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Healthier and Environmentally Responsible Sustainable Cities and Communities. A New Design Framework and Planning Approach for Urban Illumination

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Abstract: Although sustainability and sustainable development are both considered necessary practices in various fields today, a recent analysis showed that the Sustainable Development Goal SDG11: Sustainable Cities and Communities established by the United Nations does not address urban illumination and its impact. This oversight is of concern because research carried out in the last 20+ years indicates artificial light at night (ALAN) in cities, and the light pollution this generates can have negative consequences on human health and well-being and the entire environment, including ecosystems and the flora and fauna that inhabit them. By applying a literature review, analysis and synthesis method, this work offers a new perspective on lighting and a timeline of key events that established ALAN and light pollution awareness in different disciplines and professional groups connected to urban illumination. It also identifies three fundamental aspects which require further transdisciplinary research and the translation of this knowledge into practice in order to enable the development of sustainable cities and communities at night. Finally, it presents in detail a new, theoretical environment-centred design framework for responsible urban illumination, with four iterative design phases, in order to help guide various stakeholders in cities, along with a four-level pyramid model that can be applied to urban illumination in the form of principles, processes, practices, and tools. This framework is especially relevant for those urban planners, architects, and landscape designers, who are unfamiliar with the subject in order to present the most effective and appropriate lighting design approach and methods that should be taken into consideration with the design of a given urban nighttime environment/situation.

Keywords: SDG11; sustainable cities and communities; environment-centered design; urban design and planning; responsible urban illumination; urban lighting; design framework; artificial light at night; ALAN; Semantic Scholar; Environmental Lighting Impact Assessments

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1. Introduction

Since the invention of electricity, artificial light after dark has supported humanity in its growth and expansion. It has been used to provide and enable safety and security, wayfinding, travel, manufacturing, nighttime entertainment, tourism, hospitality etc.

However, in the past, lighting was applied without restraint as there was a lack of awareness about its impact, and today, our current use of lighting needs to be questioned because research carried out in the last 20+ years indicates that artificial light at night (ALAN) in cities and the light pollution this generates, especially from new lighting technology such as LEDs, can have negative, lasting consequences on the entire environment [1]. Cities, in this context, play a key role because incorrectly designed nighttime illumination(s) may adversely affect human health and well-being, resulting in road accidents and collisions [2], reduced pedestrian safety [3], lowered life quality [4], lack of sleep [5] and other health-related consequences [6]. Moreover, it can impact the natural environment, not only disrupting the physiology and behaviour of flora [7] but also adversely harming local and

migratory fauna [8]. Due to the far-reaching impact of ALAN, light pollution in the form of urban skyglow can also affect non-urban areas that exist well beyond the boundaries of a city or town by up to 320 km away [9], negatively affecting protected national parks, nature parks, strict nature reserves, special nature reserves, outstanding natural landscapes, monuments of nature, and protected habitats, such as the Natura 2000 ecological network [10]. Although sustainability and sustainable development are both considered necessary practices in various fields today, a recent analysis performed by the author of the Sustainable Development Goal SDG11: Sustainable Cities and Communities established by the United Nations does not address urban illumination and its impact [11].

In 2016, researchers created a New World Atlas of the Artificial Night Sky Brightness model using high-resolution satellite data [12] with visible colours that correspond to the ratios between artificial sky brightness and natural sky brightness (Figure 1). When this visual impression was made widely available, the scale of the global problem of light pollution was revealed for the first time. It also divulged the extent of urban sky glow associated with human settlement, indicating both population and development levels simultaneously [13]. According to this research, 83% of people live under a light-polluted sky, with the figure being even higher in Europe and North America (99%), and light pollution was reported to be increasing at around 2% the annual rate. However, a more recent study indicated this figure could be much higher, as much as a 270% increase globally, with some specific regions recording an increase of up to 400% [14].

