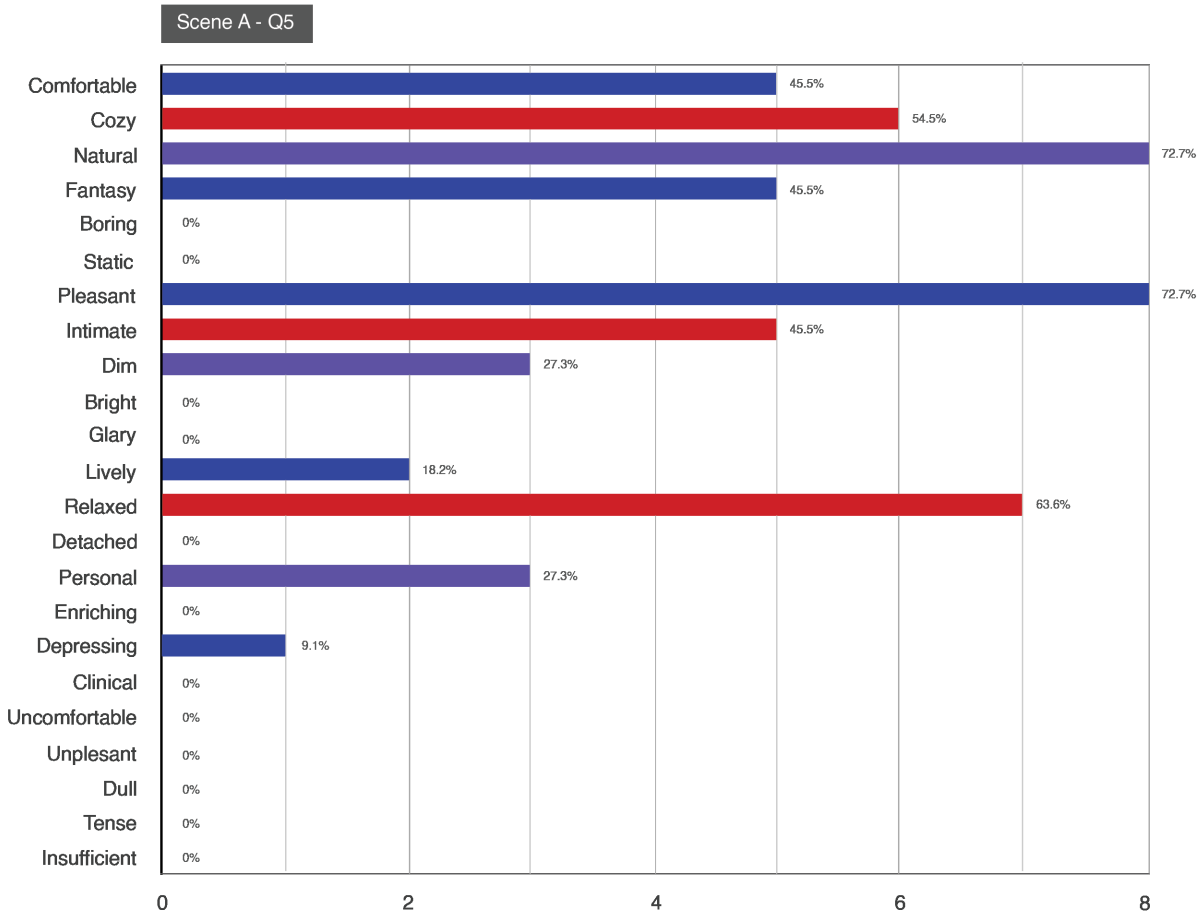


Figure 8.12 Emotions and Reactions, Scene A, User response bar graph, Tahlani.D, self produced, 2021

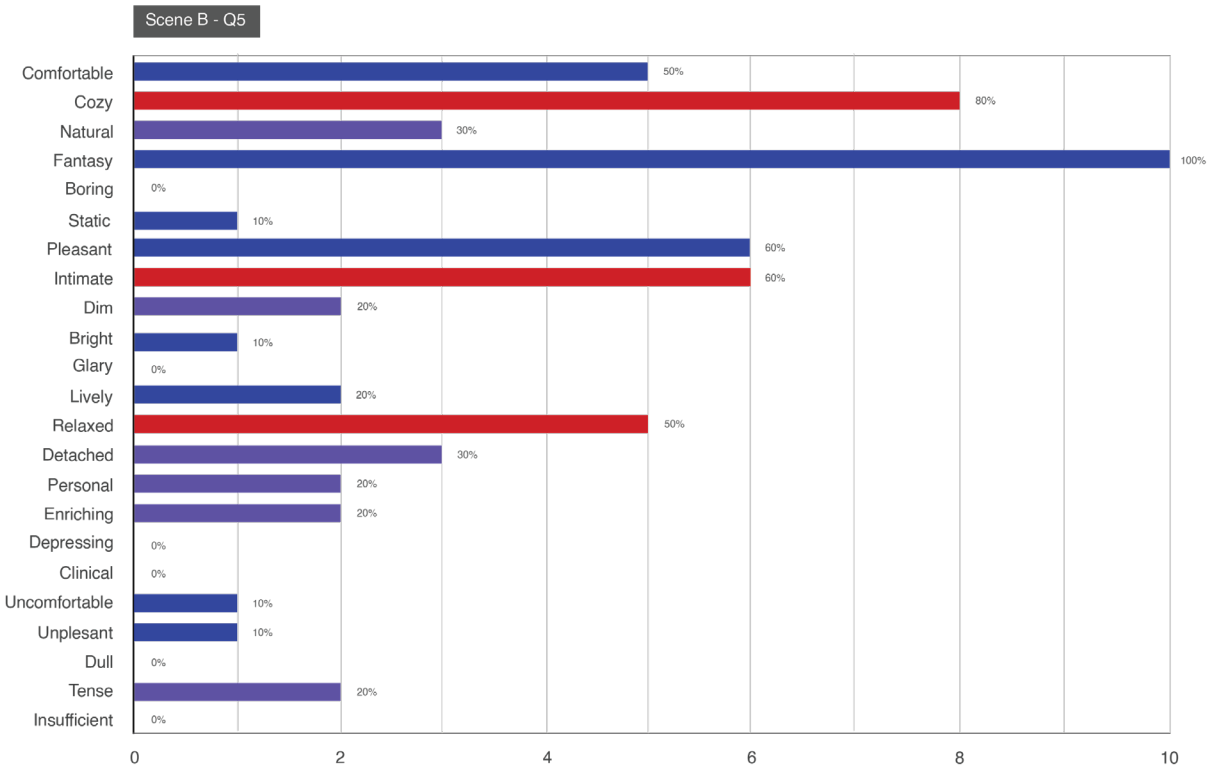


Figure 8.13 Emotions and Reactions, Scene B, User response bar graph, Tahlani.D, self produced, 2021

6. Preference

10 out of 11 users prefer Scene B to Scene A. The users use the following words to defend their preference through an open ended question generating a qualitative response. The responses have been analysed based on categorizing the repetition of words used by multiple users and deriving quantitative data from it.

