



## LITERATURE REVIEW

### History And Evolution Of Light Pollution

Understanding the historical context and evolution of lighting systems is crucial when examining the growing threat of light pollution and its implications for building facades. For instance, the recent transition of major cities like Chicago from traditional high-pressure sodium lighting to energy-efficient LED systems exemplifies how cities worldwide are reimagining their urban environments. This shift not only transforms the night-time appearance of city streets but also has far-reaching consequences for the night sky. (Shedding Light on Urban Development, 2021)

A comprehensive analysis of the escalation of light pollution in the main Columbian cities between 2012 and 2022 was presented in the Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales (Magazine of the Colombian Academy of Exact, Physical and Natural Sciences) by a group of researchers, who established the relationship between increase in light pollution and the evolution of lighting systems. (Rueda-Espinosa, Guerrero-Guio, Vargas-Domínguez, Vinasco-Téllez, & Goéz-Therán, 2023) Contrary to instinctive assumption, this study proposes to eliminate the role of population and density in the escalation of light pollution across major cities in Columbia. However it holds accountable the growth of urban fabric and the shift to an LED based lighting system.

This issue was also previously highlighted by John D. Bullough in his paper Historic Streetscape Lighting: Integration Of Aesthetic Concerns With Modern Technology, wherein he explores the prospect of preserving the historic context of a city at the face of technological advances in the lighting systems. According to Bulloch, the advancements in lighting systems must be thoughtfully integrated to maintain the historic and aesthetic qualities of a city. (Bullough & Bullough, 2013)

The astronauts at The International Space Station (ISS) have shot millions of photographs of our home planet over the past 20 years. This has been a vital cornerstone in the research of Christopher Small of Columbia University. By analyzing night images of Earth, he is working to gain insight into how cities grow and evolve. A key part of Small's research has been the identification that light in urban environments almost entirely comprises of outdoor lighting rather than from within the buildings, and most of this light is on streets and roads. (Shedding Light on Urban Development, 2021)

### Causes of Light Pollution

Being a uniquely man-made problem, the main causes of light pollution are often improper and thoughtless planning in the form of:

#### *Street lamps*

Street lighting is a significant contributor when it is not designed or maintained properly. High-intensity bulbs and

improper placement can often lead to glare and light spillage, affecting both the night sky and the surrounding environment.

#### *Advertisement boards and Signages*

Brightly lit advertisements and signage often use excessive illumination, contributing to light pollution. Poorly designed lighting for these elements can lead to light trespass, where light spills onto unintended areas.

#### *Building Facade Illumination*

Many buildings employ facade lighting for aesthetic purposes. However, when this lighting is not carefully planned, it can result in over-illumination, detracting from the character of the building and contributing to light pollution.

#### *Overpopulation and Dense Urban Clusters*

Urban areas with high population densities lead to the clustering of buildings and increased outdoor lighting. This aggregation of artificial light sources creates skyglow, obscuring the natural night sky.

#### *Air Pollution*

Air pollution, such as smog and airborne particles, can scatter and diffuse artificial light by refracting light into unintended areas.

#### *Lights from Motor Vehicles*

Vehicle headlights, especially those with high-intensity bulbs or misaligned beams, contribute to localized light pollution. Glare from oncoming vehicles can disrupt drivers' vision and impact pedestrians.

#### *Public Places Requiring Heavy Illumination*

Public spaces like parks, plazas, and sidewalks are often illuminated for safety reasons. However, if these areas are excessively lit or not properly designed, it can result in light pollution without significantly improving safety. (Mehmedinovic & Heffernan, 2014-2020)

## Effects Of Light Pollution

### *On Humans*

The human body possesses a circadian rhythm or a biological clock that is linked to a regular pattern of (sun)light through day and night. Too much light exposure can have adverse effects on health and the quality of life (Rinkesh, n.d.)

Poorly designed roadway lighting produces a condition known as the "disability glare." This glare is so intense that it can cause momentarily blind a person. Older drivers are especially vulnerable to disability glare because with old age the eye loses its ability to quickly adjust to changing levels of illumination. (Filmer, 2013)

### *On the Ecosystem*

The ecosystem is heavily dependent on natural light. Everything in nature is fine tuned to run according to the cycle of the sun and light pollution disrupts this natural clock which in turn hinders the ecological processes. "Artificial light disrupts interspecific interactions evolved in natural patterns

of light and dark, with serious implications for community ecology.” (Longcore & Rich, 2004) The bright lights on high towers confuse migratory birds and cause them to crash head-on into buildings. “The New York skyline kills 10,000 birds per year, and one billion die from collisions across North America alone” (Sims, 2018).