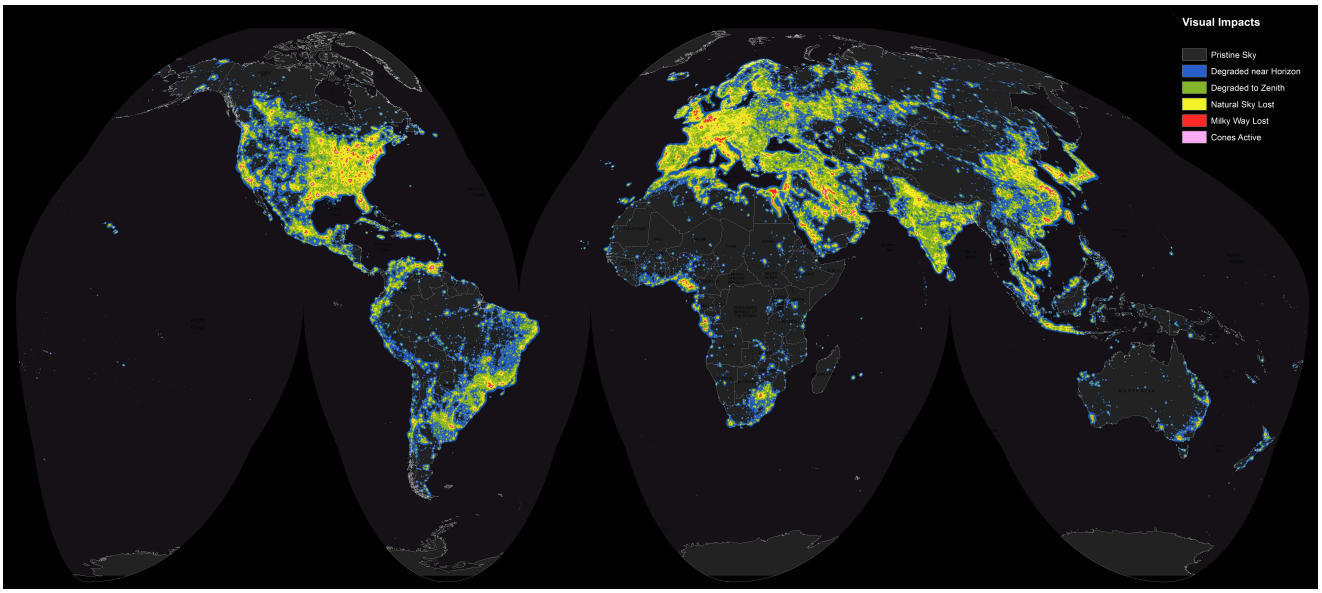

Figure 1. A map from the New World Atlas of Artificial Night Sky Brightness, capturing the light pollution/visible urban sky glow that has produced from human settlements. Source: [12].

In view of the above, responsible urban illumination is needed more than ever before for street and area lighting, building and nonbuilding structure lighting, industrial and commercial lighting, sports field facility lighting, advertisement lighting, park and garden lighting, safety and security lighting, and event lighting. This involves carefully thought-through and skillfully applied lighting that better supports human health, safety, and life quality and also protects biodiversity, the environment and dark skies. Therefore, the aim of this work is to provide a new environment-centred design framework for responsible urban illumination (which involves both human and non-human users), as well as specific recommendations to minimise the negative effects of urban illumination and light pollution, in order to help guide various stakeholders in the city. Additionally, a new design approach for responsible urban illumination has been created in the form of planning principles, procedures, methods and tools in order to help educate the urban planners, architects,

landscape designers and lighting professionals that are involved in city planning. This model integrates the latest research.

2. Research Question

In order to accomplish the research aim, the following research question has been investigated:

Question 1. What essential elements are needed for urban illumination in order to facilitate responsible design and planning (minimising the impact of ALAN and light pollution on health, well-being, and the environment) so cities and communities can be more sustainable after dark?

3. Methods

In order to generate a timeline of key years and events that established ALAN and light pollution awareness, scientific research papers and books were searched with the help of Semantic Scholar [15]. This is a new artificial-intelligence-powered search engine for academic publications, which uses advances in natural language processing. This tool allowed for the setting of different basic criteria such as: field of study, date range, publication type sorted by relevance and citation count, as well the most influential papers. A keyword-based search method was performed using the words and phrases such as: "light pollution", "astronomical light pollution", ecological light pollution", "urban lighting", "external illumination", "artificial light at night", "ALAN", "LED lighting", and "sustainable cities". Additionally, further inquiry involved an in-depth assessment of published information in the form of lighting standards, regulations and environmental reports, and newspaper articles that were found online. Lastly, the creation of a new design framework and planning approach for healthier and environmentally responsible sustainable cities and communities were supported via the insights and evidence provided by the author's 20+ years of hands-on experience as an architect and practising lighting professional and as an active Technical Committee member of the International Dark-Sky Association (IDA), the Illuminating Engineering Society (IES), and the International Commission on Illumination (CIE).

4. Global Awareness of ALAN and Light Pollution—The Timeline

In order to understand the temporal relationships of milestone dates and events connected to the development of ALAN, a timeline of chronological events was generated. This includes the impact of global urban illumination and light pollution in natural and urban environments (Figure 2).

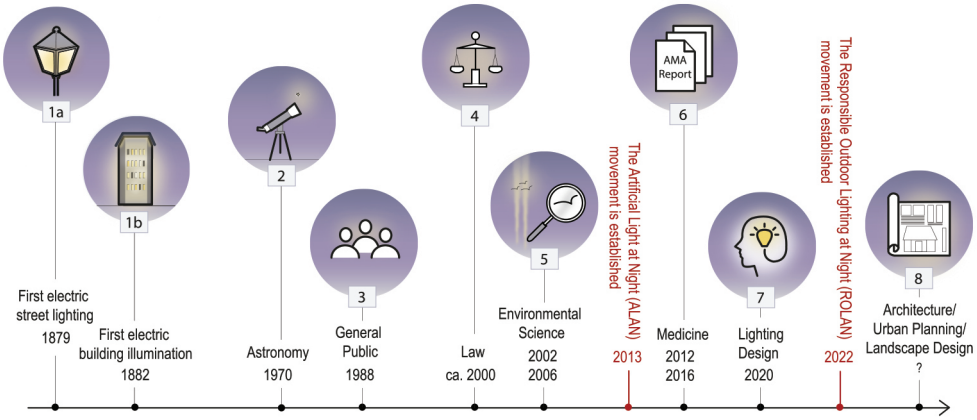

Figure 2. A timeline of key years and events that established ALAN and light pollution awareness in different disciplines and professional groups. Source: author's own work.