Open-ended question Response Data Collection													
Which scene did you prefer and why?	**Colourful**	**Magical/ Fairytale**	**Bright**	**Aware of nature around**	**New/Different**	**Stars**	**Connected/ Immersive**	**Safe**	**Festival/ fun**	**Alive**	**Positive feeling**	**Comfortable**	**Total Response Category Count**
Total respondents who answered X	4	2	3	5	8	2	6	2	4	3	4	3	32
% of respondents who answered X	12.5%	6.3%	9.4%	15.6%	25.0%	6.3%	18.8%	6.3%	12.5%	9.4%	12.5%	9.4%	
A													
I cant really decide. The A was less lagged, but the B one war more comfortable and atmospheric, intimate, bright and festival celebration like			1						1			1	
I enjoyed the second simulation much better, light and colors made the scene magical and I felt like that would be a place i would visit all the time. The stars and the light in the park was very connected and looked very natural and like they belong together.	1	1		1		1	1						
Scenario B, it was a new experience and made me connect to the nature around.				1	1		1						
scene B, a lot of things to see, gave me something new and interesting, it was beautiful but I can't imagine it in real life. It was fun, childish, immersive and intense Also even though i prefer this it should not be everywhere.					1		1		1				
Scene B, as it was an unusual experience, was exciting to witness with the colours around, the glowing stones added a certain sense of life and made the experience come alive which was really great. And the choice of colours gave a positive feeling, while still meeting the basic requirements of visibility and safety.	1				1		1			1	1		
scene B, its because its unknown, coming from the plants makes me feel close to nature, its the plants choice, it doesn't feel like lighting for humans. different colours and different sources add variety.	1			1	1		1			1			
scene B, more lighting makes me feel safer while in the first scene some parts of the pathway might not be lit completely. more visible, has a unique vibe, safe, festival feeling, looks like a fairytale, yet subtle not flashy. Surreal feeling, felt a bit artificial but really enjoyed the experience.		1			1			1	1		1		
second one, there was more lighting and it felt more personal and more comfortable than the one before. I felt more secure and this makes me rate the second scenario as the best one in terms of visibility. It felt like a different world, focussed on nature, made me appreciate where every tree was as in scene a I only focussed on the path.			1	1	1			1			1	1	
The second one. I felt in a more cozy space where you can feel more the essence of the space made to enrich the environmnet.More sense of detail, I could observe more around me, unusual experience very organic				1	1	1	1			1	1	1	
The second scene, it was the brightest and had the prettiest colors and brightest colors, it light up the woods and made it feel spacy	1		1		1				1				

Figure 8.12 Preference, Open ended answers, User response analysis, Tahlani.D, self produced, 2021

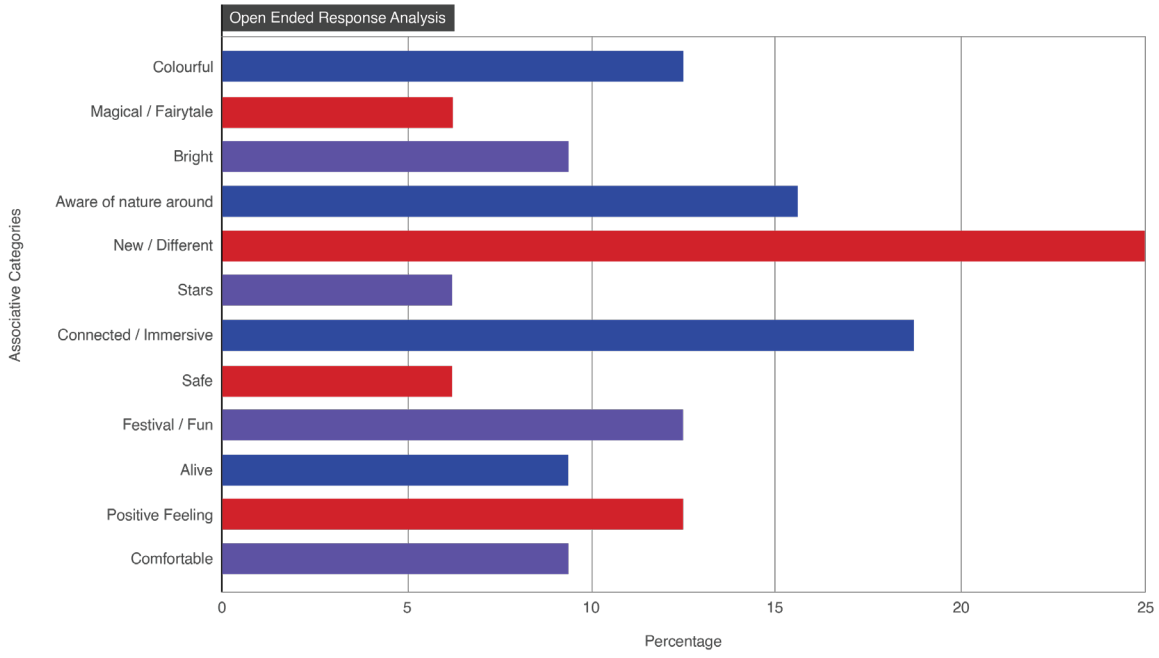
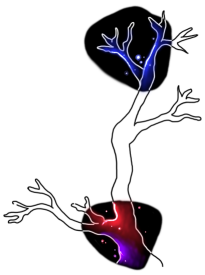


Figure 8.12 Preference, Open ended answers, User response graph, Tahlani.D, self produced, 2021

The data derived from the qualitative responses of the users is categorized into the following associations, emotions and reactions of being **colourful, magical/ fairytale, Bright, aware of the nature that surround them, New/different, stars, connected/immersive, safe, festival/fun, alive, positive feeling and comfortable**. These associations help describe the reasons why the users prefer scene B and can be correlated with the success criteria to validate the design concept.



09 EVALUATION

The following chapter discusses on evaluating the proposed design concept with the set criteria and understandings derived from the users response. They compare the goals with the solution proposed and discover if they are fulfilled.

09 Evaluation

This chapter discusses the evaluation of the proposed design concept with the set criterias, to declare if they were fulfilled.

