Night Lights: An Ecological Lighting Plan for the Future University of Washington Campus

Autumn Davis

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Abstract

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The rapid environmental changes caused by human impact have led to a significant decline in the health and quality of life of various species on Earth. The built environment, in particular, often fails to address the needs of nonhuman inhabitants, leading to habitat destruction, invasive species, pollution, and climate change. This thesis explores how thoughtful exterior lighting design can mitigate these environmental changes and promote biodiversity.

Exploring the relationship between the built environment and nonhuman species, this paper shows the negative consequences of inadequate design and excessive electric lighting at night, including disrupted habitats, interruptions to vital ecosystem services, and contributions to biodiversity loss. By focusing on the potential of better exterior lighting design as a solution, this research highlights the importance of contextual and sensitive design approaches that consider the needs and behaviors of nonhuman inhabitants.

Through site analysis and a review of existing literature, this thesis demonstrates the positive impact of well-planned exterior lighting design on various species, ecosystems, and the broader environment. The findings suggest that improvements in exterior lighting design can minimize the adverse effects of electric lighting on ecosystems.

This thesis emphasizes a collaborative and interdisciplinary approach to addressing the needs of nonhuman inhabitants in the built environment, contributing to developing a more inclusive and responsible design practice. By outlining practical strategies and recommendations, this research encourages professionals and stakeholders to adopt more environmentally conscious and sensitive exterior lighting design approaches, ultimately fostering a harmonious coexistence between humans and the natural world.

Night Lights:

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TABLE OF CONTENTS:

CHAPTER 01: INTRODUCTION

"To go in the dark with a light is to know the light. To know the dark, go dark. Go without sight, and find that the dark, too, blooms and sings, and is traveled by dark feet and dark wings." – Wendell Berry

The Project

This thesis project examines the existing outdoor lighting guiding principles created by the Illuminating Engineering Society (IES), Dark Sky International, and The Royal Astronomical Society of Canada from an ecological perspective. It builds upon a 2017 student-led study of the University of Washington campus exterior lighting and further explores the relationship between electric lighting and its ecological impacts.

Through a comprehensive review of the current literature, this study investigates the potential consequences of poorly designed exterior lighting for the local ecosystem, such as disrupted habitats, altered animal behavior, and diminished biodiversity. Furthermore, it considers the IES's outdoor lighting guidelines and their adherence to ecological principles, addressing potential shortcomings in these recommendations.

The following thesis includes a literature analysis focusing on the benefits and drawbacks of particular outdoor lighting design strategies in the context of the University of Washington's campus. By analyzing the impact of these designs on the local ecosystem, this study offers a more detailed understanding of exterior lighting and its impacts on the urban ecology.

Finally, the thesis proposes a list of updated, ecologically-focused guiding principles for the University of Washington's outdoor lighting decision-makers to consider when making future decisions regarding exterior lighting design. The recommendations are informed by the findings from the 2017 Lighting Roadmap and the current research, aiming to enhance the campus's sustainability, promote wildlife-friendly environments, and minimize the negative impact of electric lighting on the local ecosystem while still considering human safety and navigation needs.

This revised set of guiding principles adopts an ecological lens and incorporates the concerns of nonhuman inhabitants. It serves as a blueprint for the University of Washington campus and paves the way for greener, more inclusive design approaches in architectural lighting.

Why is this important?

Light pollution is a significant cause of stress for both humans and animals. The well-being of all depends on their natural circadian rhythm, which is disrupted by excessive exposure to light. "Circadian rhythm refers to the physical, mental and behavioral changes that occur in most living things over a 24-hour cycle, primarily regulated by the light or darkness of the surroundings."(B.Pharm, 2016)

Exposure to electric light at night negatively affects human health and can put people at a higher risk for sleep disorders, depression, obesity, diabetes, heart disease, and cancer.(Staff, 2023)
In urban areas, different types of animals—nocturnal, crepuscular, and vespertine—rely on darkness for hunting, feeding, and mating. Unfortunately, most streetlamps and outdoor lighting fixtures spread light in all directions, contributing to light pollution and stress on humans and nocturnal animals.

Light pollution is harmful to all living beings and is increasing by approximately 2% a year. A recent study shows that the average night sky has increased brightness by nearly 10% in the past eleven years. Eighty percent of the world currently lives under light-polluted skies; however, 99% of the United States and Europe live with excessive light pollution. The good news is that this type of pollution can be mitigated easily and quickly by simply turning off, reducing, or changing exterior lighting.

Research Methods

The upcoming chapters of this thesis commence with a comprehensive review of current practices in outdoor lighting in the United States. It delves into the impact of exterior lighting on nonhuman species and their habitat. The third chapter outlines the rationale for selecting the University of Washington as a study site, citing its unique blend of urban and natural environments. The data collection method combines observation and existing documentation from the 2017 campus study, which is described in detail.

The fourth chapter presents the current state of exterior lighting practices in the United States and explores the effects of exterior lighting on animal habitats. It also examines the link between the University of Washington's outdoor lighting design and the disruption of nocturnal animals' habitats and analyzes the impact of light pollution on the campus. In the fifth chapter, proposed design guidelines created from the research for this project are described. Finally, the conclusion summarizes the findings, recommendations, and implications for the University of Washington campus.

Personal Interest

As a kid growing up, I remember being afraid of the dark. I always had a night light and would make sure to check the closet and under my bed for monsters before hopping into bed and pulling the covers up tight. As I think back on this, I only remember being afraid of the dark when I was inside. Something about dark doors and hallways seemed to scare me, but when I was outside, the nighttime was a magical time full of fireflies, shooting stars, and moonlit walks. My family lived at a state park for a few years, and the stars were easy to see and rarely blocked out by light pollution. I remember multiple groups of people with large telescopes gathering at the park to look at different planets and star constellations on nights with a new moon. I was too young to fully understand why the clarity of the night sky was so special, but I do remember how excited everyone was.

When I first moved to Seattle in the fall, I found myself muttering the same phrase most people who move from southern latitudes say, "Ugh, it's so dark." I found myself staying indoors once the sunset, but quickly realized that it felt like the walls were closing in by spending so much time inside. Eventually, I decided to brave the dark and started going on walks with my dog after sunset. At first, I strapped lights to my dog, myself, and the leash between us but noticed that the light bubble I created made it harder to decipher my surroundings. I turned all the lights off and realized that once my eyes adjusted to the dark, it was easy to see, and that childhood love of moonlit walks and being able to see the stars came back. Those night walks became a much-needed break from screen time and bright exterior lights. I had not realized how much I missed the calm and quiet of dark moonlit walks until then.

My love of moonlit walks inspired my interest in darkness, light pollution, and ways to design better urban landscapes.

CHAPTER 02: LITERATURE REVIEW

"It often seems to me that the night is much more alive and richly colored than the day" – Vincent Van Gogh

The Impact of Exterior Lighting on Humans

Humans have sought brighter and more energy-efficient lighting since the discovery of fire. (Aileen Hallie, 2023)The most recent iteration of lighting technology, light emitting diode (LED), has proven to be the most energy-efficient design thus far. However, we are now experiencing light pollution and the brightest nights in human history. Therefore, the future of lighting lies not in brighter but better lighting design. (see fig. 2.1)

In Western culture, lighting has been a symbol of safety and wealth, with only the wealthy being able to afford bright and excessive lighting. For many European cultures, light and day are often associated with good things like health, life, activity, consciousness, protection, and knowledge. On the other hand, night and darkness are frequently linked with evil: sickness, death, passivity, unconsciousness, danger, and ignorance. Although darkness can also be mysterious, romantic, dramatic and full of life. Much like movie theatres, strolls through the park at night or going to parties after the sun sets.

However, the concept of darkness being evil or ignorant is not universal. For example, Jun'ichirō Tanizaki writes in his book, In Praise of Shadows, that,

> *"we Orientals tend to seek our satisfaction in whatever surroundings we happen to find ourselves, to content ourselves with things as they are; and so darkness causes us no discontent, we resign ourselves to it as inevitable. If light is scarce then light is scarce; we will immerse ourselves in the darkness and there discover its own particular beauty. But the progressive Westerner is determined always to better his lot. From candle to oil lamp, oil lamp to gaslight, gaslight to electric light—his quest for a brighter light never ceases, he spares no pains to eradicate even the minutest shadow."*(Tanizaki et al., 2008)

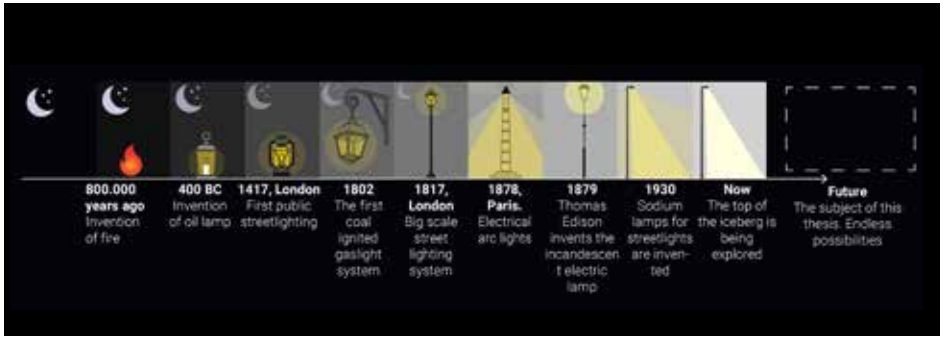


Figure 2.1 The development of streetlights. (Aileen Hallie, 2023)

Safety and Darkness

For decades, researchers across various fields have been interested in nyctophobia, fear of darkness. The origins of this fear have been debated, with some suggesting that it is an innate, primal fear. In contrast, others argue it is learned through observation, traumatic experiences, and anchoring.(Francis, 2019)

From an evolutionary perspective, the fear of darkness has been regarded as a mechanism that has helped humans survive. The human brain creates anxiety when faced with rational fears like dangerous animals, which has served as a survival mechanism. The human eye cannot perceive danger as quickly in the dark, and by avoiding places with low lighting, humans can avoid being the target of nocturnal dangers.

In contemporary society, technology has made it easier for individuals to navigate through the darkness, yet the fear of the dark persists. Women, in particular, are often advised to take precautions when walking alone at night despite the relatively low likelihood of danger. While the fear of the dark may seem unnecessary in a world with GPS tracking and flashlights, it is difficult to unlearn fear that has been ingrained through observation, traumatic experiences, and anchoring.

Therefore, researchers need to continue to explore the origins of nyctophobia, and society needs to address the underlying reasons for the perpetuation of this fear, particularly regarding gendered experiences of fear and safety.

One organization addressing this fear of crime and safety concerns in the urban environment is CPTED, Crime Prevention Through Environmental Design. This organization, originally inspired by the observations and writing of Jane Jacobs, *The Death and Life of Great American Cities* (Jacobs, 1961), uses urban planning, architecture, and facility management to reduce victimization, deter offenders, and build a sense of community among inhabitants so they can gain territorial control of areas and reduce crime opportunities.(*The International CPTED Association (ICA) - A Brief History of the ICA,* n.d.)

The first-generation concepts of CPTED (see figure 2.2) were based on Architect Oscar Newman's book *Defensible Space* (Newman,1972) and include the following four principles.(*The International CPTED Association (ICA) - Primer in CPTED - What Is CPTED?,* n.d.)

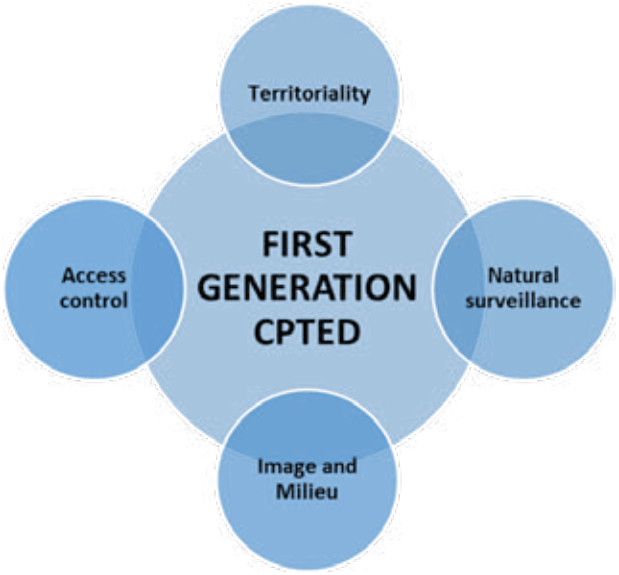


Figure 2.2 The First Generation Concepts of CPTED. (The International CPTED Association (ICA) - Primer in CPTED - What Is CPTED?, n.d.)

Territoriality: By designing semi-public spaces in residential areas or using other architectural strategies as outlined below, it is possible to help residents assume informal ownership of public spaces, thereby making it difficult for offenders to cause harm with impunity. When residents see spaces around their homes as their own, they are more likely to take care of those spaces and exert some positive influence over them. Strategically locating safe activities, such as food vendors, also helps establish territorial control of unsafe areas.