Since the invention of electric lighting, cities and communities have undergone radical changes in their character at night due to the application of new lighting technologies.

In 1879, the first city of Newcastle upon Tyne in England installed electric street lighting (Figure 2(1a)) [16]. Three years after this, the first city building was illuminated in New York/US (Figure 2(1b)) [17]. During the early XX century, the light was used to illuminate vehicular paths and to also make tall buildings stand out at night. Then once the advertisement industry discovered the marketing potential of artificial illumination, cities began to be filled with illuminated signs [18].

In the decades that followed, more light was applied in urban environments, and light pollution drastically increased beyond the boundaries of cities and towns to the point that in the 1970s, both professional and amateur astronomers acknowledged problems with their nighttime observations (Figure 2(2)) identifying outdoor lighting as growing threat to this profession [19]. As light pollution continued to escalate, many astronomical observatories located adjacent to cities had to move away to a less light-polluted position [20]. This professional group started regularly monitoring sky brightness in regard to location, visible wavelengths, and time. They also called for protective actions to be adopted by governments to assist observational astronomy without compromising the rightful needs of outdoor lighting by society, so in 1980, the International Astronomical Union (UIA) and the International Commission on Illumination (CIE) published joint guidelines for minimising urban sky glow near astronomical observatories [21]

Then in the year 1998, due to concern about losing dark nights and the negative impact of obtrusive lighting, the nonprofit International Dark-Sky Association (IDA) was established by two astronomers with the goal "to preserve and protect the nighttime environment and humanity's heritage of dark skies through quality outdoor lighting" (Figure 2(3)) [22]. The IDA's principal approach was to raise awareness about the value of the dark night skies field with stars and to inspire their protection through the free education of the general public, from children to adults, about the problems and solutions, including responsible outdoor lighting practices that reduce less light pollution. The IDA is known for its award-winning International Dark Sky Places (IDSP) programme, which encourages urban dark sky places [23], communities, parks, and protected areas around the world to preserve, protect and improve various sites through responsible lighting policies and public education.

At the end of the XXI century, urban planners, building architects and landscape architects used permanent illumination to highlight historic buildings, landmarks and landscapes, as light became a symbol of a city's prosperity and prestige. Following this rise, around the year 2000, light pollution received local recognition at the European level with the first proclaimed light pollution prevention laws. They were created by environmental lawyers who worked alongside astronomers, and their purpose was to legally stop the increase in light pollution (Figure 2(4)) [24]. A few years later, in 2007, light pollution was also recognised at the international level with the Declaration in Defense of the Night Sky and the Right to Starlight, also known as the "Starlight Declaration". It was signed by the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the International Astronomical Union (IAU), the World Tourism Organisation (UNWTO), and the International Astronomical Center (IAC) [25].

Around the same time, environmental scientists began to report the impact of ecological light pollution from artificial light sources on flora and fauna. The first research article (2002) discussed how the environment was being deprived of darkness due to ALAN [26], and the first book about this topic was published (2006), introducing the new term "ecological light pollution" (ELP). It explained how different animals were affected and included examples (Figure 2(5)) [27].

As more scientific studies were published, it became clear that light pollution was impacting various fields, not only astronomy. Therefore, researchers from different disciplines gathered together, and in 2013, the Artificial Light at Night (ALAN) movement was proclaimed during the first ALAN Conference held in Berlin/Germany [28]. Although the ALAN movement and the ideas behind it are very valuable and important, it involves quite an enclosed circle of researchers whose findings are often highly scientific, with very little

direct applicable knowledge for urban planners, architects, landscape designers and lighting professionals. Additionally, the language and physical quantity/measurement units used differ from those that lighting professionals currently apply in their daily practice, which also hinders communication and the application of these new research findings [29].

In the first two decades of the XXI century, cities started to replace their conventional street lighting with new LED technology in order to reduce energy consumption and the use of fossil fuels. Furthermore, colourful, dynamic changing illumination was applied to historic and modern buildings. Then due to the availability of lighting technology, media façades and illuminated advertisement screens also became more popular, and they were soon considered an essential element of the nighttime strategy to attract residents, visitors and tourists. However, the consequence of the widespread application of urban illumination has caused such a significant increase in light pollution that the general public can no longer view star constellations and the Milky Way with the naked eye. Too often, outdoor electric lighting installations at night in the urban realm are overlit, as the new lighting technology is far brighter than older light sources, with a more harmful spectrum. In fact, the excess radiance of LEDs and other different spectral properties are major reasons why light pollution has dramatically increased and why it has been acknowledged as a growing global environmental issue that can reduce our quality of life.

As a consequence of the above events, the medical research field also took action (Figure 2(6)). In 2009, the council on the science and public health sector of the American Medical Association (AMA) adopted a resolution endorsing the use of fully shielded street lighting to minimise nighttime glare in cities. Three years later, in 2012, it published a comprehensive report expanding its position on glare that addressed the adverse effects of light at night on public health [30]. Lastly, in 2016, the AMA adopted guidance (based on findings from an increasing body of scientific evidence) to reduce the harm of new, high-intensity, white LED street lighting technology that emits excessive amounts of blue light. The groundbreaking information published in this report suggested that new LED street lighting installed in residential areas might be up to five times more disruptive to the sleep cycle than conventional options, adversely impacting sleep quality and daytime functioning, as well as increasing the risk of developing obesity, diabetes, cardiovascular disease, and various forms of cancer [31].