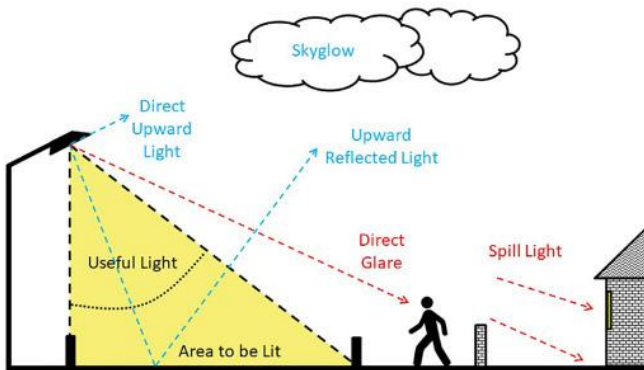
**On Buildings**

Light is to architecture what mortar is to bricks, it binds architecture cohesively. “Light sets houses and façades centre stage, shows historical buildings and modern architecture off to full effect, emphasizes natural spatial structures and brings squares, parks and green open spaces to life” (Zumtobel). While daylight or natural light is essential in architecture, night lighting is just as important. It is what helps us distinguish between say a historic building and a shopping mall, because while the architecture is visible in broad daylight, without proper night light it loses its character.

Perhaps the least popular effect of light pollution is seen on architecture. We see it every day all around us but it is never perceived as a problem. A building loses character if it is poorly lit or overly lit, or because of light trespass (See Figures 3). According to the Rensselaer Polytechnic Institute Lighting Research Center, “light trespass occurs when spill light is cast where it is not wanted.” (Light Trespass Regulations – Can They Cross the Line?, n.d.)

Figure 3

Components of light pollution. Upward components are shown in blue, and downward components are shown in red.



Note. Image by the authors (Mander, Alam, Lovreglio, & Ooi, 2023), modified from (Engineers, 2005)

A great amount of resources are spent on a building’s façade only to be overshadowed by the glare from street lamps or neighboring buildings, so much so that the building itself becomes “unnoticeable.” (See Figure 4) The buildings are merely a backdrop for the orange glare of the street lamps and the overall sky glow.

Figure 4

Sky glow and glare from street lamps at a park



Note. (W., Steven W.- Photostream ) (Ganguly, 2016)

Taking example from a building in Milan (See Figure 5), The Municipal Technical Services Tower (part of an ongoing project Growing by numbers, in which high rise buildings are progressively numbered). The light trespass and the glare makes the streetscape a bright blurry mess.

Figure 5

Growing by numbers, Milan, IT



Note. (Zumtobel)



**Figure 6***Growing by numbers, Milan, IT**Note. (Zumtobel)*

The design of the signage and facade is clearly visible and much more noticeable without the surrounding glare. (See Figure 6)

### Findings

The following findings were derived from the literature review conducted:

1. Light Pollution is a rapidly growing urban threat.
2. Historical analysis of light pollution highlights that the increase in the density of street lighting systems is one of the major causes of light pollution in a city.
3. The shift towards LED-based lighting systems is a contributing factor in the altered nightscapes.
4. Major chunk of light pollution at present comes from poor lighting strategies, where unnecessary light is used and does not hit the targeted area.
5. Light Pollution has an adverse effect not only on the ecosystem, but also on humans and the architecture.

### RESEARCH METHODOLOGY

The first part of this research is aimed at establishing why light pollution is a threat. After a methodical assessment of various scholarly articles, websites and books about light pollution was conducted to underline the historic context and the evolution of light pollution. The research further delves into the various causes and sources of light pollution that are relevant in the present day, and lastly analysis of the negative impact of light pollution.

The second part of this research consists of analyzing various methods of measurement of light pollution, followed by identifying standardization organizations and policies culminating in a set of guidelines.

### STANDARDIZATIONS & POLICIES

International standards and guidelines play a pivotal role in mitigating light pollution's impact on buildings. These standards provide architects, designers, and lighting

professionals with essential criteria and recommendations to reduce light pollution while enhancing the aesthetics of architectural design.

A leading pioneer in the standardization and guideline publication for lighting is the International Electrotechnical Commission (IEC). As a non-profit membership organization, IEC is dedicated to the preparation and publication of international standards, encompassing all aspects of 'electrotechnology' (electrical, electronic and all related technologies). These standards include critical elements for reducing light pollution. (International Electrotechnical Commission, n.d.)