Natural surveillance: Closely linked to territorial influence, Newman employed Jacob's eyes-on-the-street and described how to construct places to maximize resident's ability to casually observe semi-public spaces. This is achieved through lighting, landscaping, clear sight-lines, and other design forms that enhance visibility to reduce crime opportunities and lower fear.

Image and Milieu: Newman also felt that the social characteristics of residents was linked to urban safety, such as their perception of nearby areas, whether they were fearful of public areas, and the conditions of nearby land uses. He proposed mini-neighborhoods where residents could better know one another and he cautioned against building residential properties nearby other areas with high crime rates. Linked to the idea of milieu was the concept of image. This was the idea that the physical condition and maintenance of properties signaled that an area was cared-for or neglected, and therefore safer or unsafe. Image programs include graffiti removal, litter clean ups, and beautification.

Access control: Although not subdivided as separate category in Newman's work, access control supported territorial influence by using architectural strategies to limit access into properties. The idea was to help those who had legitimate purpose residing or managing properties to control access into their properties. This included street access controls such as road barriers, to create mini-neighborhoods in residential areas or landscaping to control access into the fronts of buildings.

Since the advent of electric lighting, cities, and urban environments have been continually seeking ways to increase brightness, often arguing that brighter spaces make for safer places. The rationale is that criminal activity can be deterred by enabling people to see what is happening around them. However, despite living in an era where light levels are at their highest in human history, instances of crime and theft continue to persist.

A study conducted in England and Wales in 2015(Steinbach et al., 2015) examined the impact of reduced street lighting on crime and road safety. The researchers analyzed data for road collisions and crime in sixty-two local authorities. They found little evidence to suggest that dimming lighting, partial lighting, or turning off lights had any detrimental effects.(see fig. 2.3)

In 2000, another study carried out in Chicago examined the relationship between crime and improved street and alley lighting.(Morrow & Hutton, 2000) The study evaluated the impact of increased lighting by comparing two different police districts. One district received increased alley lighting, while the other did not. Both were similar in terms of demographics, socioeconomic status, and crime. According to police reports, all types of reported crimes had increased in the area with brighter street and alley lighting, one year after implementing the 1998 multi-stage plan to reduce crime through improved lighting. (see fig. 2.4)

A study from Australia in 2019 (Kalms, 2019) found that brighter streets did not necessarily make for safer places due to how the human eye perceives color. The report observed that people are likelier to feel safer in warmer-colored lighting, based on the color spectrum that the human eye can perceive.

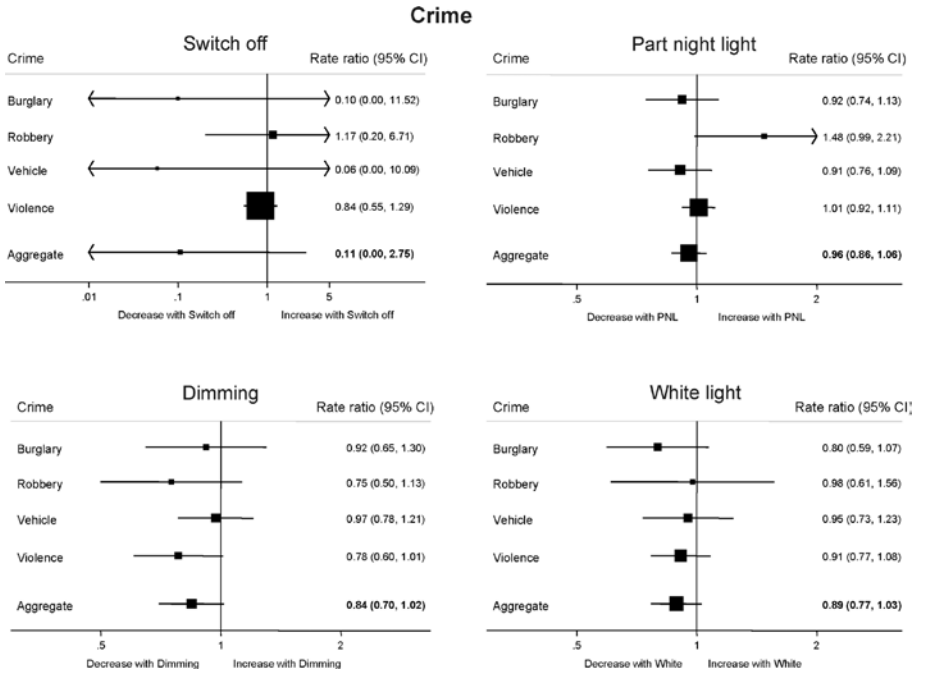


Figure 2.3 Associations between street light adaptation strategies and crime. (Steinbach et al., 2015)

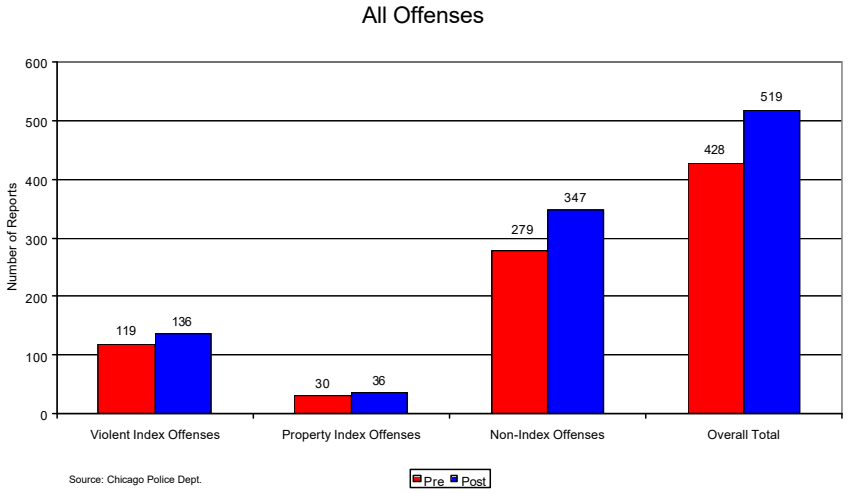


Figure 2.4 Change in reported incidents in experimental area: one year pre and post-installation of alley lights. (Morrow & Hutton, 2000)

How is Light Pollution Harmful to Humans?

The adverse effects of light pollution on human health cannot be ignored. The natural circadian rhythm of humans is imperative for rest and healing. (see fig. 2.5) Bright artificial lighting can alter this natural cycle and cause sleep disruption or inadequate sleep, leading to a range of health issues, such as sleep disorders, depression, obesity, diabetes, heart disease, and even cancer.(Staff, 2023) The dangers of blue light, in particular, should not be underestimated, as prolonged exposure can cause damage to retinal cells and vision problems and contribute to cataracts, eye cancer, and growths on the clear covering over the white part of the eye. Children are particularly vulnerable as their eyes absorb more blue light from digital devices.(Health, n.d.)

Figure 2.5 Infographic of a conventional circadian rhythm. (B.Pharm, Y. S. (2016)

Light color is measured along the Kelvin (K) temperature scale. (see fig. 2.6) The color of light relates to Correlated Color Temperature (CCT). White color refers to cool lighting, while warm lighting is characterized by a softer yellow hue.

It's worth noting that electric lighting can be specified in a range of correlated color temperatures (CCT), with cooler light sources producing more blue light. This is significant because blue light stimulates the brain, making it more alert because it mimics the bright blue sky in the middle of the day. The Kelvin scale measures light color, and the accompanying graphic demonstrates how blue light is similar to a bright blue sky day.

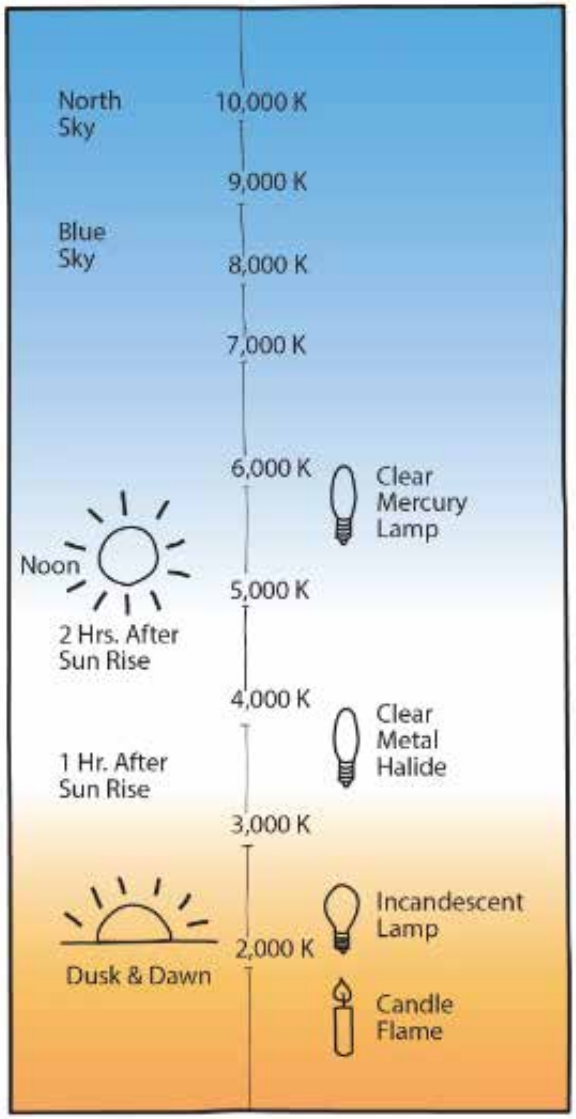


Figure 2.6 Graphic of the CCT (Kelvin) Scale. (Staff, (2023)

The Impact of Exterior Lighting on Nocturnal Animals

Light pollution is a significant environmental issue that harms nocturnal animal habitats. The human-made alteration of outdoor light levels disrupts the natural light-dark cycle, causing adverse consequences for various plant and animal species.

Electric light sources at night can negatively impact the behavior, survival, and reproductive patterns of nocturnal animals, including amphibians, birds, mammals, insects, and reptiles. These species depend on light cues for their vital life functions, such as regulating their circadian rhythms, reproduction, hunting, foraging, communication, and sheltering.(Longcore & Rich, 2004) (Hölker et al., 2010)

The impact of light pollution on nocturnal animals is as follows:

- Disruption of the nocturnal activity of various animals, including their foraging patterns, leads to decreased reproductive success.
- Confusion for migratory birds, causing them to become "trapped" in the light. It also creates hazards, resulting in fatal collisions with buildings and towers due to the lighted windows and structure.(La Sorte et al., 2017)
- Alterations to the mating and reproduction patterns of amphibians, reptiles, and insects cause a decline in population numbers.
- Disruption to the natural food chain and the insect population, which is essential for many species, including birds, bats, and other animals.
- Disorienting and exposing nocturnal animals to predators can also result in significant population declines.
- Increased mortality from roadkill.(The IES Outdoor Environmental Lighting Committee, n.d.)
- Disruption to movements and wildlife corridor use.(The IES Outdoor Environmental Lighting Committee, n.d.)
- Possible support for invasive species (mostly insects)

The impact of light pollution on plants is as follows:(The IES Outdoor Environmental Lighting Committee, n.d.)

- Seed germination
- Stem elongation
- Leaf expansion
- Flower development
- Fruit development
- Bud dormancy (when leaves stop growing)
- Leaf senescence
- Leaf drop

In summary, the significance of light pollution and its influence on nocturnal animals and plants cannot be overstated. The adverse impacts on various species' behavior, survival, and reproduction patterns can have cascading effects on the entire ecosystem, ultimately affecting human health and well-being. Therefore, it is crucial to adopt effective strategies to mitigate the impact of light pollution on nocturnal animal habitats.(Gaston et al., 2012)

Current Outdoor Lighting Practices in North America

Dark Sky International, also known as the International Dark-Sky Association, is a globally recognized authority that strives to protect the night sky from light pollution. The organization's mission is to restore natural darkness at night and safeguard communities and wildlife from the harmful effects of over-lighting. To fulfill this mission, Dark Sky International provides leadership, tools, and resources for individuals, policymakers, and industry to reduce light pollution and promote responsible outdoor lighting that is both aesthetically pleasing and functional.

Dark Sky has worked in collaboration with the Illuminating Engineering Society (IES) to create five principles for responsible outdoor lighting.(Staff, 2024) (see fig. 2.7) These principles include reducing glare, minimizing light trespass, using appropriate light levels, utilizing energy-efficient lighting, and minimizing blue light emissions. By following these principles, communities can mitigate the adverse effects of outdoor lighting and reduce light pollution.

Figure 2.7 Five Lighting Principles for Responsible Outdoor Lighting (darksky.org)

Dark Sky International's position on color temperature is to use no higher correlated color temperature (CCT) than necessary for color appearance of intended tasks. Low CCT is recommended to reduce negative impacts on wildlife(Longcore et al., 2018) A maximum CCT of 3000K for area lighting in commercial zones is recommended, while CCTs lower than 2200K should be used to minimize impacts in sensitive environments.