Despite the efforts of the medical field, the lighting industry was quick to dismiss the content of the reports and downplay the numerous risks [32].

In the year 2020, the Five Principles of Responsible Outdoor Lighting were introduced by the International Dark Sky Association and the Illuminating Engineering Society (Figure 2(7)). This work informed lighting professionals and the lighting industry about the need to reduce urban light pollution and how to do this practice with a few simple steps. By joining forces, their shared goal was to prevent and reduce light pollution through the proper application of quality outdoor electric lighting [33].

In the year 2022, the Responsible Outdoor Lighting at Night (ROLAN) movement was established, with the first online conference organised in May [34]. This two-day event gathered not only well-respected ALAN researchers but also esteemed lighting professionals whose recent work is more environmentally conscious and sensitive to protecting dark skies and the nocturnal landscape. This platform provided a new form of communication and exchange between these two divergent groups, as well as the opportunity to present their work and share their unique knowledge.

Unfortunately, the urgent global issue of over-illumination in built-up environments continues to be overlooked by the vast majority of urban planners, architects, landscape designers, and municipal decision-makers. Too often, these stakeholders are limited by ignorance about the adverse impact of ALAN, which then contributes to the process of environmental degradation and, indirectly, also to climate destabilisation (Figure 2(8)) [35]. Therefore, this timeline highlights the urgent need for education of the above group as well as research-based practice and collaboration with experts from different fields.

5. Three Fundamental Aspects Which Require Further Transdisciplinary Research and Translation into Practice

The above timeline also identified three fundamental aspects, namely: (1) environmental, (2) public health and well-being, and (3) regulatory and legal, which require further transdisciplinary urban research. Additionally, it is essential that research outcomes are then translated into practice, using units of measurement and nonscientific language that is understandable to those who design urban illumination in cities in order to create healthier and environmentally responsible sustainable cities and communities [36].

5.1. Environmental Aspect

There are already several studies providing evidence that ALAN and light pollution from ground-based installations have a negative impact on astronomical observations as well as affecting flora and fauna.

Many professional astronomical observatories have had to move their location to their native countries or even continents due to an increase in light pollution from human settlements, as it was no longer possible to perform any meaningful discoveries [37]. Some countries, such as New Zealand, with the third highest number of astronomical observatories in the world, have put in place special regulations in certain areas to improve the existing situation, but as uncontrolled urban sky-glow can travel hundreds of kilometres from its source, more widespread and stringent steps may be needed. Another aspect is the fact that urban lighting in the majority of cities around the world prohibits visibility of the dark night sky and viewing of celestial bodies (stars) and galaxies (Milky Way) with the naked eye by the general public. This is an ancestral global common of cultural and historical significance, and every person should have the right to an unpolluted night sky. With four officially confirmed IDA Dark-Sky Places and almost two dozen applications currently underway, New Zealand is aiming to become a dark sky nation [38], following in the footsteps of the first dark sky nation, the Pacific island of Niue [39]. Astro-tourism in New Zealand has been on the rise, with almost 6% of the country's gross national product (GDP) providing almost 9% of the overall employment numbers. Other cities surrounding the world, such as the City of Fulda in Germany [40] and Bisei Town, Ibara, in Japan [41], are also following astro and eco-tourism as an important economic trend, so for them, having dark skies is essential; therefore, more research is required to oversee the current increase and identify problematic sources of light pollution.

Urban sky glow from cities and towns also negatively impacts pristine dark habitats with flora and fauna [42]. ALAN can affect the behaviours of nocturnal species such as birds (local and migratory), turtles, bats, insects and many more, which by nature rely on darkness to survive. Urban trees and plants can also be harmed by ALAN as it interferes with their photoperiod and diurnal rhythm and, as a consequence, affects their growth and survival during harsh winter conditions.

Only recently, a transdisciplinary systematic review was published, which calls for more research identifying the specific animal and plant groups in areas where such studies are still lacking [43]. Furthermore, from another review of the ecological impact of ALAN and strategies and measures to protect at-risk species and habitats, it is unclear if the proposed measures would be sufficient to limit possible adverse impacts on species [44] as they are based on current research and some additional undiscovered facts might be still be missing.

5.2. Public Health and Well-Being Aspect

The impact of light pollution from urban illuminations and its health effects on humans have not been as well studied as for flora and fauna, although there is already convincing epidemiological evidence that supports a link between exposure to ALAN and health issues and illnesses from disrupting the master circadian clock in humans [45]. However, there is much more to be discovered and learned, as research confirms that almost every cell in

the human body also has its own circadian clock and rhythm, which is why the impacts of ALAN have such wide-reaching effects on different organs.