Similarly, the International Commission on Illumination (CIE) holds a significant role in establishing standards for light and lighting. This organization is recognized by the Organization for Standardization (ISO) and the Electrotechnical Commission as a standardization body at the international level. (International Commission on Illumination, n.d.) The CIE is segregated into 8 divisions that oversee specific topics, broadly fundamental research and lighting applications. For instance, CIE's 'Division 4: Transportation and Exterior Applications' offers publications that provide essential guidelines for proper urban illumination, particularly in reducing sky glow, a critical consideration in facade lighting. (Hermann, The International Commission on Illumination - CIE:, 2001)

Narrowing down to the national authorities, the National Lighting Code of India (NLC), published in 2010, lays out various guidelines for various aspects of the lighting systems, based on the usage, type and requirements. It also provides somewhat vague inputs on the evolving technologies. (Bureau of Indian Standards, 2010).

Apart from the NCL, The Indian Society of Lighting Engineers (ISLE) is a professional body of scientists, engineers, architects, and others that partake in regular seminars on lighting related issues. This organization is affiliated to the CIE, and is closely associated with Bureau of Indian Standards, Bureau of Energy Efficiency, the Department of Science and Technology, the Ministry of Power, the Ministry of Non-Conventional Energy Sources and the Electrical Lamp and Component Manufacturers Association of India. (ISLE, Madhya Pradesh State Centre, Indore, n.d.)

### Findings

Despite the efforts of these international organizations and national authorities, a noticeable gap remains in comprehensive guidelines solely for optimal façade lighting. The current challenge lies in providing easily accessible and readily understandable publications, which are crucial for practical implementation.

### MEASUREMENT OF LIGHT

Investigating and highlighting the technologies and methods available for measurement of light pollution is an important

aspect in addressing the problem. Many different measures and units exist that are used to quantify light. For instance, Illuminance, weighted by the human eye, measure of electromagnetic radiation on a surface, is measured in lux (lx) and luminance, weighted by the human eye, brightness of that surface, is measured in candelas per square metre ( $\text{cd}/\text{m}^2$ ). For sky brightness the unit magnitudes per square arcsecond ( $\text{mag}/\text{arcsec}^2$ ) is used. (Mander, Alam, Lovreglio, & Ooi, 2023) The measurement tools have been classified onto 4 broad categories: Spaceborne, Airborne, Ground-based, and Ground-based imaging sensors.

### Spaceborne

Spaceborne methods include satellites that can detect the light emitted upwards, however, they cannot accurately measure all wavelengths generated by LED lighting or horizontally radiated light, which means that the actual level of light pollution from the ground can increment significantly. (Rueda-Espinosa, Guerrero-Guio, Vargas-Domínguez, Vinasco-Téllez, & Goéz-Therán, 2023)

### Airborne

Airborne methods include to attaching a camera to an aircraft in order to capture manufacturer defined values of luminance and red, green, blue and opaque measurements. While the limiting factor in all aircraft methods is the cost of flights, drones and air balloons have the potential to become a vital aid in future research methods.

### Ground-based sensors

Ground-based sensors have the ability to measure from the viewing angle of the human eye. These panchromatic tools include Sky quality meters, which are low cost point-and-shoot devices, more sensitive to short wavelengths, Illuminance and Luminance meters designed to mimic the human photopic eye. These devices are easy to handle and appropriate for amateurs, however the quality of measurement results varies widely and with discrepancies.

### Ground-based imaging sensors

Ground-based imaging sensors include digital cameras often combined with the fish eye lens to capture the night sky. Other methods include smartphone apps, although there may be issues with accuracy, spectrometers (essentially telescopes fitted with UVRI filter wheels), and hyperspectral cameras.

### GIS software

Another method that can be employed in the analysis of light pollution is the Geographic information system (GIS) software. Using the GIS software combined with mapping and digital photos, areas infested with unwanted light (horizontal and vertical) can be determined through comprehensive data in the form of graphs. (Bakr, 2007)

### Findings

After subjectively analyzing each method of measurement the following can be concluded that ground based measurement methods are the most optimum in measuring the lux levels of a

building façade. Using simple tools such as a digital camera and softwares light pollution can be analyzed and therefore curtailed.

### INTERVENTIONS

An essential aspect of urban lighting design involves determining the placement of luminaries responsible for illuminating specific areas. This decision must take into consideration the coverage needs in designated zones, influenced by safety requirements and the nature of the work being carried out. Simultaneously, it should guarantee the cost efficiency of the chosen installation layout. (Hammad & Akbarnezhad, 2018)

#### At the authority level

The following suggestions for policy adjustments can be considered to reduce the overall light pollution of a city:

Identification of dark spots and overly lit areas.