The IES is a non-profit organization that develops and publishes lighting standards for the United States and internationally. The organization collaborates with the International Commission on Illumination to promote uniformity in lighting standards globally. The IES provides lighting standards and recommendations for various applications: roadway and parking facility lighting, tunnel lighting, industrial facilities, security, and healthcare. In addition, the IES offers resources and tools for individuals and organizations to reduce light pollution and promote responsible lighting practices. They also provide educational materials and resources for public outreach and guidance on creating and implementing effective lighting policies and practices.

According to the IES's Outdoor Environmental Lighting Considerations, in order to create the best outdoor lighting practices, it is essential to minimize the effects of light generated by human practices. The guidelines listed on page 12 are suggested lighting zones so that lighting standards can be created for the existing conditions. Lighting zones help communities minimize the contrast and conflict between extremes in lighting.

Illuminating Engineering Society's Lighting Zones

LZ-0 No ambient light	Lighting Zone 0 should be applied to areas in which permanent lighting is not expected and when used, is limited in the amount of lighting and the period of operation. LZ-0 typically includes undeveloped areas of open space, wilderness parks and preserves, areas near astronomical observatories, or any other area where the protection of a dark environment is critical. Special review should be required for any permanent lighting in this zone. Some rural communities may choose to adopt LZ-0 for residential areas.	Recommended default zone for wilderness areas, parks and preserves, and undeveloped rural areas. Includes protected wildlife areas and corridors.
LZ-1 Low ambient light	Lighting Zone 1 pertains to areas that desire low ambient lighting levels. These typically include single and two family residential communities, rural town centers, business parks, and other commercial or industrial/storage areas typically with limited nighttime activity. May also include the developed areas in parks and other natural settings.	Recommended default zone for rural and low density residential areas. Includes residential single or two family; agricultural zone districts; rural residential zone districts; business parks; open space including preserves in developed areas.
LZ-2 Moderate ambient light	Lighting Zone 2 pertains to areas with moderate ambient lighting levels. These typically include multifamily residential uses, institutional residential uses, schools, churches, hospitals, hotels/motels, commercial and/or business areas with evening activities embedded in predominantly residential areas, neighborhoods serving recreational and playing fields and/or mixed use development with a predominance of residential uses. Can be used to accommodate a district of outdoor sales or industry in an area otherwise zoned LZ-1.	Recommended default zone for light commercial business districts and high-density or mixed use residential districts. Includes neighborhood business districts; churches' schools and neighborhood recreation facilities; and light industrial zoning with modest nighttime uses or lighting requirements.
LZ-3 Moderately high ambient light	Lighting Zone 3 pertains to areas with moderately high lighting levels. These typically include commercial corridors, high intensity suburban commercial areas, town centers, mixed use areas, industrial uses and shipping and rail yards with high night time activity, high use recreational and playing fields, regional shopping malls, car dealerships, gas stations, and other nighttime active exterior retail areas.	Recommended default zone for large cities' business district. Includes business zone districts; commercial mixed use; and heavy industrial and/or manufacturing zone districts.
LZ-4 High ambient light	Lighting zone 4 pertains to areas of very high ambient lighting levels. LZ-4 should only be used for special cases and is not appropriate for most cities. LZ-4 may be used for extremely unusual installations such as high density entertainment districts, and heavy industrial uses.	Not a default zone. Includes high intensity business or industrial zone districts.

Another organization that has created illumination guidelines with the goal of reducing light pollution is the Royal Astronomical Society of Canada. The RASC mission is, 'To enhance understanding of and inspire curiosity about the Universe, through public outreach, education, and support for astronomical research'(*Mission Statement,* 2019) This work is greatly hindered by light pollution and so they have created the following guidelines for illumination levels for urban pathways and public building exteriors. (Dick, 2018)

Table 4.4 Pathway Illumination Guidelines (Maximum Values)

4.4 Pathways	Type	Light	Level (lux)	Height	Curfew
4.4.1 Pathways	None	None	N/A	N/A	N/A
4.4.2 Illuminated Paths	FCO ShCO	Amber Incandescent, CFL or LED, Filtered	~1 lux	1 m	Yes
4.4.3 Main Pathways	FCO ShCO	Amber Incandescent, CFL or LED, Filtered	~1 lux	1 m	No

N/A – not applicable

Table 4.1 Building Illumination Guidelines (Maximum Values)

4.1 Area	Type	Light*	Level (lux)**	Height	Curfew
4.1.1 Admin. Bldgs.	FCO ShCO	Amber Incandescent, CFL or LED, Filtered	~2 lux	2.5 m	Yes
4.1.2 Public Bldgs.	FCO ShCO	Amber Incandescent, CFL or LED, Filtered	~2 lux	2.5 m	Yes
4.1.3 Retail Stores	FCO ShCO	Amber Incandescent, CFL or LED, Filtered	~2 lux	2.5 m	Yes
4.1.4 Vending Machine	FCO ShCO	Amber Incandescent, CFL or LED, Filtered	~2 lux	2.5 m	Yes
4.1.5 Toilet, Washroom, Shower Facilities	Marker (FCO)	Amber Incandescent, CFL or LED, Filtered	~2 lux	2 m	No

* Wattages for individual lamp types are not specified due to differences in efficacy.
** 2 lux = illumination by clear sky about 20 minutes after sunset

The current outdoor lighting standards for North America incorporate design and installation principles that minimize glare, light trespass, and skyglow while providing adequate lighting levels for human safety and visibility. The standards prioritize energy efficiency, quality of light, and specify which fixtures should be used for specific applications. By following these guidelines, communities can reduce the negative effects of outdoor lighting on the environment and promote sustainable lighting practices.

Best Practices for Exterior Lighting

Based on the criteria previously listed and described, the following list is a set of recommended criteria for the campus lighting for the University of Washington:

USE LIGHT ONLY WHEN NEEDED

- Light should be targeted and controlled to only the places that need to be lit for the tasks to be performed. Studies have shown that more light does not make urban environments safer, nor does it give the perception of a more active space. By having lights on only as needed it reduces energy costs, reduces stress on nocturnal wildlife and reduces light pollution.

- Lights should be useful and on timers or motion sensors to reduce excess lighting. Using motion sensors and timers allows for spaces that are sometimes active at night to have adequate safe lighting for humans without the facility manager having to make changes to the lighting design.

- Lights should be no higher than 3 feet tall along pathways and no higher than 8 feet for building entrances. This guideline could be translated into designing for the pedestrian experience. Lowering the light fixtures and designing with the intention of facial recognition and pathway illumination, reduces the glare and confusion that happens with bright overhead light fixtures.

THE LIGHT SHOULD ONLY BE AS BRIGHT AS NEEDED

- Illuminated pathways should not exceed 1 lux. This measurement is based on RASC's guidelines and would be an illumination level to aim for. The preferred lux level may vary based on human perception. The intention is to design the exterior lighting with the lowest possible illumination to reduce light pollution and not add undue stress to nocturnal habitats.

- Main pathways should not exceed 1 lux. This measurement is based on RASC's guidelines and would be an illumination level to aim for. The preferred lux level may vary based on human perception. The intention is to design the exterior lighting with the lowest possible illumination to reduce light pollution and not add undue stress to nocturnal habitats.

- Admin and Public Buildings should not exceed 2 lux. This measurement is based on RASC's guidelines and would be an illumination level to aim for. The preferred lux level may vary based on human perception. The intention is to design the exterior lighting with the lowest possible illumination to reduce light pollution and not add undue stress to nocturnal habitats.

THE LIGHT SHOULD BE WARM-COLORED

- The light color temperature should be 3000K or lower, up to 3220K measured. Studies have shown how harmful the cooler colored lighting can be for both humans and animals. Using a warm colored bulb for exterior lighting fixtures, reduces the number of animal fatalities due to light entrapment.

CHAPTER 03: METHODOLOGY

The University of Washington Campus Site

The University of Washington campus in Seattle, Washington, is a 700-acre site. The site servers the community users: students, visitors, residents and the animals of the Union Bay Natural Area. Due to its unique combination of natural and urban areas, it is an excellent choice for studying how light pollution affects nocturnal urban wildlife habitats. The campus has the Union Bay Natural Area, home to various nocturnal wildlife species. At the same time, the campus also has urban areas with electric lighting, which can be used to study the effects of light pollution on wildlife behavior and ecology.

The campus's location in a major city like Seattle also provides easy access to a variety of urban lighting sources, such as streetlights, buildings, and other electric light sources. This allows research to study the impacts of different types and intensities of light pollution on wildlife.

The University of Washington is a 24-hour campus that is utilized by the community at all hours. The campus is located along the Burke Gilman trail, and in between two light rail stations, along with numerous bus stops and parking locations. The University of Washington hospital is located adjacent to the campus and staff often walk across parts of campus to get to work both during the day and night. With a site that is active during both daylight and evening hours, exterior electric lighting is an important part of the experience of the campus. With technology continuing to create brighter more energy-efficient lighting, it brings up questions around light pollution and human safety. Are brighter lights the best way to design? How do users of the site feel about the current lighting design?

Figure 3.1 Map of the greater Seattle area with the University of Washington Campus highlighted.

A student-led research study was completed in 2017 that assessed and evaluated the current exterior lighting on the University of Washington campus. The study involved input from a survey for students, faculty and other UW staff to share personal experiences in regards to the exterior lighting on campus. The participants were asked to identify locations that were night time destinations, areas to avoid, places with great lighting, areas that were too bright and areas that were too dark.

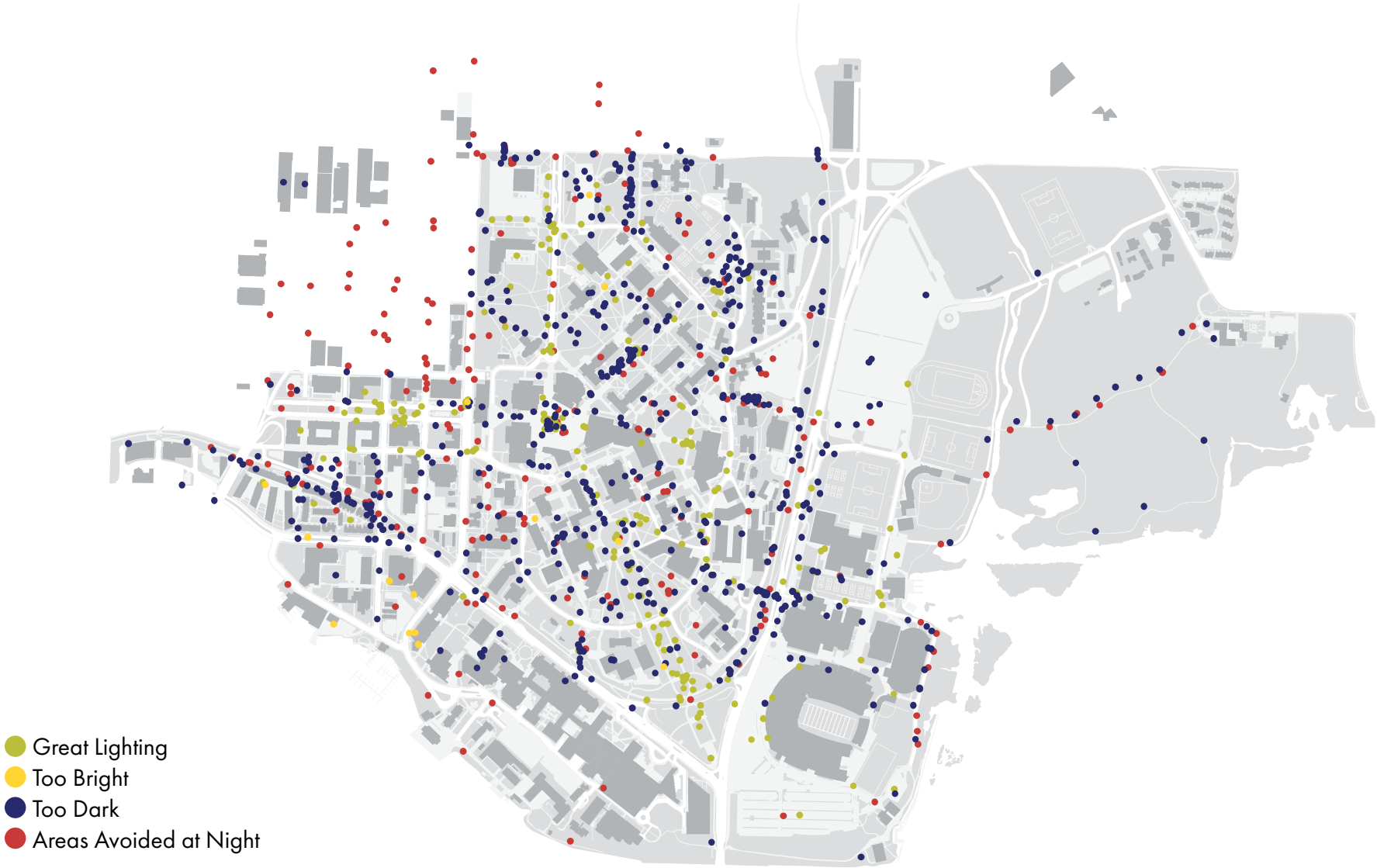
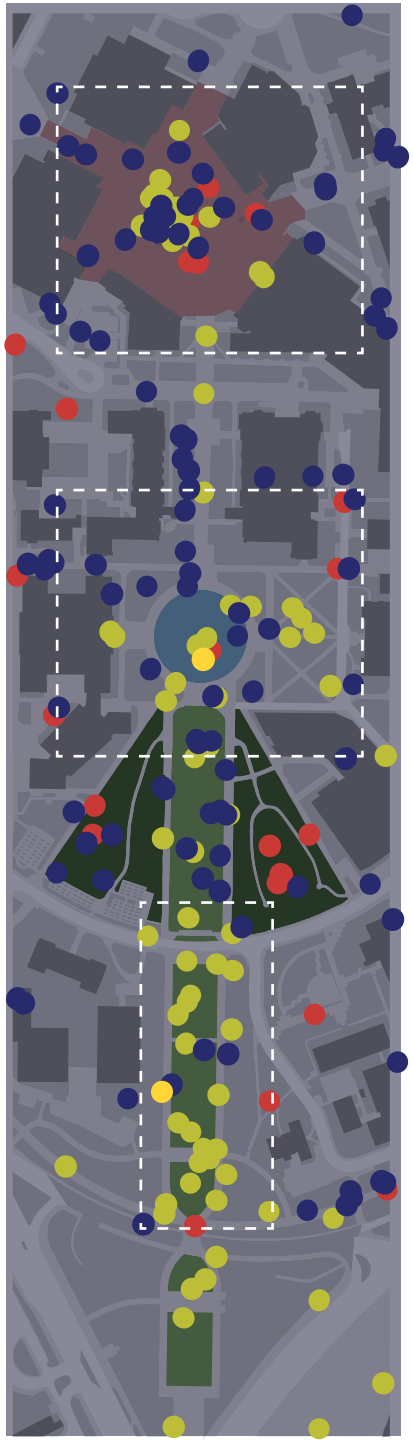