Also, research findings in the fields of medicine and neuroscience have demonstrated a direct link between human health and well-being and the spectral characteristics of light sources and their luminous intensity. The increase in light pollution is related to a number of severe health challenges, including obesity, an increase in the likelihood of preterm birth in pregnant women and a higher chance of delivering a baby with a reduced birthweight [46]. There's also the possibility that adults have a higher risk of developing various types of cancers, from thyroid cancer [47] to breast and prostate cancer, cardiovascular disease, cardiac function and mental disorders. Furthermore, a recent study highlights the possible association between exposure to outdoor light at night and the development of autism spectrum disorder in children [48].

There are also more and more people filing citizen petitions to various governmental bodies, as well as bringing legal cases to court, as their life quality has been dramatically impacted by street lighting that has been retrofitted with the new LED light sources, general LED lighting (building and advertisement), and blinding LED headlights on vehicles. These appear to be incompatible with the human nervous system, causing serious side effects, including sleep disruption, visual distortion, headaches and epileptic seizures, discomfort, pain, migraines, nausea, panic attacks, mental confusion, with some people so severely affected they are incapacitated for days [49–51].

Researchers also confirm that an additional hazard to residents/visitors exists with the external illumination of buildings. As with street lighting, building illumination is often left on all night, and as with most street lights, it also emits blue-rich white light, which can suppress the secretion of melatonin. All living beings need a well-functioning circadian rhythm which depends on balanced melatonin levels to enable the body to renew cells overnight. In the developed world, it is now recognised that sleep problems significantly worsen all illnesses, with poor sleep linked to many prevalent diseases. Sleep disturbances such as insomnia can be caused by light trespass from the decorative illumination of buildings at night located in mixed-used developments from media facades and non-static LED displays entering residents' bedrooms, balconies or gardens [52].

From an ergonomic/human perspective, the following aspects of lighting should be avoided during the planning process: poor light distribution and improper lighting contrast, which can hinder visibility and also result in discomfort glare. It is also important to avoid excess brightness and flicker and to be aware that these factors, as well as specific colour/wavelengths, can adversely harm people who are disabled by artificial light, specifically from exposure to LED light sources.

Also, placing LED displays near junctions, intersections, and pedestrian crossings, where increased attention is required, is of concern as the typical LED displays used these days have sudden changes in luminance levels and/or colour and movement, which can disturb pedestrians, compromising their safety, as well as distracting motorists and cyclists, resulting in traffic accidents [53]. For safety reasons, any urban illumination should not compete with streetlights or traffic signals/lights.

5.3. Regulatory and Legal Aspect—Hard and Soft Law

It is critical that the numerous environmental, public health and well-being aspects of urban illumination are efficiently legislated and enforced by hard laws (legal acts) and soft laws (such as recommendations, guidelines, procedures, standards and codes), ensuring they are "fit for purpose" and that they integrate the latest knowledge, leading to the implementation of the envisioned new city model. Although soft laws are legally not binding, they serve the beneficial purpose of taking action by addressing pressing issues, as well as accelerating the process of international law-making. The SDGs proclaimed by the UN General Assembly are regarded as a form of soft law intended for eradicating severe poverty, establishing collaboration, and encouraging economic growth worldwide [54]. Hard law refers mostly to legal obligations that are and can be legally enforced before a

court. The application of existing, as well as the creation of new types of laws, is essential in order to support responsible design and planning practice. For example, Natura 2000 sites are sometimes located in urban/semi-urban areas with endangered bats occupying the heritage buildings and sites. Any illumination, even a temporary one, might have negative consequences for the existence of the whole bat population, so it is crucial to ensure that research-based knowledge is implemented and monitored at the local level [55]. The existing lighting soft laws rarely address aspects such as light pollution, and if such information is provided, it is only descriptive/general and not detailed enough to be applied in urban lighting projects.

Another necessary research aspect which should be taken into consideration is the translation of complex environmental knowledge into meaningful information, for example, specific lighting parameters, in order to create evidence-based guidelines, recommendations and lighting standards that can be applied by lighting professionals.

Also, there are conflicting views and dialogue that need to be encouraged. Some believe that providing such information would be too restrictive as they see lighting design used for placemaking, and with the help of vertical illuminance, they create legible spaces and journeys throughout the city, so the pros and cons have to be balanced.

A recent study also confirms that citizens are taking various actions against light pollution, with a three-fold increase in the number of lawsuits since 1990. With eight ALAN nuisance categories of lighting types which can negatively impact human health, well-being and entire ecosystems, the illumination of building and nonbuilding structures and sports facilities was the most disturbing [56]. Furthermore, non-legal actions such as petitions are on the rise. These findings indicate that citizens' awareness about lighting pollution is evolving along with the work of the IDA and other organisations; however, citizens will benefit from the information that is research-based, reasoning their cases with more scientific arguments.

6. Environment-Centered Design Framework for Sustainable Urban Illumination in Sustainable Cities and Communities

The proposed framework is a synthetisation of four interrelated phases which help in solving the real-world problem that the SDG11: Sustainable Cities and Communities goal does not currently address urban illumination and its impact. This framework is universal in nature and scalable for large and small cities, as well as towns. It aims to make urban lighting designs environmentally, socially and economically sustainable by focusing on the needs of human and non-human users (Figure 3).