Biologically Beneficial **Illumination for Biodiversity - Trees**

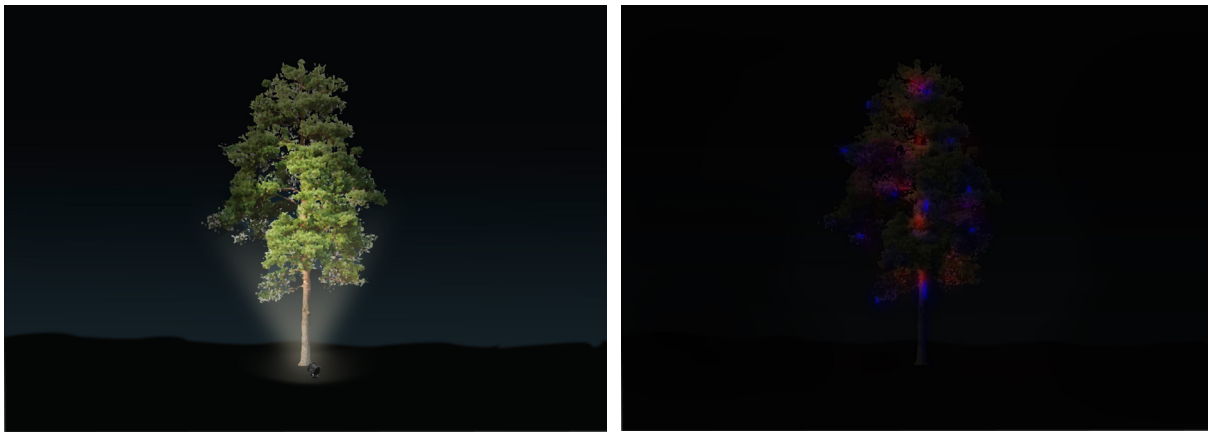
Illuminating trees with specific colour temperatures from the light spectrum can be used as a strategy to evolve urban lighting to be biologically and aesthetically efficient.

Urban Glowscape uses colours from the light spectral distribution that have proven to improve the growth of plants and trees. These colours include Red, Blue and Ultraviolet. Red light wavelengths (particularly around 660nm) encourage stem, leaf, and general vegetative growth – but most commonly, tall, stretching of leaves and flowers. A balanced pairing with blue light is necessary to counteract any overstretching, like disfigured stem elongation. Blue light spectrum is widely responsible for increasing plant quality especially in leafy crops. It promotes the stomatal opening which allows more CO2 to enter the leaves. Blue light drives peak chlorophyll pigment absorption which is needed for photosynthesis. UV light is often associated with darker, purple coloring – in fact, small amounts can have beneficial effects on color, nutritional value, taste, and aroma. Research shows environmental stress, fungus, and pests can also be reduced using controlled amounts of UV. (Ouzounis.T, 2015), (Naznin.M,2019)

The source of illumination designed for trees as a part of this concept uses these specified colours in relative proportions according to its species and growth stage. Such a strategy not only allows improvement in growth of the trees and plants but also creates a unique experience of colours blending into the natural environment. Fulfilling the criteria of Illuminating trees with specific colour temperatures from the light spectrum can be used as a strategy to evolve urban lighting to be biologically and aesthetically efficient.

Reduce Light Pollution **Impact of illumination on environment at night**

If illuminating systems for urban public spaces are programmed to be adjusted in intensity as per the time of the day, seasonal and growth evolutions in trees, it can help minimize light pollution.



Scene A Scene B

Figure 9.1 Light Pollution Comparitive analysis based on perception, Tahlani.D, Self produced, 2021

Above are illustrations of a comparative view between existing lighting practice and the proposed lighting concept. From the point of view of perceived value of intensity of illumination, it is clearly observed that the scene A of existing lighting strategy is visually much brighter, higher intensity illumination. It is also observed that the directionality and distribution of illumination in scene A is wider and emits a considerable amount of light into the atmosphere. However, in scene B it is observed that illumination

intensity is very low, just enough to make the tree visible. And the distribution of illumination is omni directional yet due to low intensity it emits relatively less light into the atmosphere. And its direction of being placed along the structure of the tree allows it to illuminate the tree significantly reducing the possibility of light trespass. It is also observed that the concept introduces the possibility to adjust the intensity of illumination according to the time of the day and the seasonal change in trees as shown in figxxx. This reduces the amount of light that leaks into the atmosphere by a significant amount helping to minimize light pollution.

From a perceived state of evaluation, it can be concluded that the proposed design is a strategy that can help reduce light pollution in a relative comparison proving the criteria of, illuminating systems for urban public spaces that are programmed to be adjusted in intensity according to the time of the day, seasonal and growth evolutions in trees, it can help minimize light pollution.

Natural Night Light **Urban Nightscapes**

Majority of urban inhabitants prefer volumetric lighting of public parks and are able to adapt to low levels of illumination.

Looking into a hopeful future with street lighting poles becoming obsolete, public lighting will eventually transform and evolve into modular lighting structures with the capability of creating luminous volumes and design different experiences of night with varied dimensions. These user-friendly environments with volumetric lighting approach would be able to cater to community well being by developing anti stress environments, rhythms, light therapy, chromotherapy, dark therapy and encourage interactions and encounters. It will have the ability to transform its form and shape its surrounding illuminated environment to interact visually with the space and people to enhance, highlight and multiply its purpose and functionality. (Narboni R, 2020) (Urban Glowscapes, Chapter 1.4)

The proposed design concept utilises the nature in our cities and converts them into luminous volumes that can create a new typology within urban lighting. Majority preference of the users from tests conducted to compare existing scenarios with the proposed design using VR headset was Scene B i.e., proposed concept. This helps us to conclude that majority users preferred volumetric lighting. And through the perceived scale of visibility test, majority users responded to a scale between 8-10, showing that they were able to adapt to low levels of illumination as shown in Fig 8.5 in Chapter 8.3. The design is able to achieve a composition of colours and low level illumination to create a unique experience for its users. It makes the user appreciate the night sky while immersed into their natural surroundings
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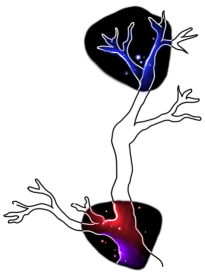


10 FUTURE WORK & DISCUSSION

The purpose of this chapter is discuss the significance of the findings and evaluations explained in the previous chapter, add on any new understanding that emerged as a result of the problem framework as summarised in the research question. It also provides an outlook on the developments and improvements that can be made in the future with new technology and possibities.

10 Future Work and Discussion

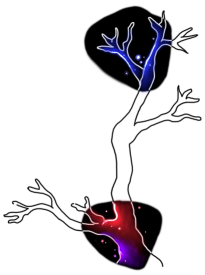
The purpose of this chapter is discuss the significance of the findings and evaluations explained in the previous chapter, add on any new understanding that emerged as a result of the problem framework as summarised in the research question: How can illumination of trees be designed to be biologically beneficial, reduce light pollution as well as contribute towards creating natural night light? The proposed concept is able to fulfill the defined criterias as discussed in the previous chapter and it also proposes a vision for the future, to create illumination through luminous volumes of our natural surroundings. This new vision is a direction towards a new typology in urban lighting design. It provides an entire new dimension to explore and create luminous environments and zones in urban cities. This movement is illustrated in this project in a harmonious balance with nature. It is lighting for people and its surrounding biodiversity. It does not solely rely on functional qualities, it allows an opportunity to explore qualitative aspects of a users experience whilst creating adaptability to lower levels of illumination and making room for darkness and natural light of the night sky.