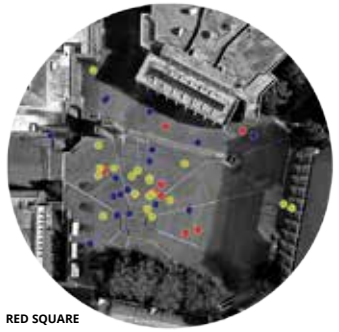
Figure 3.2 Map of the University of Washington Campus with 2017 student survey markers.

This research thesis will look more closely at three unique sites on campus. Although these sites are in close proximity to each other, they each have different purposes, uses and lighting strategies.

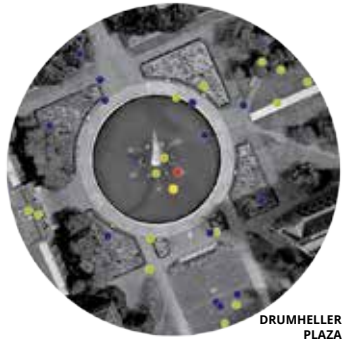
The results of the 2017 survey showed a variety of personal experiences, with some areas having contradiction results. Red Square and Drumheller Fountain were both areas that had positive and negative feelings towards the lighting.

RED SQUARE
"Red Square is always easy to find"





Contradicting Results



Contradicting Results

- Great Lighting
- Too Bright
- Too Dark
- Areas Avoided at Night

Overarching campus comments from the 2017 student survey.

LIGHTING QUALITY

"I urge UW to gain an understanding of how nighttime illumination works to create a feeling of community, safety and belonging. Instead of just focusing on expediency, general illumination needs (horrible colors), look at how cities like Paris, San Francisco, Vancouver BC employ nighttime lighting with a mind towards illumination as a tool for civic improvement."

"If new lighting is installed, don't go overboard. It doesn't need to wash out an area with very bright, intense light; it just needs to be enough to see and be seen by."

Figure 3.3 Nighttime image of UW Seattle Campus. (Douglas, 2017)

SOURCES OF BRIGHTNESS

"Perhaps this isn't the proper venue for this, but I think that INDOOR lighting at night is an issue that needs to be addressed. I see dozens of unoccupied buildings across campus lit up like Christmas trees all the time, and it seems tremendously wasteful. I know UW embraces the idea of environmental awareness, and this seems like an aspect that would be very easy to address and change."

"I see enough lights around the campus however, somehow it still looks dim and gloomy. It may be because of the orange/ yellow light that is being used for the street lights? I think it'll be a lot brighter if we can use LED lights."

Figure 3.4 Nighttime image of UW Seattle Campus. (Douglas, 2017)

REDUCING CONTRAST

"I face campus across Portage Bay at home - way too many lights shining out on water versus down on ground – need full cutoff lights installed to keep dark skies but permit pedestrian safety. Work nights in my office (I'm an astronomer) so need safety when leaving at midnight or 5 am."

"Some areas need more illumination but if the light is too bright it makes it difficult to see after I pass through the bright area or look away from the light (affects night vision until I re-adjust). I work overnights and walk a loop around campus for breaks, 5 nights per week."

Figure 3.5 Nighttime image of UW Seattle Campus. (Douglas, 2017)

Research Methods

The following data was collected after sunset through observation, photographs, and light measurements. The collected data includes human and animal activity, weather conditions, moon phase, CCT data, measured illuminance, and overall site assessment.

Research Design

The first step in the data collection was to observe the sites during the day to see what signs of nocturnal animals are around. This included looking for nests, animal droppings and other markings left by animals. The next step was to spend one hour at each of these sites after sunset observing human and animal activity. During this hour, light measurements were taken, the number of people and what direction they were traveling was documented, and photographs were taken. After the on-site observation, an assessment was written, and the photographs were annotated with observations.

OBSERVATION LOG
Date:
Start Time:
End Time:
Weather Conditions:
Sky Glow Light Levels:
Moon Phases:
Observation Location:
What are the primary tasks of this site? What human and animal activity is observed on site?
Light Levels and Correlated Color Temperature (CCT) at critical junctions and paths:
Notes:

On-Site Animal Habitat Observations

After conducting numerous on-site observations, the following species were identified:

Figure 4.1 Photo of spider web attached to the railing of the pedestrian overpass by the University of Washington lightrail station.

Cross Orb Weaver Spider
(Araneus diadematus)

This non-native species seems to thrive under the electric lights that attract insects. This species was introduced to North America from Europe but does not seem to be invasive.(Kennedy, n.d.)

Figure 4.2 Squirrel nest in tree outside of Gerberding Hall.

Figure 4.3 Gray Squirrel. (Ashtonpfaffen, 2023)

Eastern Gray Squirrel
(Sciurus carolinensis)

This non-native species was introduced to Washington in the early 1900s and is now the most common tree squirrel in urban areas.(Eastern Gray Squirrel | Washington Department of Fish & Wildlife, n.d.) It is considered an invasive species because it has largely pushed out the native Western Gray Squirrel which is on the endangered species list.(Western Gray Squirrel | Washington Department of Fish & Wildlife, n.d.)

Figure 4.4 Photo of crow's nest and hornet's nest on Meany Hall.

The Northwestern Crow's Nest
(Corvus caurinus)

This native species lives year round in the Seattle area and is typically associated with tidal areas. They are omnivores and also eat carrion and garbage.(Northwestern Crow, n.d.)

Bald-faced Hornet Nest
(Dolichovespula maculata)

This native species lives in large colonies and consumes a diet of soft-bodied insects. They also harvest nectar and pollen and are known as minor pollinators.(Bald-Faced Hornet Facts - NatureMapping, n.d.)

Figure 4.5 An Eastern Cottontail Rabbit Sitting in Grass. (Pewterblack, 2022)

Eastern Cottontail
(Sylvilagus floridanus)

This non-native species was introduced as a game animal in the 1930s. (Eastern Cottontail (Rabbit) | Washington Department of Fish & Wildlife, n.d.) This species causes a lot of damage to planned landscapes due to foraging. People often put up fencing to keep the rabbits out.

On-Site Exterior Lighting Observations

The site survey focused on each site individually to obtain as much detailed information as possible. The observations were conducted after sunset, and measurements were taken with a CL-200A Konica Minolta Light Meter. The author took the photos.

Figure 4.6 Image of light meter used in research observations.

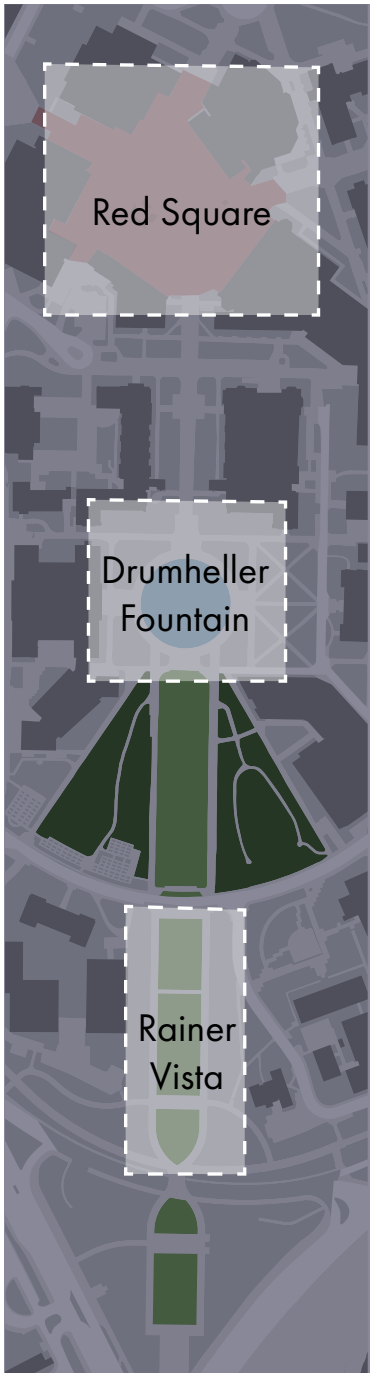
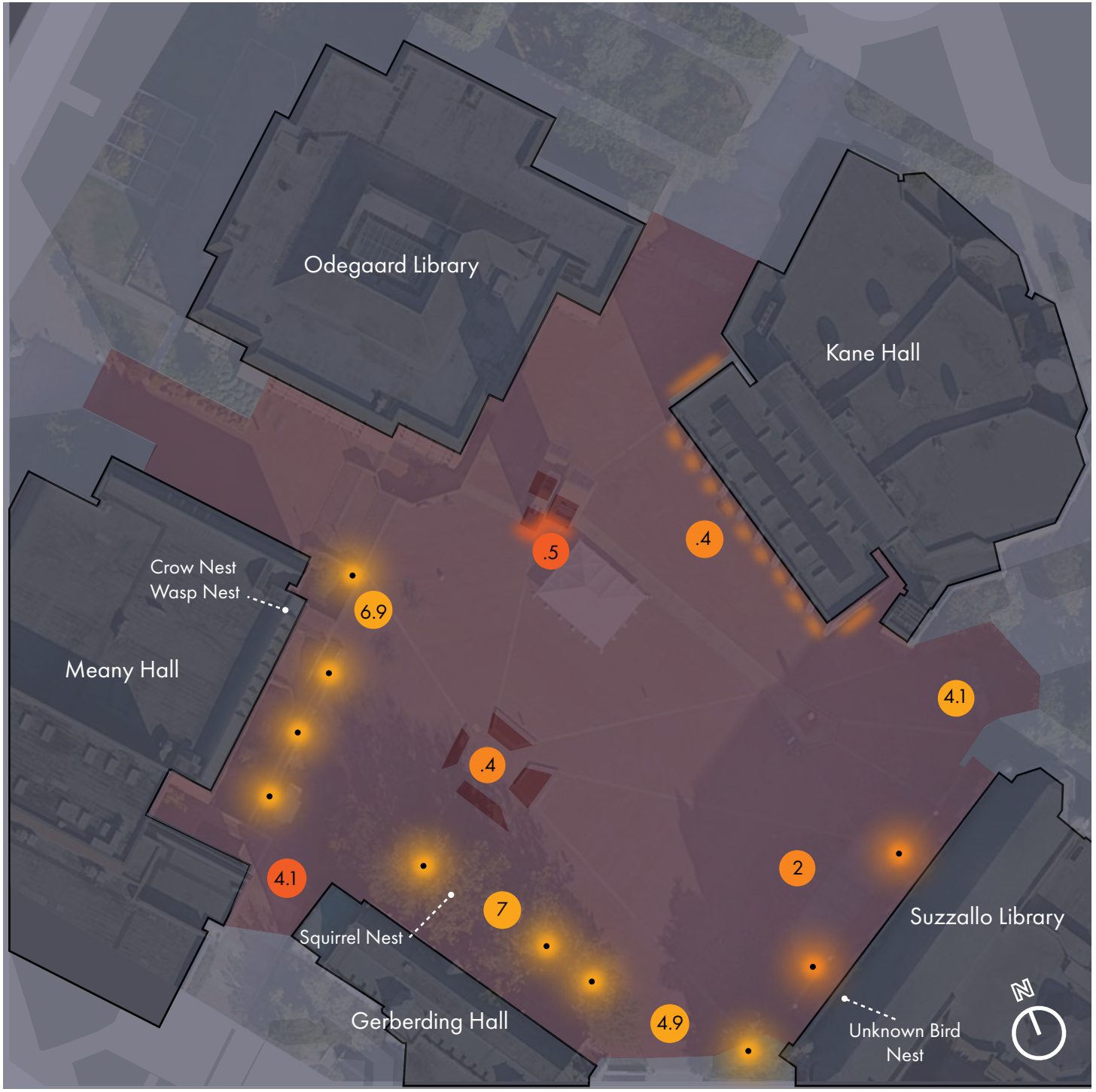


Figure 4.7 Map of UW Campus with site areas highlighted.