It is an iterative process, which means that lighting professionals go back to certain phases repeatedly to improve their designs and create the best possible design solutions:

1. Understand how the user(s) experience the urban site at night.
2. It is crucial to know how the user(s) will engage with a proposed urban lighting design or the context in which they will experience it. Understanding this requires a lot of research, such as defining the possible impact of lighting on the environment and specific animals, observing users in action during site visits, and conducting interviews with residents and visitors.
3. Specify the user(s)'s needs.
4. Based on performed research, work out which user problems related to the impact of urban illuminations are the most important to be solved.
5. Design responsible urban lighting solutions for the identified user(s) problems.
6. Coming up with good urban lighting design proposals that can address the identified user(s) difficulties.
7. Evaluate the proposed urban lighting solutions designed for the user(s)' needs.
8. In order to know if the proposed lighting design can solve the user(s)' problem(s), test the solution on the urban site with hands-on lighting mock-ups and/or perform research with scientists to collect data and feedback. Furthermore, perform ELIA and HLIA.

9. This phase also involves public participation in an environmental impact assessment to obtain the necessary feedback [57].

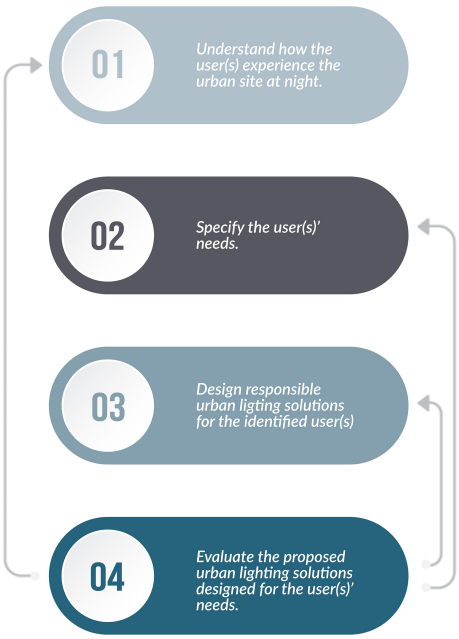

Figure 3. Environment-centered Design Framework for sustainable urban illumination with four iterative design phases. Source: author's own work.

7. Four-Level Pyramid Model: Principles, Processes, Practices and Procedures as well as Tools

This model encompasses four of the most important elements, based on its hierarchy (Figure 4), which will help lighting professionals to design responsible urban illumination in sustainable cities. The model takes into consideration aspects such as the impacts of lighting on health, well-being and the environment. These elements reflect current, state-of-the-art research; however, as more studies and evidence are produced in the coming years, these will need to be updated to incorporate the latest information.

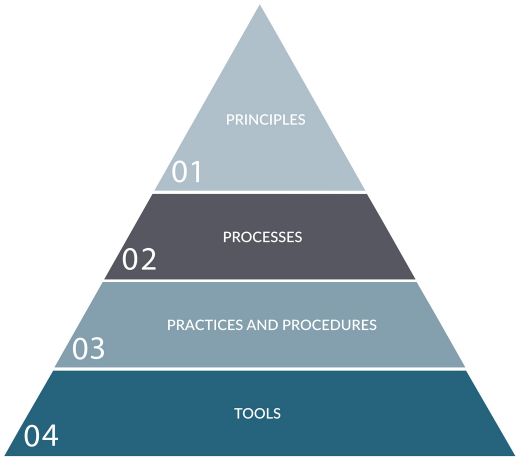

Figure 4. Four-level Pyramid Model for designing urban illumination in sustainable cities. Source: author's own work.

7.1. Principles

The Five Principles of Responsible Outdoor Lighting, published in 2020 by the IDA and the IES, are design considerations which represent the collected knowledge of international researchers and practitioners in urban lighting design and related fields. By applying these

principles, properly designed and positioned electric lighting at night can be beautiful, functional and far less disruptive to health. Projects that incorporate these principles will not only save energy and money, but they will also reduce light pollution, provide improved lighting conditions, and minimise the disruption of ALAN on wildlife.

7.2. Processes

In an urban lighting design project that is environmentally responsible and sustainable, it is necessary to have a well-defined approach that consists of six specific steps to enable good results with urban illumination (Table 1).

Table 1. Six steps for an urban lighting design project. Source: author's own work.

Stage Number	Stage Name	Stage Description
Stage 1	INCEPTION & FEASIBILITY	This stage involves developing details of the brief, including identifying possible health and environmental issues and ensuring the necessary improvements can be realised on the site.
Stage 2	CONCEPT DESIGN	This stage involves brainstorming urban lighting ideas, ensuring the urban lighting design concept is correct and then presenting the design to others for feedback. The look and feel of the illumination must meet the client's vision, brief and budget, as well as the expectations of the general public. An Environmental Lighting Impact Assessment (ELIA) and Health Lighting Impact Assessment (HELIA) should be part of this concept design stage.
Stage 3	DESIGN DEVELOPMENT & COORDINATION	This stage is involves integrating feedback and improving the concept, as well as coordinating the urban lighting design proposal with the design of other parties such as urban planners, architects, landscape architects, and other consultants.
Stage 4	DETAILED DESIGN & PRODUCTION	This stage involves developing the information required to manufacture and construct the urban lighting design project on-site. This requires detailed information from the design team and the specialist subcontractors employed by the contractor.
Stage 5	CONSTRUCTION	This stage is for when the urban design is constructed, and luminaires are being focused and the lighting controls are programmed.
Stage 6	HANDOVER	This stage occurs when the urban lighting project is already in use, and the urban lighting design solutions have been applied, and all the defects have been corrected.