Implementing lighting patterns for weekdays and festivals, also monitoring the usage of unnecessary lighting. (Zhang, et al., 2023)

Specific standards should be chalked out for lighting systems and luminaires for different building typologies.

Using smart street lighting systems that are time controlled.

Implementation of shielded street lights in order to reduce upward throw and light trespass onto nearby buildings.

Figure 7

#### Good street lighting



Note. (New Boulder Code Exterior Lighting Compliance Requirements)

#### Building facade:

Illuminating the architecture greatly enhances the identity of a city, however it is important to correctly accentuate the façade elements and surfaces. The following points provide a foundation for designer to create sustainable lighting aesthetic:

1. The lux requirement should be calculated, in accordance with the design of the façade.
2. Involving a professional will result in an optimum lighting system curated for the aesthetic requirements.
3. Luminaires should be carefully analyzed and mindfully implemented. (Wan, 2022)

4. Façade material should be seriously taken into consideration when designing a lighting aesthetic as reflective materials can increase the lux levels (Jiangtao Du, 2018) thus causing “spillage” of light
5. Warm colours are recommended as per the DarkSky International guidelines, which suggest that light sources of shorter wavelengths (blue-violet) should be strictly limited. (DarkSky International, n.d.)
6. Appropriate standards must be assessed and guidelines kept in mind for various building typologies.
7. Integration of technologies such as sensor controls should be implemented to make the system more sustainable.

## CASE STUDIES

### The Kirikkale Nur Mosque in Turkey

1. To align with sustainability principles, the degree of lighting was restricted to the minimum essential for accomplishing the design objectives.
2. Carefully controlled uplighting was implemented to prevent light pollution and any undesirable overspill of light into the surroundings
3. Energy usage was curtailed by employing adaptable lighting schemes tailored to various time periods. (Kirikkale Nur Mosque, 2017)

Figure 8

*Kirikkale Nur Mosque, Turkey*

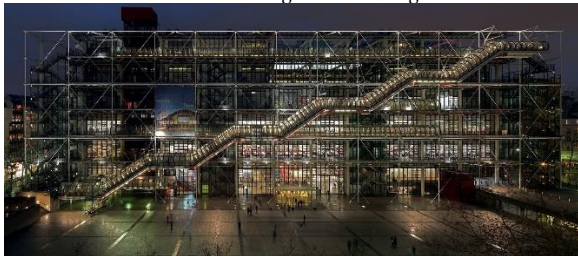


*Note.* Photographer: Ekinci, I. retrieved from (Kirikkale Nur Mosque, 2017); Lighting Design by ZEVE Lighting Design Studio

### The Pompidou Centre, Paris

Figure 9

*The Beaubourg center at night*



*Note.* Photograph by Kenzo Tribouillard, retrieved from (Wolf, 2023)

The lighting provided is just enough to highlight the building characteristics, distinguishing it from the others and making it a landmark structure.

No floodlight has been used in the illumination of the façade.

The building does not produce a glare, on the contrary it creates an ambience, that reduces the need for landscape lighting.

### Twinsset headquarter

Figure 10

*The Twinsset headquarter*



*Note.* Photograph by Daniele Domenicali, Matteo Colla, retrieved from (How to illuminate a glass facade with sunblinds, n.d.); Lighting Design by BP ARCHITECTS and SIMES

Using a controlled ellipsoidal beam allows for simultaneous illumination of two sides, where normally two lighting bodies would have been needed. Therefore greatly reducing the energy consumption. (How to illuminate a glass facade with sunblinds, n.d.)

## CONCLUSION

Light Pollution is a growing urban threat that needs immediate attention. While the causes and sources vary on various levels, small steps are required at the planning stages of a project to tackle this problem. Motivated by the lack of awareness on how light pollution alters the character of buildings at night, this paper serves as the lighting match to ignite conversations and create dialogues among fellow designers from all domains. There are various systems (being developed), as discussed in this paper, to measure and quantify façade luminance as well as broad guidelines, but there is a gap to be bridged in coherently amalgamating technology and standards. The findings presented in this paper aim to equip the designers and the architects with a foundation to create streetscapes that utilize optimum resources and do not contribute to light pollution. In conclusion, the only way forward is to adopt sustainable and ethical practices at the face of technological advancement and spread awareness among designers so that we can plan for a brighter future.

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