"The gradual abandonment of systematic, continuous and ubiquitous public lighting will pave the way for night learning and new therapies based on the pleasure of being and moving in deep darkness." - (Narboni.R, 2020)

It is also to be understood that the thesis projects demonstrating various graphs of spectral distribution peaks evolving with the growth and seasonal change in trees have been entirely based on understanding and assumptions from the knowledge of different research papers and studies. (Ouzounis.T, 2015), (Naznin.M,2019). To prove the improvement in growth, there has been no scientific evidence produced or conducted under the circumstances presented. This is due to limitations of time, scope of the project and absence of resources due to Covid19 pandemic and remains to be a study to be conducted in the future.

The design initiated in this thesis project is entirely conceptual supported with a background of existing knowledge from theories and case studies. It is unable to provide any technical viability or an existing implementable solution in this present age. Supported with case studies of Glowing plants and Advent of BioLEDs as stated in chapter 4.4 and 4.3 respectively, it envisions a possibility of a futuristic development that will allow the positioning, distribution and appearance of the lighting used in the concept to be created in reality.

The holistic approach that can be taken to create a 24th city true to its meaning that designs a nighttime experience for people in coordination with the natural rhythms of the environment and the dynamic needs and requirements of the public. (Urban Glowscapes, Chapter 5.3.2) With the new typology proposed with this thesis project it aims to serve as an example of a lighting design initiative that is flexible and is adjusted according to the time of the day and year as it defines the occupancy hours by the users and also to maintain the circadian rhythm of both humans and nature. It encourages the importance of adjustability as it not only helps maintain the biological clock of humans and biodiversity but also helps in energy consumption and reduced light pollution. The research encourages a positive change in night time experience of urban landscapes in the future.



11 CONCLUSION

The following chapter concludes the thesis project with the existing and new knowledge, inspirations and ideas and proposed design concept which has been evaluated through the user test and fulfilment of the success criterias. It is the deliberation phase of the design process model, that reflects on the entire process with the problem statement initiated for this project.

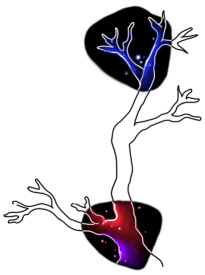
11 Conclusion

This master's thesis project intended to derive an illumination strategy for trees that is **biologically beneficial**, aims to **reduce light pollution** and can contribute in creating **natural night light**. The investigation started with analysing a project I worked on as an intern in the year 2020 at fortheloveoflight in Copenhagen. The aim of the project was to design a luminaire, a park light that illuminates the horizontal path and trees in its surroundings. This was done by using multiple luminaires inside the main shell of the park light that can be adjusted on site depending on the size, species and growth evolution of the tree. From this analysis and experience of my internship, I further investigated existing practices of illuminating trees and plants in urban landscapes. And discovered that artificial lighting was in fact extremely harmful for the biological clock of the trees and can alter their and surrounding biodiversity's circadian rhythm creating adverse effects on their health and our planet. The environment affects the complete set of physiological and psychological reactions of the living organisms. Pollution of the basic and essential components of the environment, i.e., soil, water and air threaten our everyday life. Human urban civilizations with increasing demand for intensive illumination at night disturbs the environment and influences the circadian rhythm of all living organisms. (chapter 5.1)Hence, the problem statement/ research question let to the development of a lighting stratergy for illuminating trees that can minimize the biological damage of the biodiversity, light pollution and help create an experience of a natural night environment.

This thesis project is an in depth investigation into obtaining a light recipe that can be used to create a unique experience for city inhabitants, and essentially cause minimal damage to our biodiversity. Before any further conclusions are stated, this report strongly stresses on the importance of sensitive lighting considerate of its natural surroundings and its ability to affect the social and mental well being of the urban inhabitants. We also recognise the need of building connection between humans and the natural built environment, as lighting has the ability to transform the spatial experience and perception of the environment among the users.

Based on existing knowledge obtained with the theories studied in this thesis report, it can be concluded that through use of red(500-600nm), blue (400-500nm) and UV(100-400nm) colours derived from the spectral light distribution of daylight that are essential for photosynthesis can help in improving the growth of plants (Ouzounis.T, 2015), (Naznin.M,2019). The design proposal of Urban Glowscapes uses these spectral colors to illuminate trees and provides the adjustability and flexibility to adapt to the growth, seasonal changes in trees and the time of the day. The strategy of using different spectrums that help in chlorophyll absorption hence, growth and providing light the ability to adapt to the evolution of the tree proves to be biologically beneficial. This ability to adjust intensity and adapt to the time of the day and year reduces energy consumption and minimizes light leak into the atmosphere minimizing light pollution. The project is able to create a unique homogeneous experience of being in our natural surroundings, with low intensity illumination. It discovers an entirely new typology of illumination through luminous volumes creating room for appreciation of darkness and the night sky.

After the development of the concept, this report further investigates into the validation of the design through a user experience test through virtual reality. The resulting preference of the test is observed to be the proposed design with inputs of emotions and feelings of the atmosphere a user experiences in the stimulated environment. With the future possibility of such concepts being adopted globally in urban city landscapes we can observe a significant reduction in the use of streetlights. Such transformative spatial experiences encourage public interaction with nature and create adaptability to darkness which is a significant step towards creating a natural night light. In conclusion, this thesis project was an attempt to raise awareness of conscious lighting design and approach in urban environments. It encourages defining effective parameters of design for both humans and biodiversity. A harmonious balance between functional and sustainable lighting can result in a unique qualitative experience for pedestrians, enhance the identity of the urban space and signify its presence in the city and enhance the wellbeing of residents and nature in urban landscapes.