7.3. Practices and Procedures

The ongoing pursuit of responsible urban illumination often consists of many processes, which form the best urban lighting practice, a method that has consistently shown results superior to those achieved with other means, and this is used as a design benchmark for lighting practitioners. Responsible urban illumination based on such practices delivers quality light that is pleasant to be around, provides visual and general comfort, assists visibility, wayfinding and navigation, etc., and in the end, supports life quality and benefits society.

7.3.1. Application of Environmental Lighting Zones

In an attempt to limit the negative effects of light pollution, the International Commission on Illumination (CIE) created a Guide on the Limitation of the Effects of Obtrusive

Light from Outdoor Lighting Installations with environmental lighting zones which can be used to classify land into zones of different character [58]. The zones are differentiated based on the ambient brightness of the environment to be experienced: Zone E1 (Intrinsically dark/IDA Dark Sky Parks, areas dark enough to see the Milky Way), Zone E2 (Dark/Relatively uninhabited rural areas), Zone E2 (Low district brightness sparsely inhabited areas), E3 (Medium district brightness/well-inhabited rural and urban settlements) to E4 (High district brightness/town and city centres and other commercial areas).

This methodology helps to establish an overview of which natural environments should be protected from outdoor illumination and why and can also be used to create a basis for limiting light pollution in a city. Lighting professionals must surrender their vision of urban illumination to specified requirements for a particular project located in a given environmental zone. These relate to aspects such as acceptable levels of urban sky glow, light trespass into the windows, and the permissible average and maximum luminance of the façade.

7.3.2. Urban Lighting Masterplan 2.0 = Urban Darkscape Masterplan

It is necessary to update the current high-level planning document—Urban Lighting Masterplan (ULM) [59,60], that is used by lighting professionals to present the vision of external illumination for a city, district or site. Even though it contains a detailed site analysis of the existing lighting conditions, together with suggestions for improvement, such as the operation of a lighting control system and proposals for energy savings—other important factors for sustainable developments and environmental protection have not been incorporated. This includes the functional lighting needs and the key proposals for decorative external illumination of buildings, the permitted levels of luminance on building façades, approved types and heights of luminaires, the colour temperature of the light source, as well as the proposed intensity of illumination assigned to the specific parts of the plan. Therefore, this research proposes to upgrade the ULM to version 2.0, which is called the Urban Darkscape Masterplan. It invites lighting professionals to positively change how they see the urban landscape, where the site becomes a black canvas and artificial urban lighting is added carefully with a great deal of consideration "erasing" the darkness, functional lighting is used "to see" and perform specific outdoor tasks, and decorative lighting is applied with far more care to help create a nocturnal city.

7.3.3. Environmental Lighting Impact Assessment (ELIA)

Since 2011, the EU's Environmental Impact Assessment (EIA) obliges that directive member states to prepare an assessment of the effects of certain public and private projects on the environment before projects can begin. This includes: nuclear power stations, long-distance railways, motorways, express roads, and waste disposal installations for hazardous waste or dams of a certain capacity [61]. For different project types, such as, for example, urban developments or tourism etc., it has been agreed that the individual EU member states will decide on a case-by-case basis. Unfortunately, lighting has not been explicitly mentioned as an environmental factor.

For example, in the UK, obtrusive light is now deemed a statutory nuisance within the Environmental Protection Act, and as a consequence, lighting assessments have increased significantly. With local authorities now having an obligation to investigate light nuisance and determine its impact, lighting professionals are often requested by clients to assess the direct and indirect Environmental Lighting Impact Assessments (ELIA) of the environmental consequences of lighting projects.

The UK-based Institution of Lighting Professionals (ILP) created a first-of-its-kind, detailed guideline on the subject, which can be followed [62]. This document provides information about the likely impacts of development projects for those who make the decision as to whether the project should be authorised. In order to assess the current baseline conditions on the site in question, such work might include the following: carrying out daytime and nighttime photographic site surveys and taking measurements of illuminance

(lx), vertical luminance (cd/m^2) lighting calculations with the help of professional lighting calculation software, in order to estimate the future lighting levels on-site and at the site's boundary. Additionally, it is important to identify the classified environmental zone for the site in question, the possible ecological impacts on humans and animals, and to also gather information on sky glow, light trespass and glare. Lastly, the proposed mitigation strategy needs to be aimed at satisfying planning conditions.

7.3.4. Health Lighting Impact Assessment (HLIA)

Recently, given the concern about emerging research linking exposure to LED lighting at night with numerous illnesses and conditions, there have also been commissions from various city councils to provide Health Impact Assessments. Their overall aim is to deliver an unbiased evaluation of the possible and probable impacts on health and well-being from installing outdoor lighting, especially LED street lighting [63]. These assessments might only consist of existing research but may also include lighting measurements on-site.