OBSERVATION LOG - Red Square
Date: March 26, 2024
Start Time: 8:40p
End Time: 9:40p
Weather Conditions: partly cloudy, 52 degrees
Sky Glow Light Levels: .4lux (measurement taken from the middle of Red Square)
Moon Phase: Waning Gibbous
Observation Location: Red Square
What are the primary tasks of this site? What human and animal activity is observed? -people walking to destinations in groups of 1-5 -people walking dogs -people skateboarding -people roller skating with light up skates -people biking -there are animal nests (squirrel, crow and hornets) but no visible animals
Lighting Conditions and Measurements: No direct lights are pointed onto Red Square. All lights around the site spread light either up or around, creating ambient light conditions.
Notes: Lots of people of all genders walk alone with headphones on. Personal safety does not seem to be a high concern for this area.

Kane Hall, Suzzallo Library, and the towers are the only places that meet the light level and color temp criteria. The historic lights of UW campus are too tall and point light in all directions creating glare, light trespass and contributing sky glow.

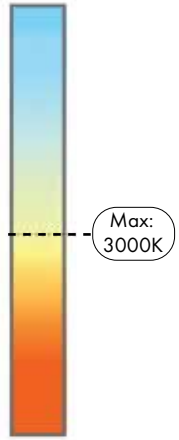


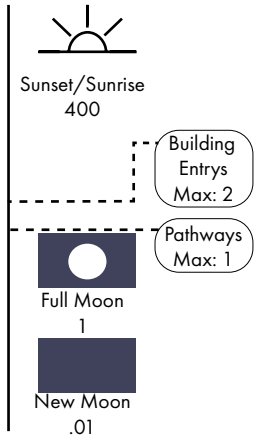
LEGEND

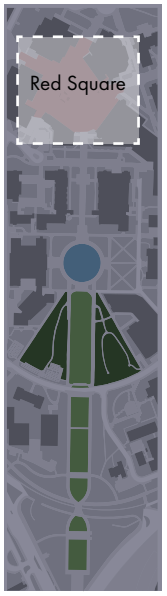
Measured CCT and lux: .0

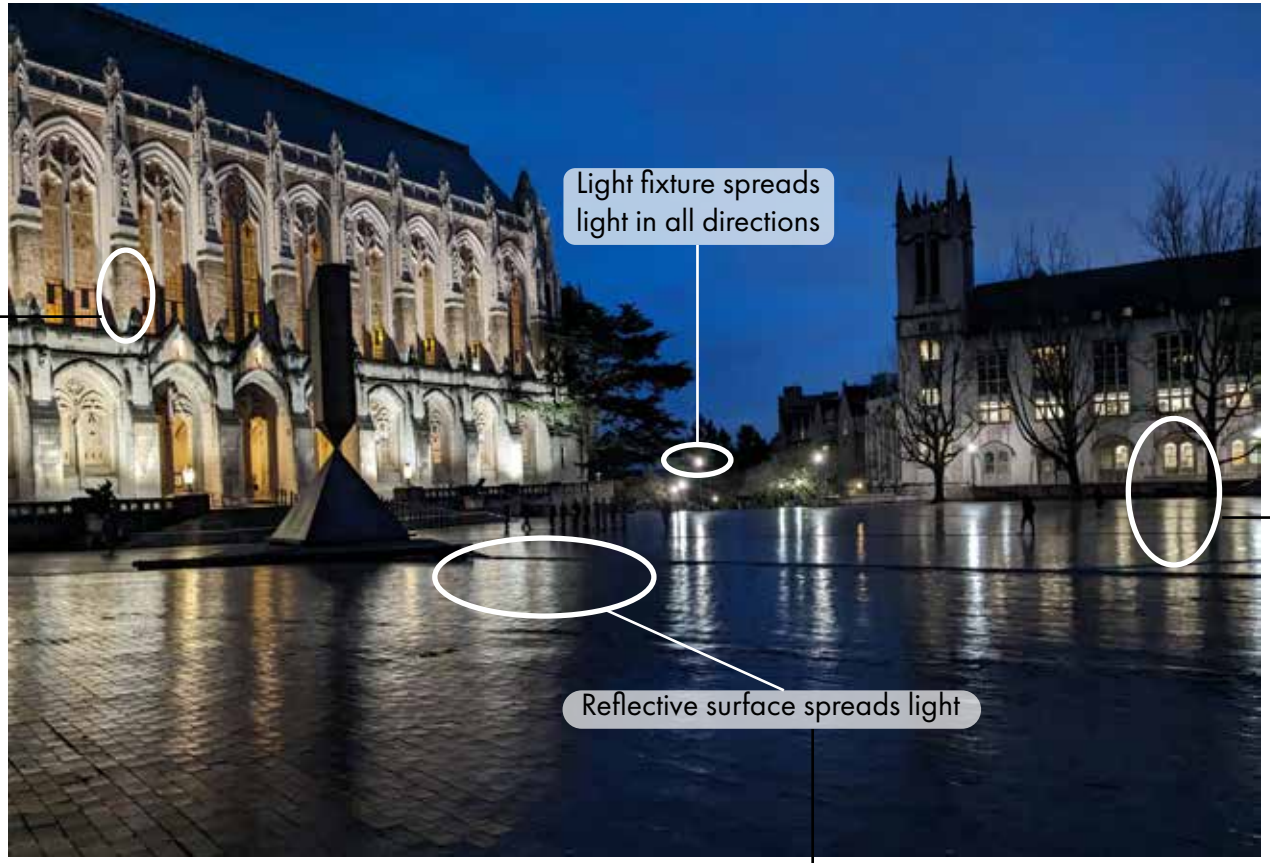
Moon Phase:

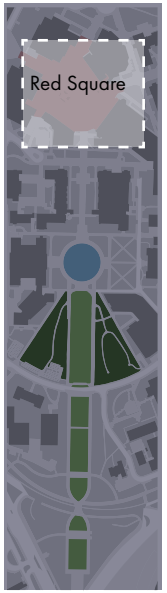
Waning Gibbous





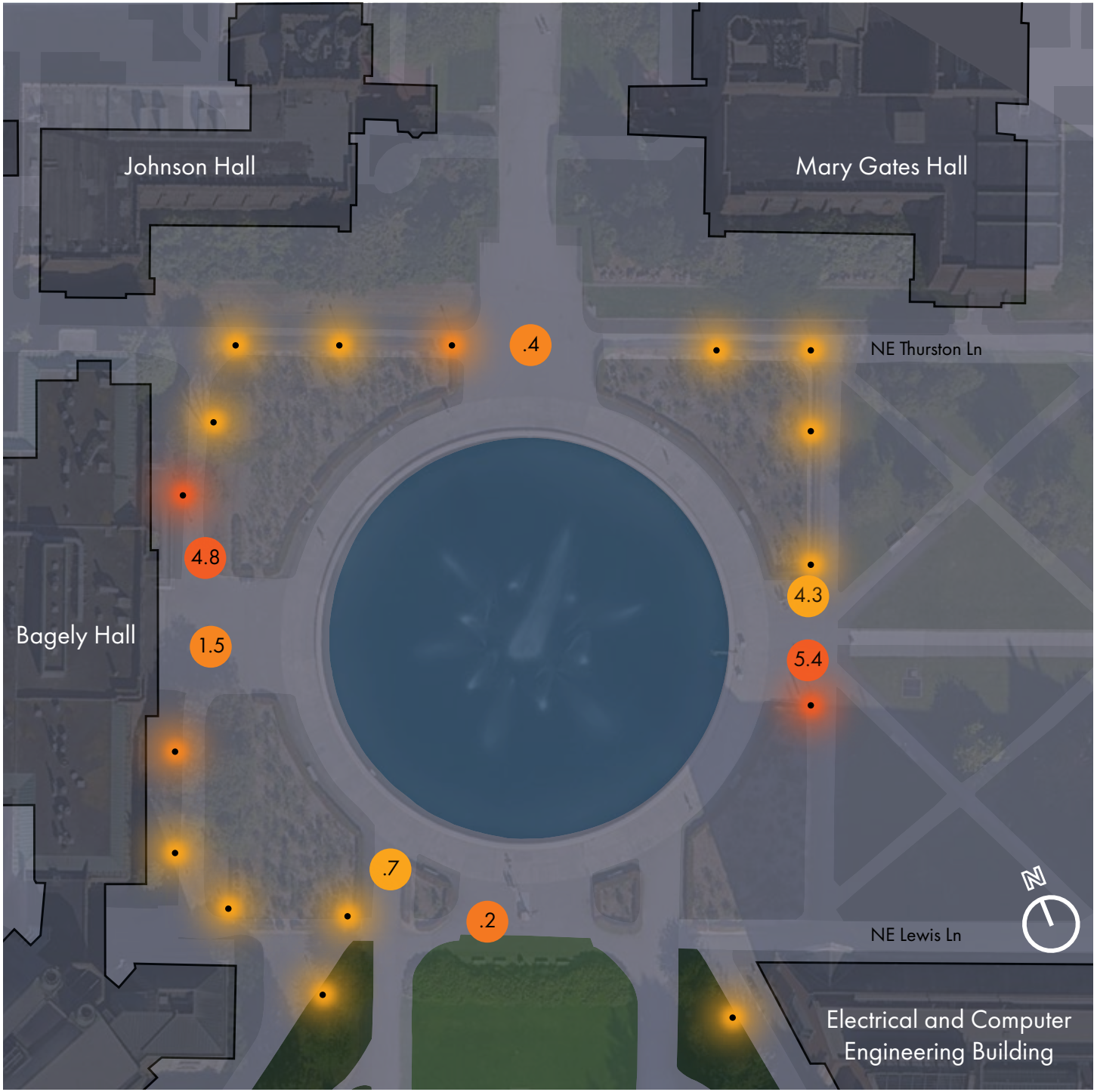



Light fixture spreads light in all directions
Lights pointed at the building
Light coming from windows and building entries
Reflective surface spreads light


Red Square

OBSERVATION LOG - Drumheller Fountain
Date: March 24, 2024
Start Time: 8p
End Time: 9p
Weather Conditions: partly cloudy, 55 degrees
Moon Phase: Waxing Gibbous
Observation Location: Drumheller Fountain
What are the primary tasks of this site? What human and animal activity is observed? -people walking to destinations in groups of 1-4 -people sitting -people taking photos -people talking on the phone -people looking at their phones for directions -people walking dogs -UW vans driving through or parking -kids with light-up scooters -people biking -one squirrel running into the bushes -two bunnies running around the rose garden, ran away when the street light turned on
Lighting Conditions and Measurements: Light is coming from no only the exterior streetlights but also the interior and entryway lights. Street lights are different colors, perhaps have been updated or replaced as needed.
Notes: The planes overhead are very loud and make it difficult to hear birds and other animals.

The lighting around the ADA ramp for Bagely Hall is almost 3x brighter than the main entry. The historic lights of UW campus are too tall and point light in all directions creating glare, light trespass and contributing sky glow.