12 REFERENCE & APPENDIX

12 REFERENCES

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TAHLANI.D (2021), Self produced, Initial Concept; *Illustration*

TAHLANI.D (2021), self produced, Story Board A/B/C; *Illustration*

TAHLANI.D (2021), self produced, Persona Character; *Illustration*

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TAHLANI.D (2021), Self Produced, Light intensity adjustment graph based on time of the day and year; *Illustration.*

TAHLANI.D (2021), Self Produced, Light intensity adjustment based on the structure of the tree; *Illustration.*

TAHLANI.D (2021), Self produced, Concept renderings through Unreal Engine 4.2; *Image*

TAHLANI.D (2021), self produced, Visibility scale, User response bar graph; *Illustration*

TAHLANI.D (2021), self produced, Safety scale, User response bar graph; *Illustration*

TAHLANI.D (2021), self produced, Feeling of being close to nature, User response bar graph; *Illustration*

TAHLANI.D (2021), self produced, cozy and comfortable, User response bar graph; *Illustration*

TAHLANI.D (2021), self produced, emotions and reaction, User response bar graph; *Illustration*

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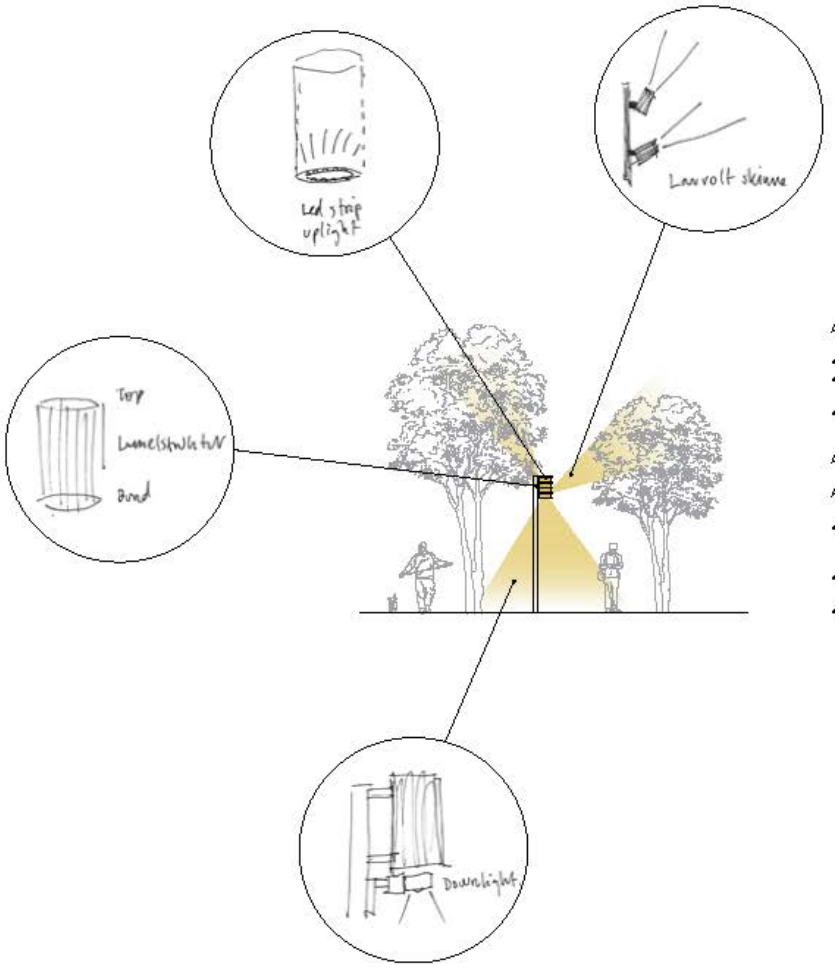
12 APPENDIX

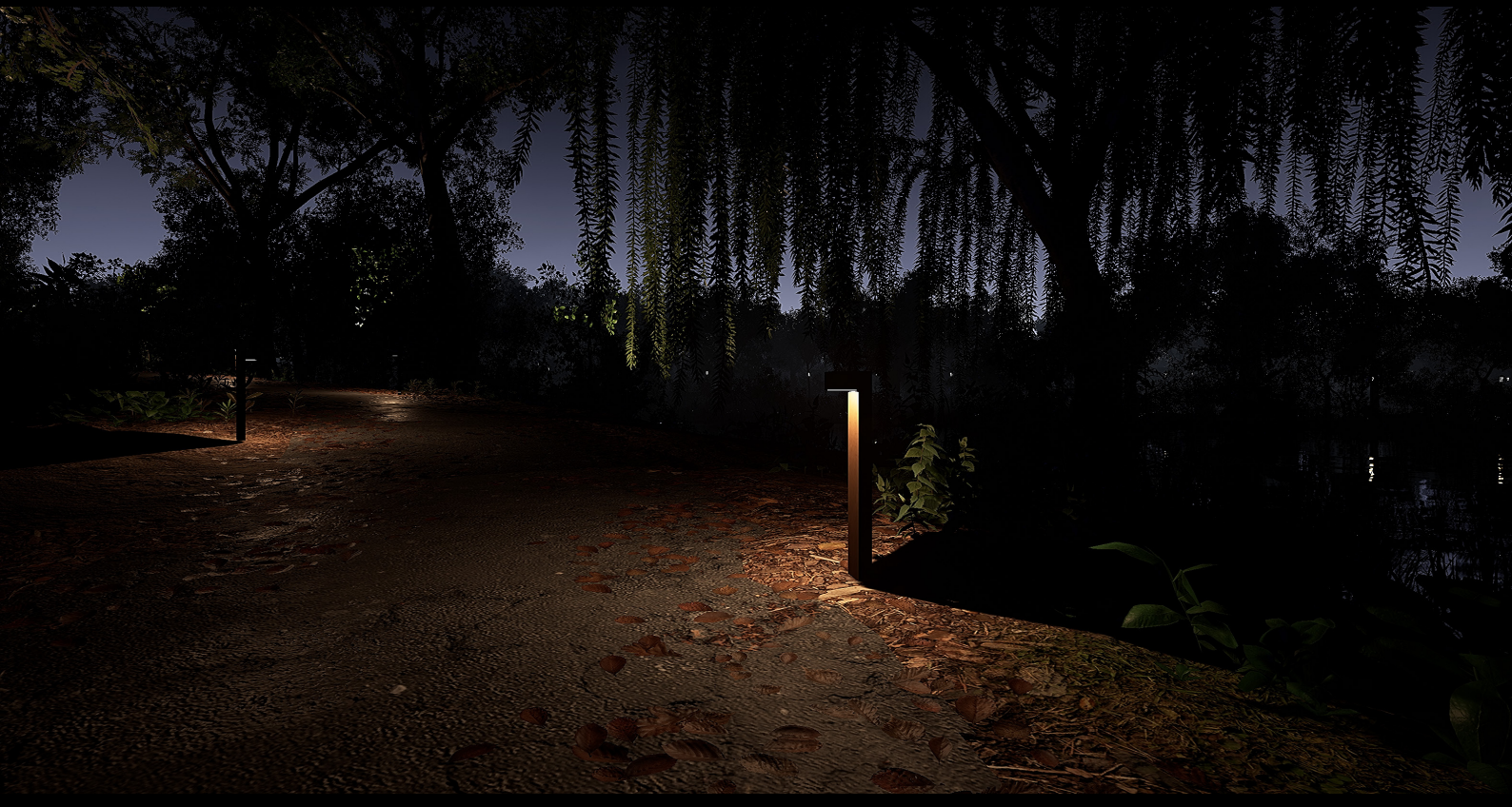
Posten Parklight a project worked on under fortheloveoflight, copenhagen. These illustrations represent the multifunctionality of the luminaire. By using different sources of illumination inside the main shell of the parklight, each with a different function, adjustable to the growth of trees, seasonal changes and intensity variation with the time of the day.