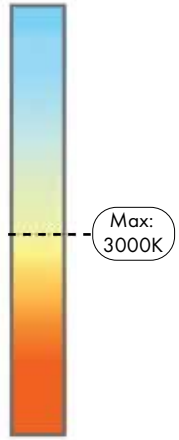


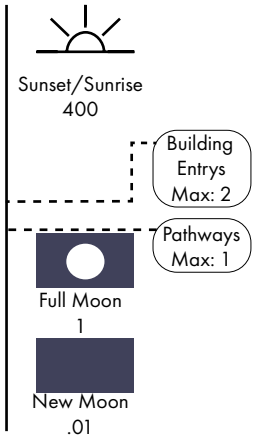
LEGEND

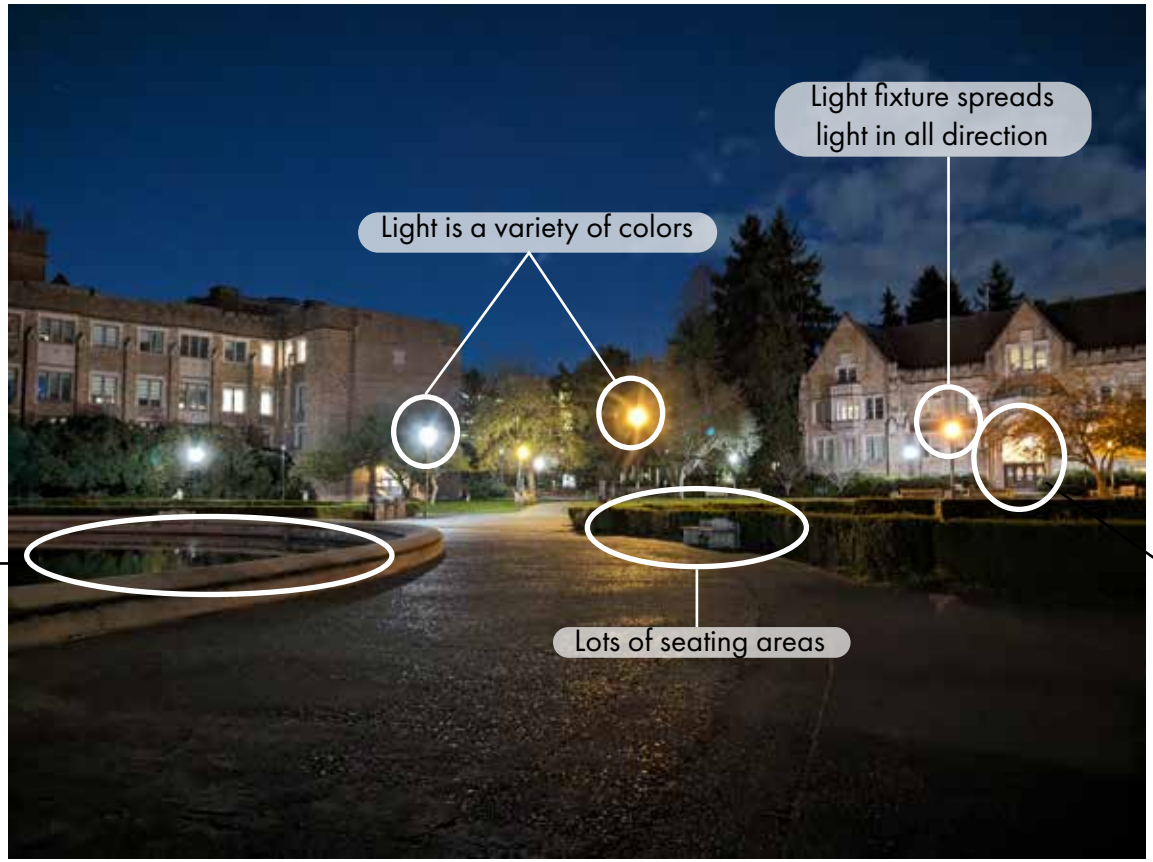
Measured CCT and lux: .0

Moon Phase:

Waning Gibbous





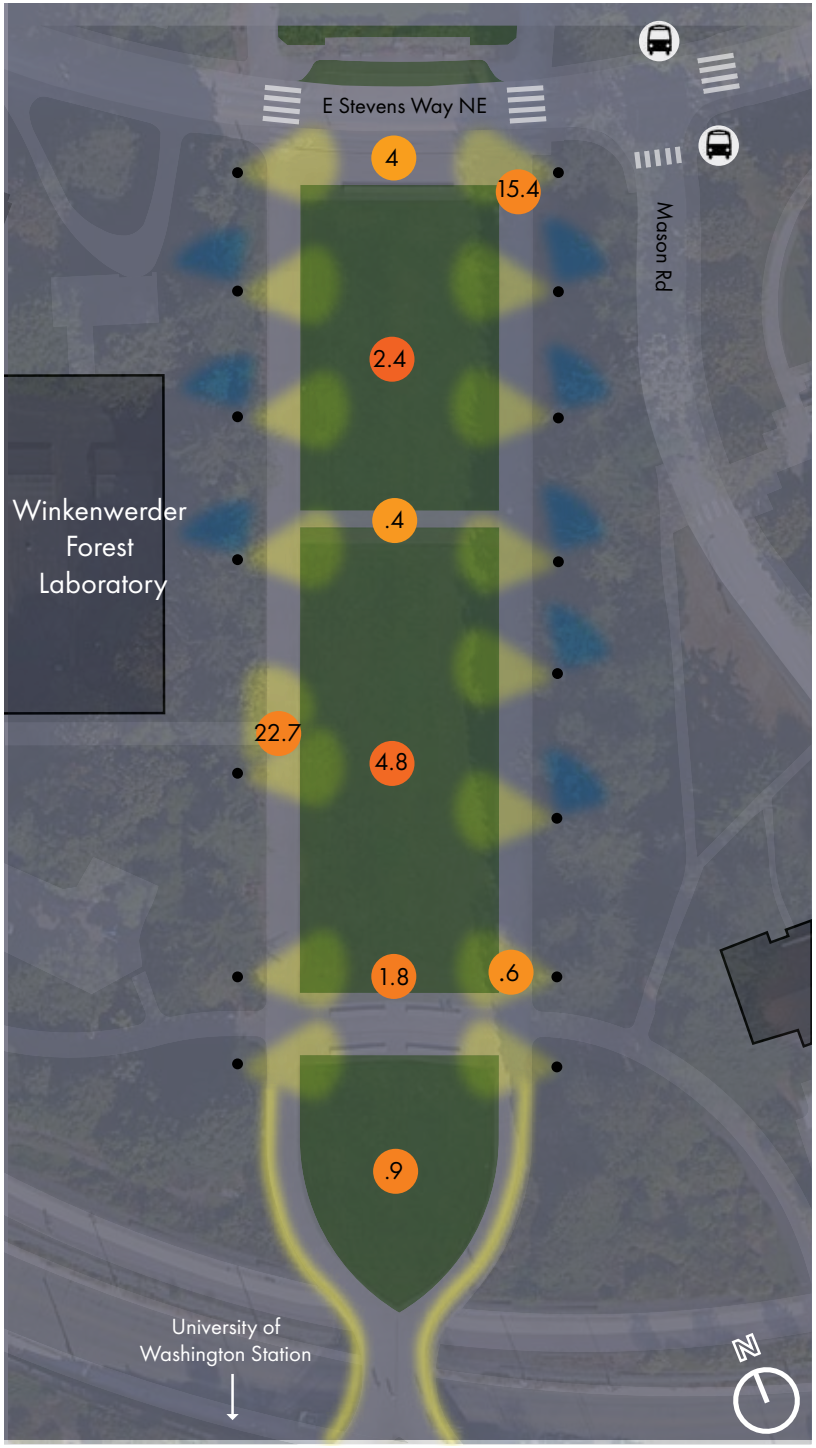


Light reflects off water

Light coming from windows and building entries

OBSERVATION LOG - Rainer Vista
Date: March 23, 2024
Start Time: 8p
End Time: 9p
Weather Conditions: cloudy, light drizzle, breezy, 50 degrees
Moon Phase: Waxing Gibbous
Observation Location: Rainer Vista
What are the primary tasks of this site? What human and animal activity is observed? -people walking to destinations in groups of 1-2, often with suitcases -people running -people talking on the phone -people looking at their phones for directions -people biking -one bunny ran across the path into the dark bushes -I heard two different bird calls but was unable to identify them.
Lighting Conditions and Measurements: Light is coming from no only the exterior streetlights but also the interior and entryway lights. Street lights are different colors, perhaps have been updated or replaced as needed.
Notes: There does not seem to be a preference for which path people take to walk across this site. The bus stop to the light rail seems to be a primary path of travel. No one cut across the open grass or used the paved path that cuts across the lawn. The cars, buses, and planes make it difficult to hear birds and other animal sounds. The lights are on some type of motion sensor or timer, but it does not seem to be working properly because some turn on and off randomly.

The lights lining Rainer Vista point a blue light into the trees. This light does not seem to serve any purpose. The lights are too tall, and although the light is direct, it points out rather than down, contributing to glare, light trespass and sky glow.

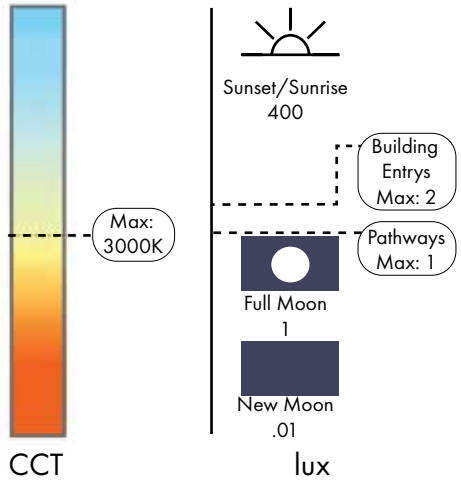


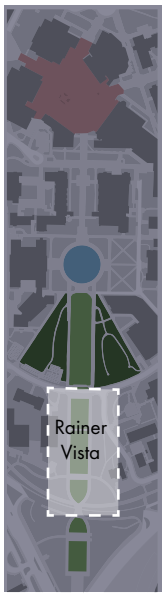
LEGEND

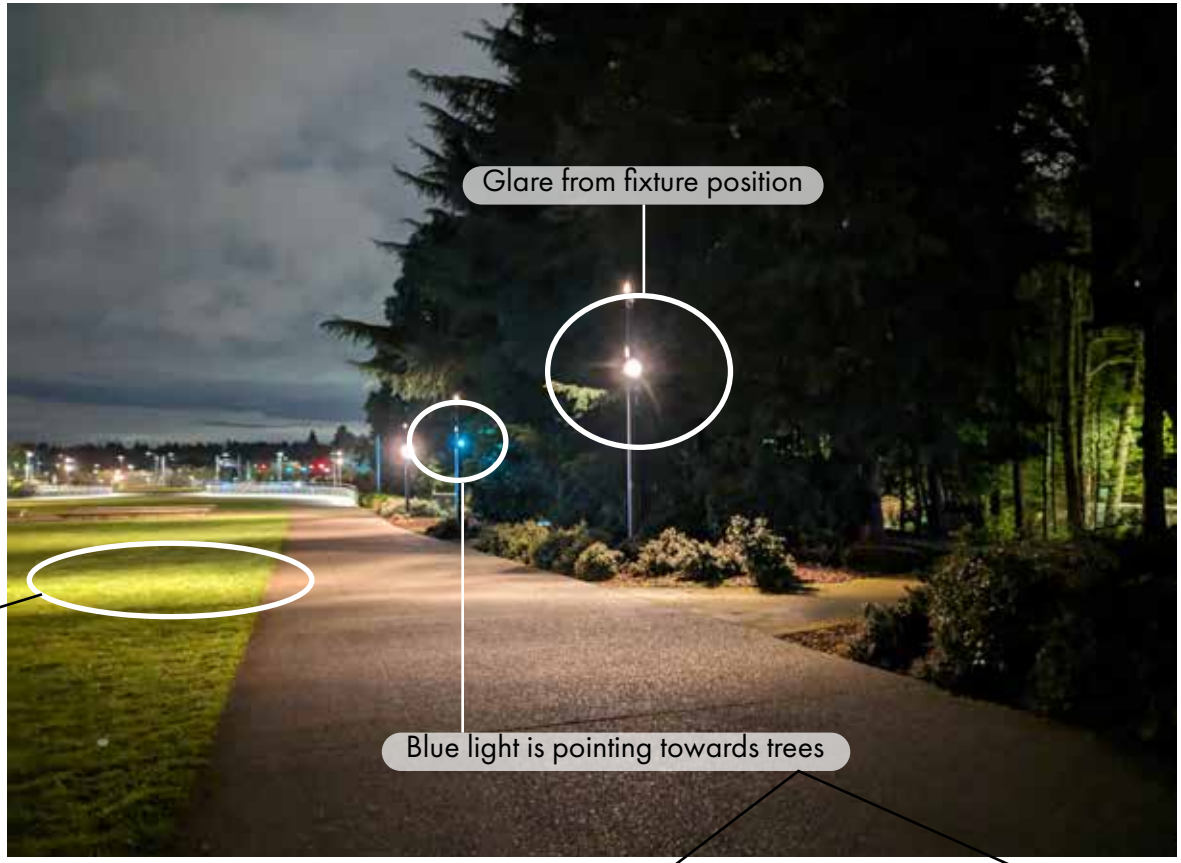
Measured CCT and lux: .0

Moon Phase:

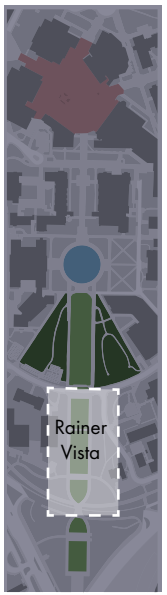
Waning Gibbous







Lights are pointed towards the lawn and not towards the path



Analysis and Summary of Findings

- The historic UW street lights are a variety of colors and light levels. They are tall lights that spread light in all directions and create glare, light trespass, and clutter.
- The lighting along Rainer Vista is very different than the rest of campus. It is unclear what the intention of this lighting design is.
- All sites were active, with people, many traveling solo with headphones. Safety does not seem to be a concern for these locations.
- Only one person was walking with a flashlight. All other extra lights came from roller skates, bikes, or scooters. The current light levels seem more than adequate for the activities happening.

Overall, the light levels measured were above the recommended lux, and the light was spread in all directions. There were little to no signs of nocturnal wildlife during the observation hours. The color of the light was a variety of warm and cool temperatures with the new LED light bulbs measuring above the recommended 3000K.

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Guidelines for Urban Ecological Exterior Lighting

Based on the previous research and analysis, the following guidelines have been created:

LIGHT CURFEW

- Exterior lighting dims to a lower light level 10p-7a. This aligns with Seattle's noise ordinance law.

LIGHT SENSOR

- Lights would only turn on after it gets dark, this reduces the wasted energy of lights being on during the summer evening hours.

LIGHT COLOR

- Lights should not exceed a color temp of 3000K.

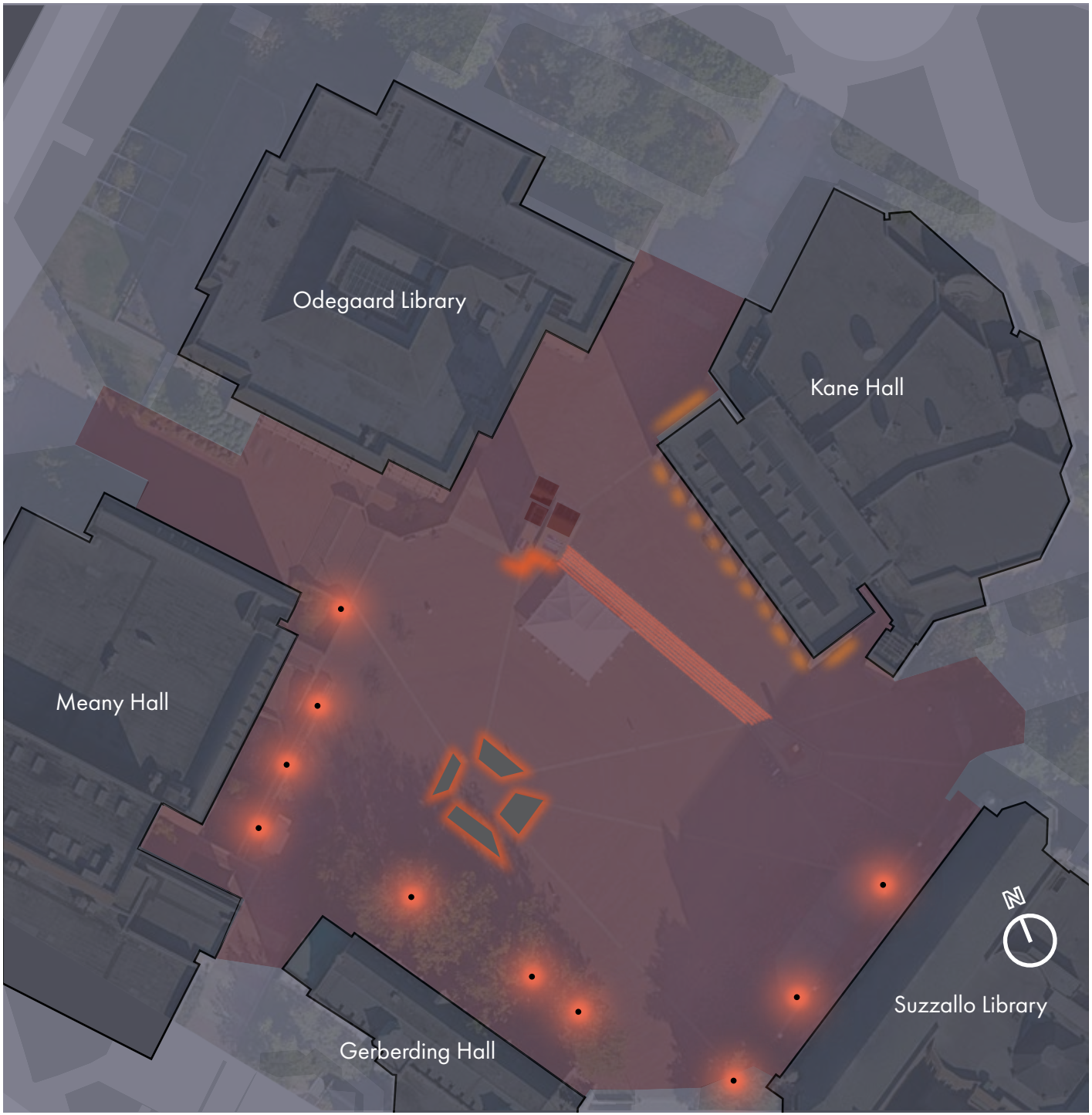
LIGHT BRIGHTNESS

- The collective lighting design should not exceed 1 lux for pathways and 2 lux for entryways. This should be measured on the ground surface of the space and not calculated based just on bulbs.

LIGHT DIRECTION

- Light fixtures should be designed to direct light downward.

The following pages are lighting designs that have been created for each site with these guidelines in mind.



GOALS:

- Change historic UW campus light fixtures to warm colored bulbs.
- Direct light downward.
- Light the tripping hazards and permanent obstacles.
- Use timers to have lights on only during active hours.

Figure 5.1 Stair lighting precedent. (UFO Lighting - Side Emitting PMMA Fibre Optic Harnesses, n.d.)

Figure 5.2 Seating with lighting precedent. (CLOUSTON Associates « Landezine International Landscape Award LILA, n.d.)

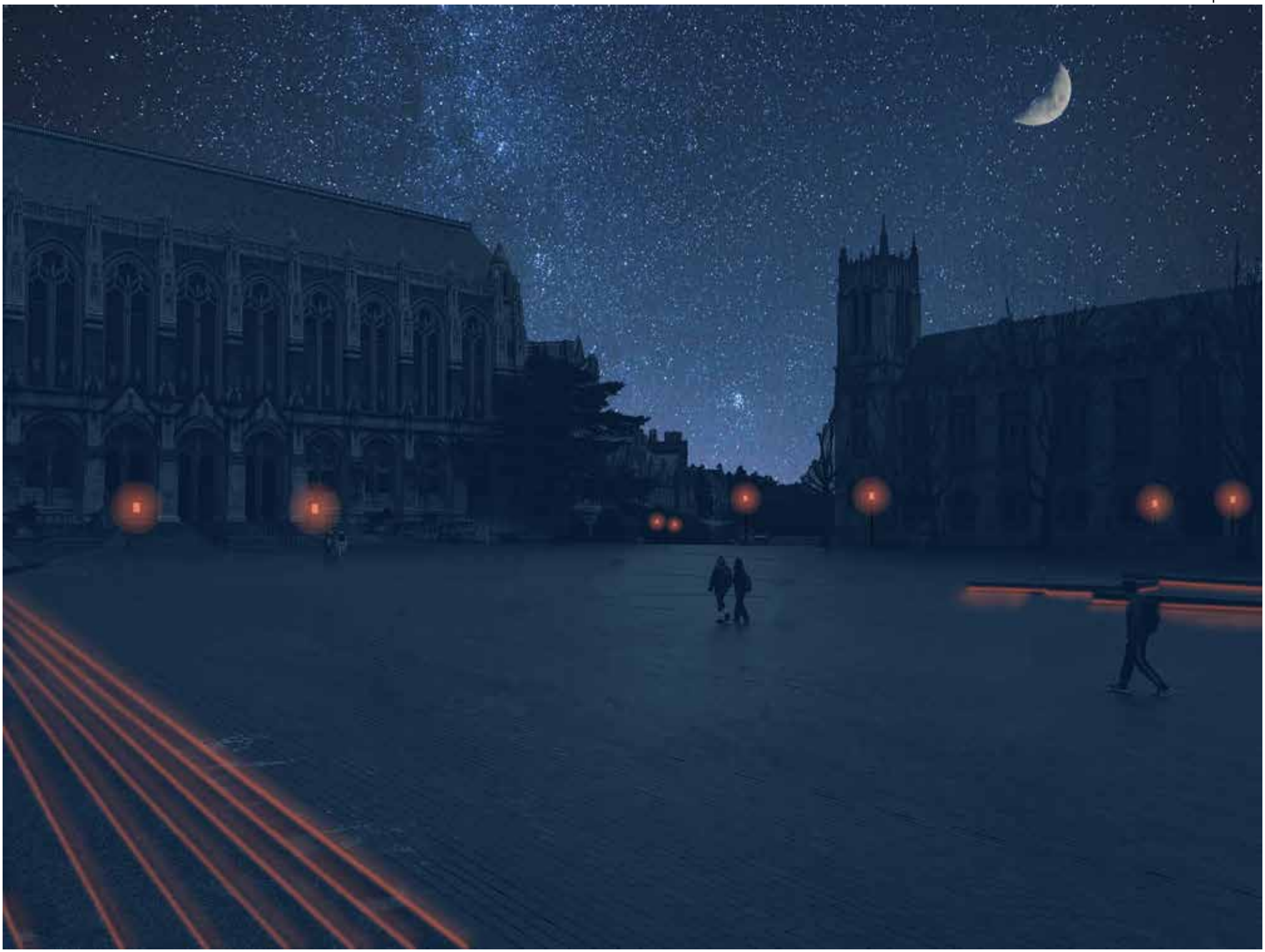
Red Square is a highly active site. This rendering is envisioning what this design would look like during the darkest part of the year. The building exteriors are well lit because they are a landmark location and help people understand where they are on campus. The historic UW street lights have been changed to be a warm color, low CCT value. The stairs and central seating have been lit from underneath to bring attention to potential trip hazards.

RED SQUARE: December 4:30p

In the evening, as classes are wrapping up, the lighting for Red Square changes. The building lights are dimmed as the number of people walking across campus slows down. The stairs, central seating and UW street lights remain the same for navigation.

RED SQUARE: December 9p

Three hours later, all scheduled campus activities have now ended. The buildings are closed and the lights are turned off. There are still a few students walking across campus. The stairs, central seating and UW street lights are still lit.



By 3a, no lighting is necessary for human activity. The UW historic lights remain on but are now dimmed. The lights remain on for orientation due to the face that the University of Washington Campus is a twenty-four hour site.

RED SQUARE: December 3a

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6pm


9pm


12am


3am

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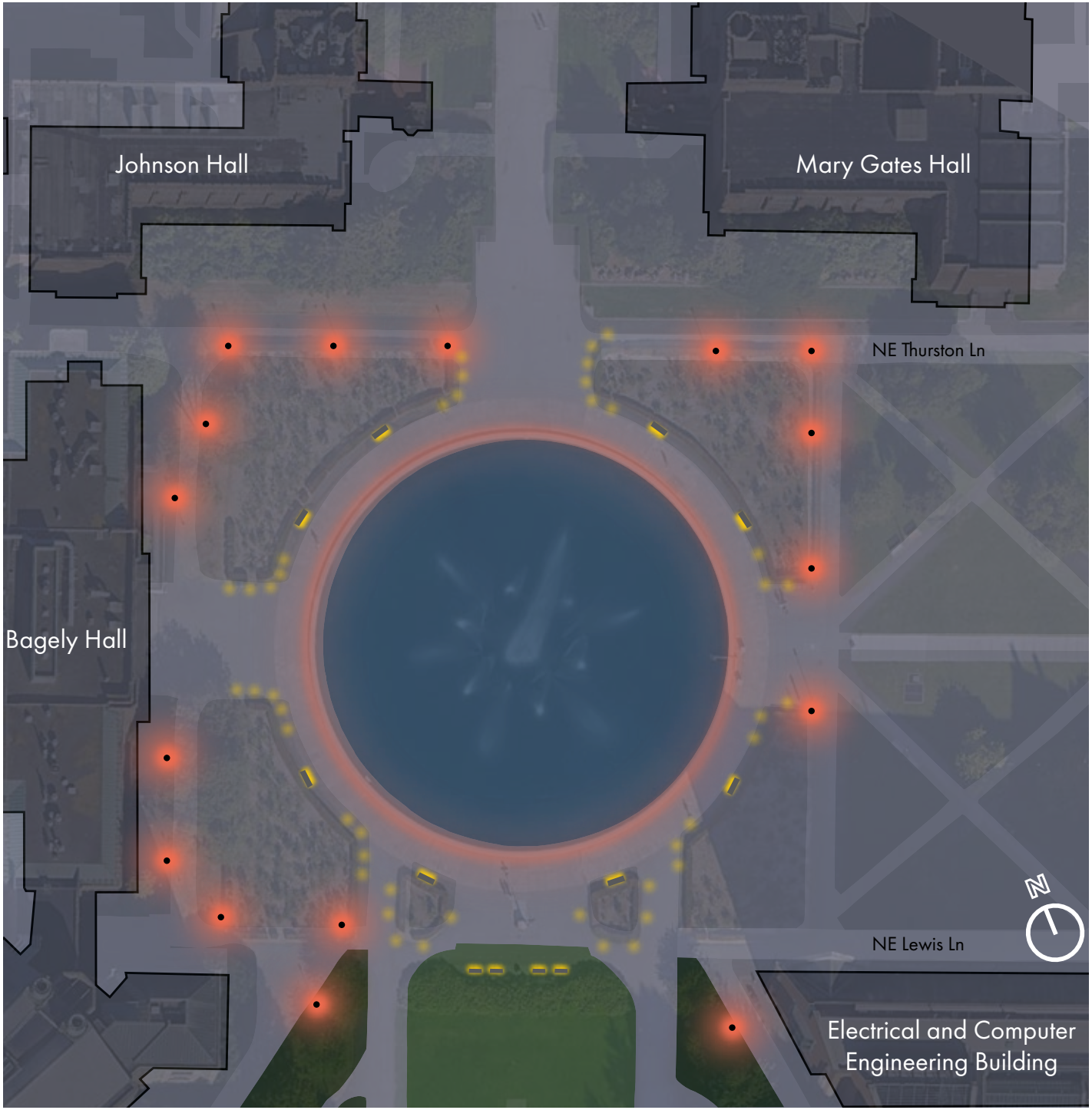

GOALS:

- Change historic UW campus light fixtures to warm colored bulbs.
- Direct light downward.
- Light the tripping hazards and permanent obstacles.
- Use timers to have lights on only during active hours.