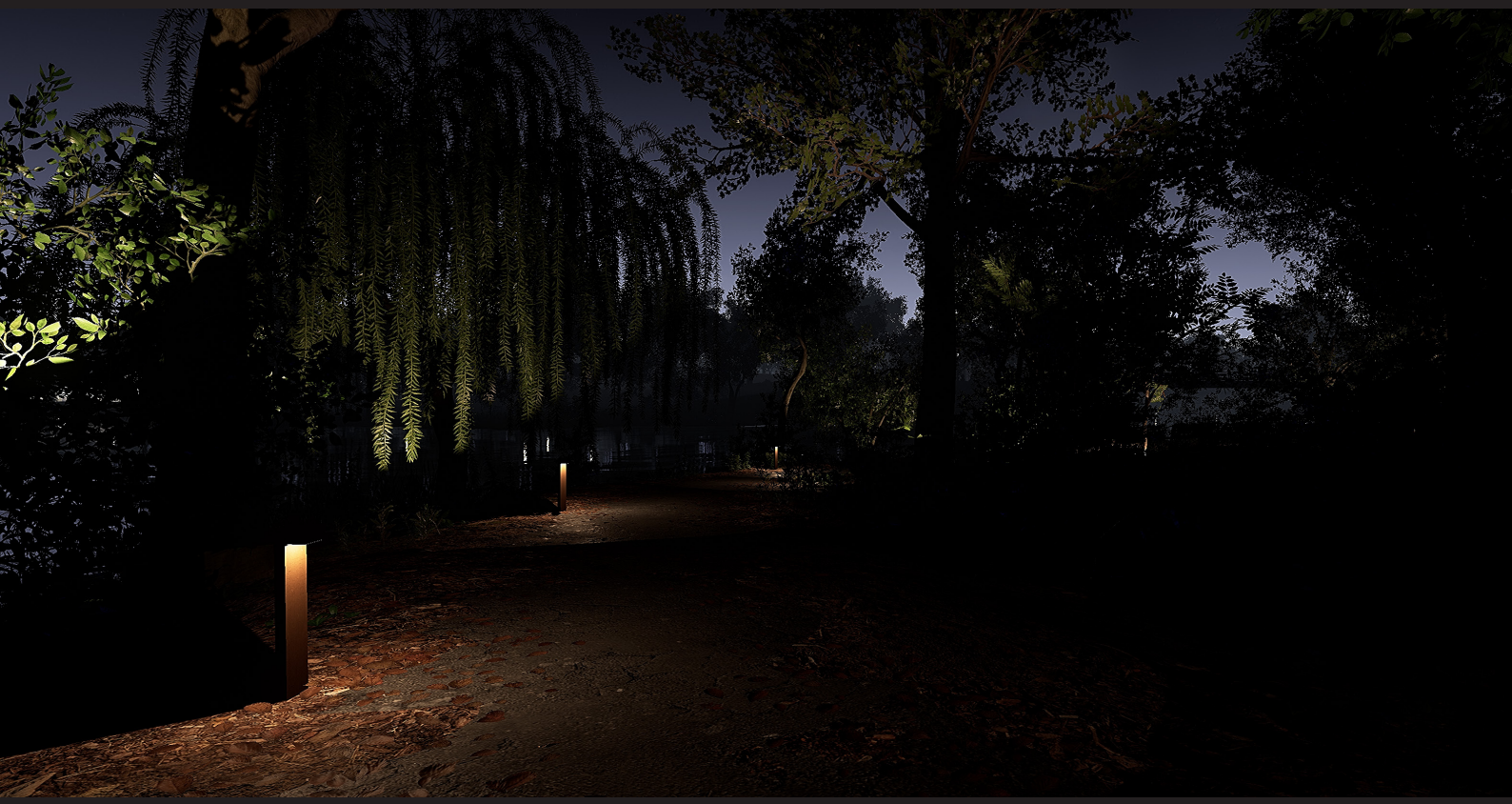
Timeline	March				
Content/ Intention	9 1st-7th	10 8th-14th	11 15th-21st	12 22nd-28th	13 29th-04th
Chapter 1: Introduction					
Chapter 2: Method					
Chapter 3: Case studies and theoritical framework					
Chapter 4: Analysis				Draft 1 to be sent to supervisors	Supervision
Chapter 5: Experiement with VR		Pinup 1			
Chapter 6: Survey and Outcome Study					
Chapter 7: Design Proposal					
Chapter 8: Evaluation					
Chapter 9: Conclusion					
Completed Draft and last changes					
Portfolio					

April				May			
14 5th-11th	15 12th-18th	16 19th-25th	17 26th- 2nd	18 3rd-9th	19 10th-16th	20 17th-23rd	21 24th-28th
	Supervision		Pinup 2			Draft 2 to be sent to supervisors	
							Final submission of report and portfolio