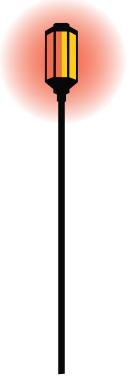

Figure 5.3 Bench lighting precedent. (Illuminated Bench - Backless | BEGA, n.d.)

Figure 5.4 Seating with lighting precedent. (CLOUSTON Associates « Landezine International Landscape Award LILA, n.d.)

The most ideal lighting conditions for ecological health are no lights. Starting with this in mind, this lighting concept begins with no additional lights and adds only what is needed for human safety and navigation.

Step 1: A clear full moonlit night. Before the invention of artificial lighting, this is how all species navigated the nighttime environment.

Step 2: The fountain is a potential hazard for humans who are visually impaired or who may not be familiar with the area. By lighting the underside of the fountain edge with a warm colored light, low CCT, that points downward, it allows for the human eye to identify the obstacle while mitigating ecological disruption.

Step 3: To keep a congruent lighting design across campus, the UW historic streetlights are changed to be a warm colored light bulb, the same as the Red Square design. The benches that surround the fountain are often used as places to gather even after sunset and by lighting the underside of the bench, people can find the seating areas with ease and also see if people are sitting on the bench.

Step 4: Draw attention to the multiple intersections around the fountain by installing in ground lights that are active during peak travel hours. Lighting the intersections just enough for human face recognition to aid in feelings of safety.

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Step 1: All Natural Lighting

Step 2: Light Fountain

Step 3: Historic Light Poles and Benches

Step 4: Light Intersections

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GOALS:

- Lower lighting fixtures.
- Direct light downward.
- Light only what is needed, the walking path.
- Use timers to have lights on only during active hours and change colors as people walk past.

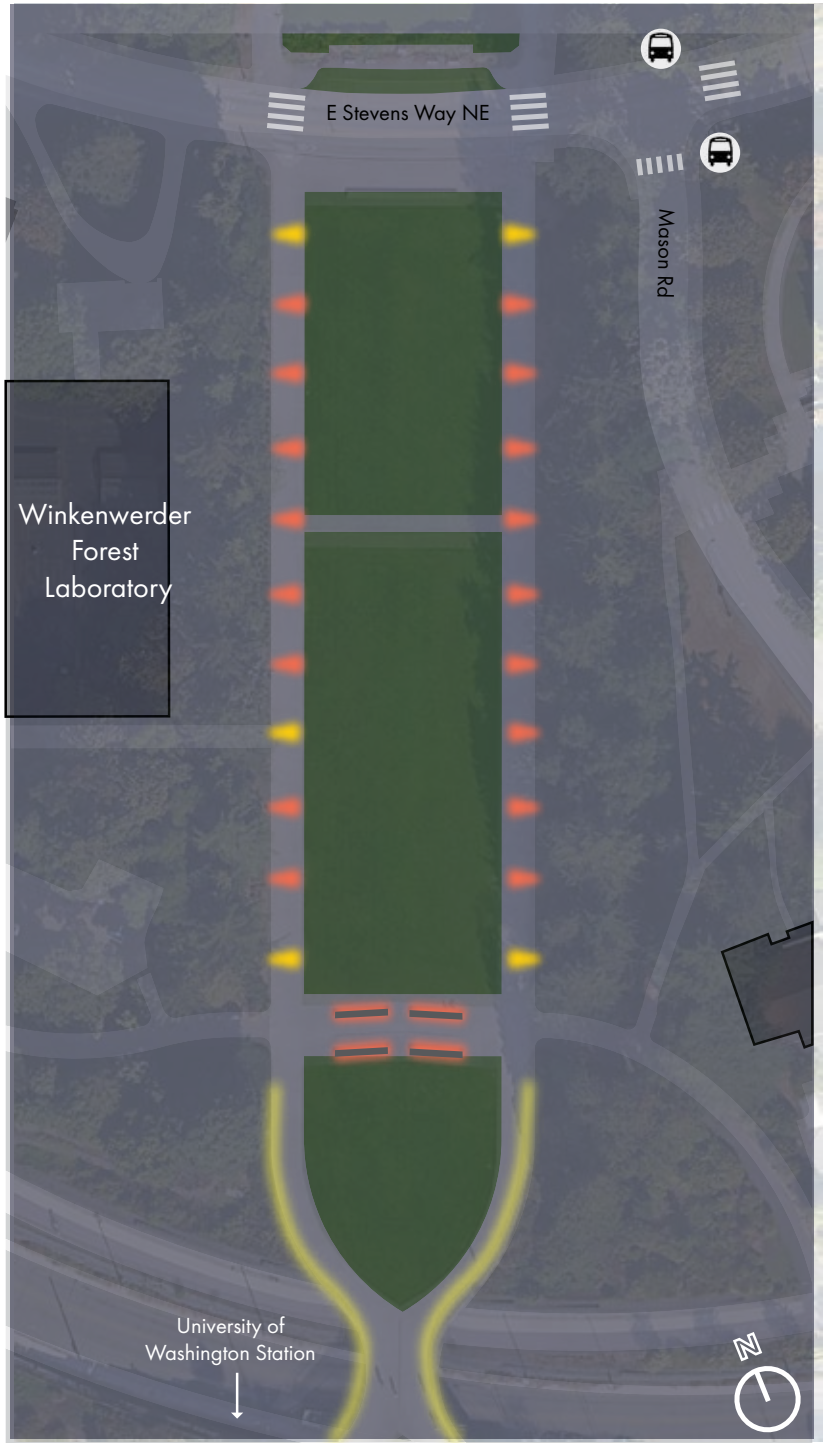
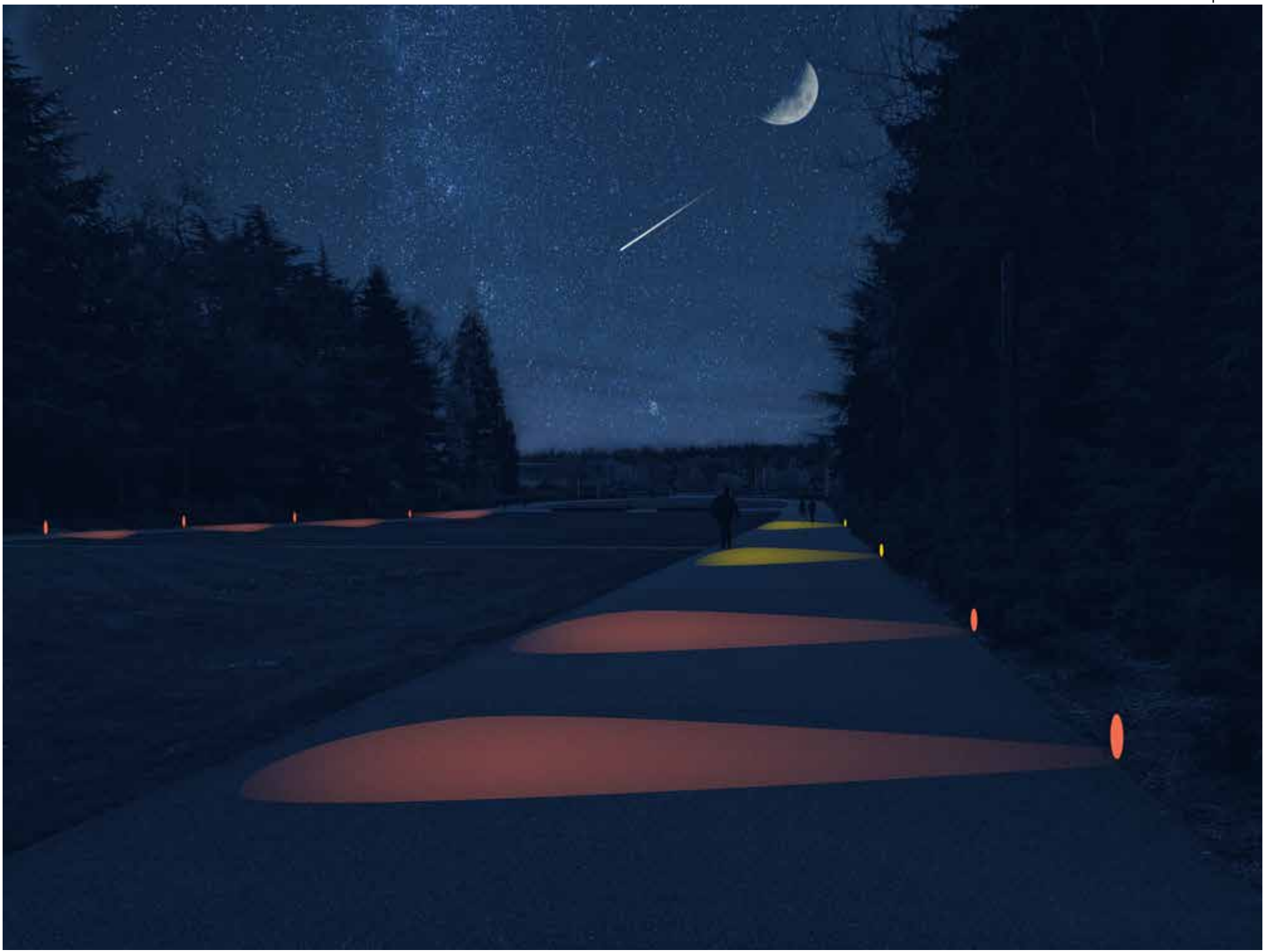


Figure 5.5 Bench lighting precedent. (Illuminated Bench - Backless | BEGA, n.d.)

Figure 5.5 Low pathway light precedent. (Home, n.d.)

Rainer Vista is an active connection between the bus stop and the University of Washington Light Rail Station. It is also a direct connection to the Burke Gilman bike trail. It is active site for multiple modes of travel throughout the night. On either side of the path are tall dense dark evergreens that are home to multiple nocturnal species. These species need darkness to travel from a safe covered area to another. By lowering the lights, changing the color temperature to a warm color and aiming the lights to only the human path it greatly reduces the stress of artificial lighting for the nocturnal species. To aid in human safety, the lights change from an orange color to a yellow color with a motion activated sensor so that people know when someone is walking towards them.



CHAPTER 06: CONCLUSION

Summary

This thesis has demonstrated the significance of re-examining outdoor lighting guiding principles from an ecological perspective. The findings of this study highlight the importance of considering the impact of exterior lighting on local ecosystems, including disrupted habitats, altered animal behavior, and diminished biodiversity. The research has also underscored the need for updated, ecologically-focused guiding principles that prioritize the well-being of both human and nonhuman inhabitants.

The proposed set of guiding principles, informed by the 2017 Lighting Roadmap and current research, offers a blueprint for the University of Washington campus to adopt more sustainable and wildlife-friendly exterior lighting design approaches. By incorporating an ecological lens, these principles can help minimize the negative impact of electric lighting on the local ecosystem while still considering human safety and navigation needs.

The importance of addressing light pollution cannot be overstated. As a significant cause of stress for both humans and animals, it is essential to mitigate its effects to promote the well-being of all living beings. The good news is that this type of pollution can be easily and quickly addressed by simply turning off, reducing, or changing exterior lighting.

This study's findings and recommendations have implications that extend beyond the University of Washington campus. They can serve as a model for other institutions and urban areas to adopt more sustainable and ecologically friendly exterior lighting design approaches. By doing so, we can work towards creating greener, more inclusive environments that prioritize the health and well-being of all inhabitants.

Limitations

This research thesis acknowledges certain limitations regarding the scope and context of the study. To get a comprehensive understanding of nocturnal activity, it would be best to have overnight observations over the span of at least a year to understand the seasonal patterns of wildlife.

Future

Recommended next steps for the University of Washington:

- Conduct further studies on the impact of exterior lighting on specific nonhuman species and their habitats.
- Create exterior lighting guidelines for all future campus development.
- Create a campus-wide congruent exterior lighting plan.
- Coordinate with facilities to create a lighting curfew.

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