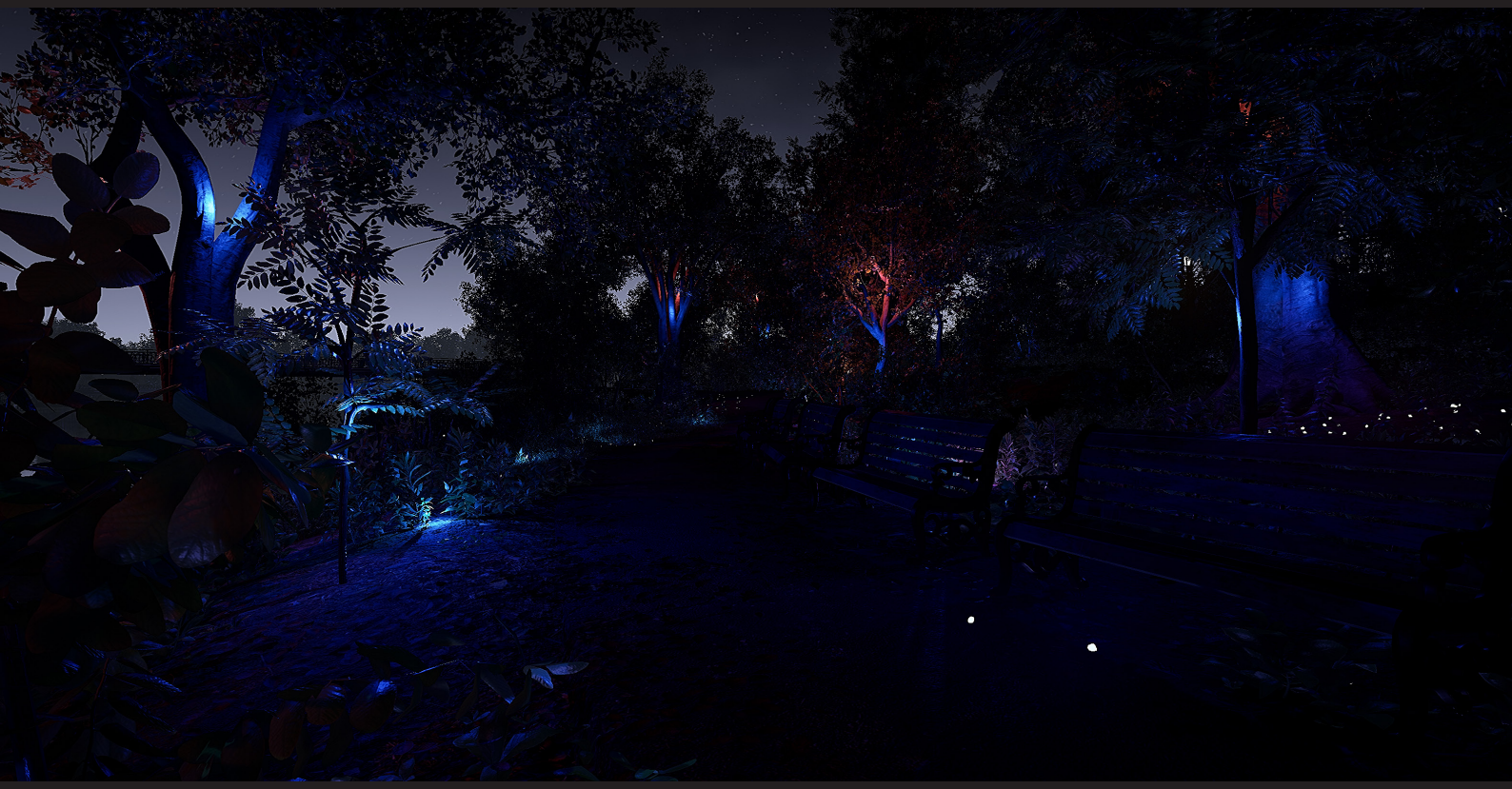
SCENE A- RENDERS



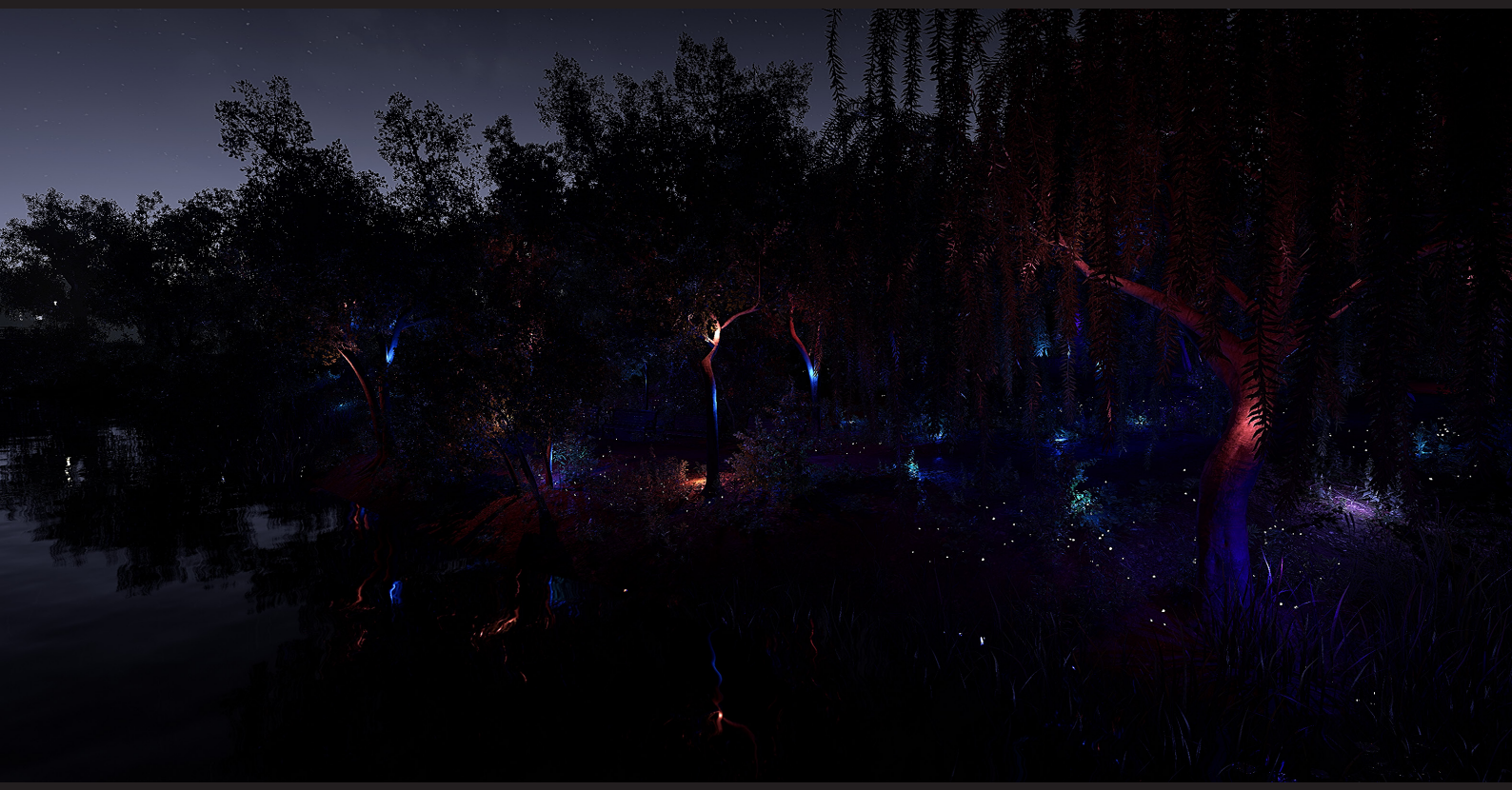
SCENE A- RENDERS

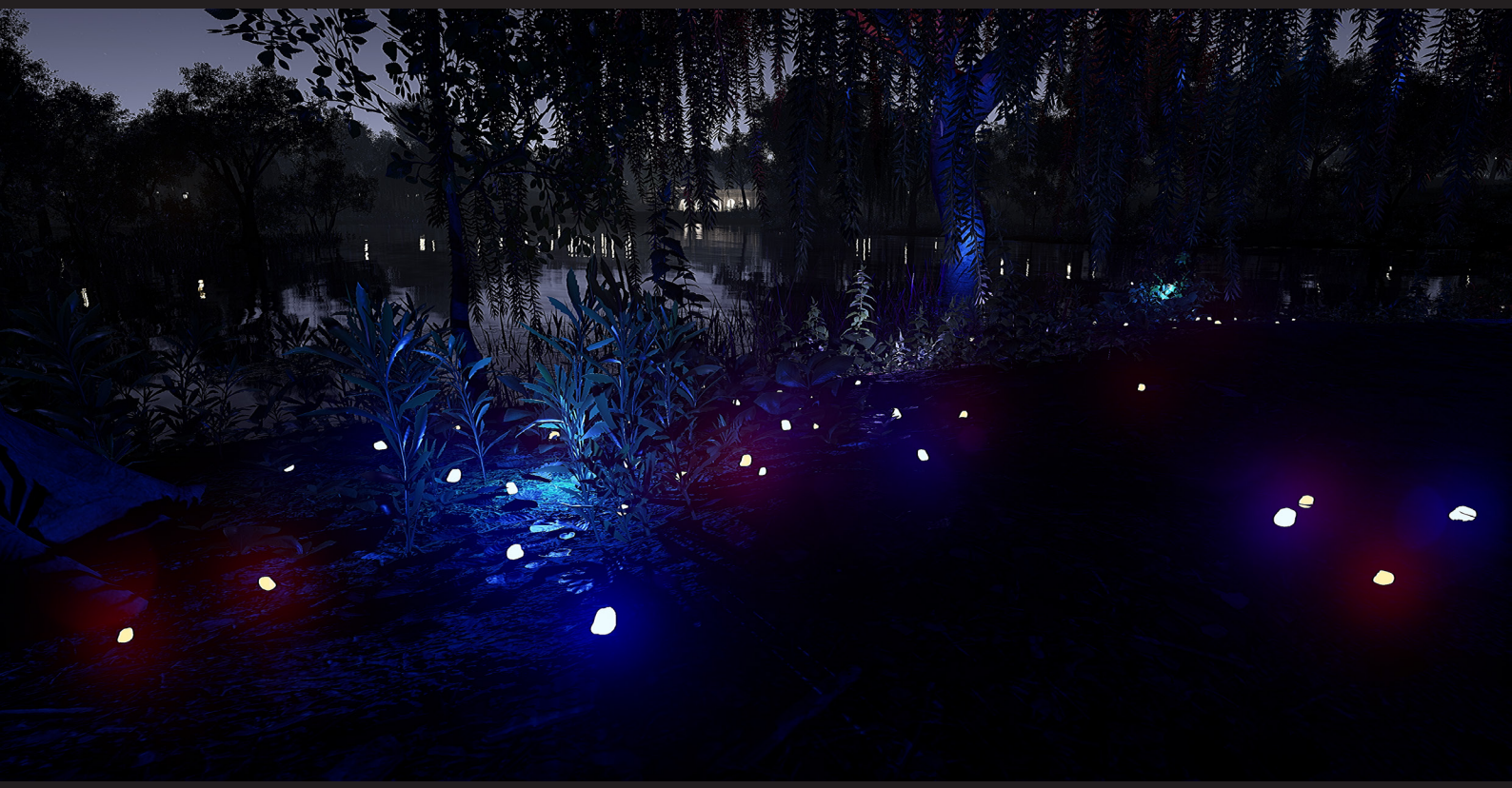


SCENE B- RENDERS



SCENE B- RENDERS





Survey Questions are as follows,

Please find the google link attached: https://forms.gle/nCFS8kLrQ5idNWr2A

1. Do you have sufficient visibility as you walk along the park? Rate the scale based on your comfort of visibility.

_____
0 10

2. If you were to bike or walk along this park on a winter late afternoon, would you feel safe? Rate the level of safety and comfort you feel.

_____
0 10

3. Does the experience of walking along this park feeling natural to you? Rate based on the perception scale

_____
Absolutely Yes, I think Maybe Not Likely No

4. Do you feel cozy and comfortable in this atmosphere?

_____
Absolutely Yes, I think Maybe Not Likely No

5. Please choose among the following reactions and emotions that help you relate to your experience of the space and its atmosphere. You may choose as many words as you like,

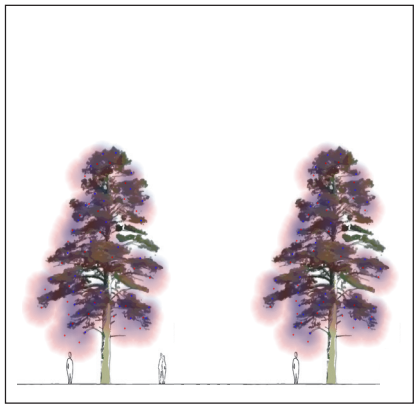
Comfortable, Cozy, Natural, Fantasy, Boring, Static, Pleasant, Intimate, Contrasting, Dim, Bright, Glary, Lively, Relaxed, Detached, Personal, Enriching, Unpleasant, Uncomfortable, Depressing, Clinical, Unnatural, Dull, Tense, Insufficient.

6. Could you describe your experience in a few words and give a review if any?

_____

Scenario A
Standard Street lighting
Transition hours from sunset to dark

Comparitive Analysis



Scenario B
New street lighting typology (volumetric)
Transition hours from sunset to dark

Individual responses to open ended question (Q6):

1. A

2. I cant really decide. The A was less lagged, but the B one war more comfortable and atmospheric, intimate, bright and festival celebration like

3. I enjoyed the second simulation much better, light and colors made the scene magical and I felt like that would be a place i would visit all the time. The stars and the light in the park was very connected and looked very natural and like they belong together.

4. Scenario B, it was a new experience and made me connect to the nature around.

5. scene B, a lot of things to see, gave me something new and interesting, it was beautiful but I can't imagine it in real life. It was fun, childish, immersive and intense Also even though i prefer this it should not be everywhere.

6. Scene B, as it was an unusual experience, was exciting to witness with the colours around, the glowing stones added a certain sense of life and made the experience come alive which was really great. And the choice of colours gave a positive feeling, while still meeting the basic requirements of visibility and safety.

7. scene B, its because its unknown, coming from the plants makes me feel close to nature, its the plants choice, it doesn't feel like lighting for humans. different colours and different sources add variety.

8. Scene B, more lighting makes me feel safer while in the first scene some parts of the pathway might not be lit completely. more visible, has a unique vibe, safe, festival feeling, looks like a fairytale, yet subtle not flashy. Surreal feeling, felt a bit artificial but really enjoyed the experience.

9. Scene B, there was more lighting and it felt more personal and more comfortable than the one before. I felt more secure and this makes me rate the second scenario as the best one in terms of visibility. It felt like a different world, focussed on nature, made me appreciate where every tree was as in scene a I only focussed on the path.

10. The second one. I felt in a more cozy space where you can feel more the essence of the space made to enrich the environmnet.More sense of detail, I could observe more around me, unusual experience very organic

11. The second scene, it was the brightest and had the prettiest colors and brightest colors, it light up the woods and made it feel spacy