7.3.5. BREEAM and LEED Certifications incl. Light Pollution Reduction Credit Points

Both the BREEAM and LEED international validation and certification systems for sustainable built environments award points for the completed credit for the reduction of nighttime light pollution. The aim of BREAAM's International New Construction Version 6.0, reduction of nighttime light pollution for non-residential and residential institutions, is to lower energy consumption and prevent light nuisance/light trespass into neighbouring properties by ensuring that external lighting is carefully placed and positioned and also well-controlled in the appropriate site/area(s), and that upward illumination is minimised [64]. The aim of the LEED's Light Pollution Reduction point—SS Credit 8, is to improve access to the night sky by reducing skyglow and enhancing nighttime visibility via glare reductions, as well as minimising light trespass from building(s) and sites and reducing the adverse consequences of development on the nocturnal environment on flora, fauna and people [65].

7.3.6. Circular Economy

A circular economy in the lighting industry is a manufacturing practice where resources are reused, recycled, and redesigned in a way that gives them value at the end of their life [66]. This means healthier and environmentally responsible sustainable cities and communities should prioritise lighting products such as luminaires which are serviceable, reusable, and refurbishable. Recyclable, long-life LED light sources that also integrate adaptive controls to lower the light output and their hours of operation can further extend their lifespan, optimise maintenance, maximise energy savings, and reduce damage to the environment.

7.4. Tools

These are the various design instruments used to perform the task of designing responsible urban lighting. Their conscious application should help with the reduction of light pollution in urban environments.

7.4.1. Outdoor Luminaires and the IDA's Fixture Seal of Approval

City or town centres usually have many luminaires to support active around-the-clock human life, from road lighting to commercial lighting. Well-designed outdoor luminaires can reduce light pollution in these urban areas. The IDA provides a Fixture Seal of Approval (FSA) programme, which gives objective, third-party certification for luminaires that reduce pollution in the night sky by preventing upward light spill, minimising glare, and reducing light trespass [67].

7.4.2. Light Sources

The spectrum of light is now key with all the blue-rich white LED lighting that has been installed in cities and towns. In order to minimise its negative environmental impacts, it is recommended to use lamps with a colour temperature rated at 2200 K CCT, phosphor-converted (PC) amber LEDs, or some filtered LEDs. According to the IDA's Value-centered Outdoor Lighting strategy, when a colour temperature higher than 2200 K CCT is used, it is necessary to keep the total emission of blue light into the environment as low as reasonably possible through low intensities, careful directing of light, and reduced operating times (introducing curfews). For urban environments near sensitive sites such as parks or stargazing sites, it is recommended that lighting installations use 0% blue light and a narrower spectrum of emission [68].

Bright, broad-spectrum lighting needs to be avoided because it not only confuses living organisms into thinking it is daylight when it is nighttime, but it also affects far more species, as it includes all wavelengths of visible light. We know that there can be a wide range of sensitivity in living organisms to light, meaning there are variations in their responses to illuminance thresholds and the spectrum of artificial light sources. So there is no one-size-fits-all solution that will work for all situations in the urban realm. For example, most insects are attracted to blue-rich white light [69], but recent studies highlight the fact that there are some exceptions to the rule [70].

Recent research also showed that many species are disrupted by levels of light that are not even detectable to humans. For example, even very low illuminance levels can suppress melatonin production for some animals. In fish, the threshold is 0.01 lux; in rodents, almost 0.03 lux; in birds, 0.3 lux; in sensitive humans, 6 lux. For comparison, the illuminance level at night, on a starry night, is 0.001 lux. On a full-moon night, it can reach a maximum of 0.3 lux, whereas the skyglow of a city can reach an illuminance of up to 0.1 lux, with some urban lighting being as high as 150 lux [71].

7.4.3. Lighting Control System

One possible solution to help reduce light intensity, which can also allow for darkness in urban areas, is a flexible lighting control system which provides light only when it is needed, according to the user's necessities and the requirements of the habitat. Such adaptive LED lighting control systems have been installed in many sites, where streetlights across the city are fitted with sensors. They can either turn right off or be dimmed down to operate at 20% of their output when there is no activity on the streets and increase the brightness when movement is detected [72].

7.4.4. Lighting Standards and Guidelines

In the last few years, different lighting organisations and authorities have published various guidelines, which can be referred to as soft laws on the topic [73–78]. However, all these documents address only a few of the technical lighting parameters, which are insufficient, mainly: illuminance, luminance, correlated colour temperature, and colour rendering index, omitting aspects such as specific wavelengths of light, flicker, peak luminance and peak radiance, which might be harmful to specific organisms.

7.4.5. Equipment to Measure Illuminance and Luminance (Perceived Brightness)

And lastly, there is various lighting measuring equipment. Today, lighting professionals use illuminance meters to measure illuminance and CCT, as well as spectroradiometers to measure the spectrum of light, flicker and other parameters. Luminance meters are still considered to be too expensive, so they can be out of reach for many people. This can mean that the few measurements that are taken to evaluate the brightness of illuminated advertisements or façade illumination will not provide the necessary data.

Another important point to make is that the current lighting standards being used around the world are based on spherical light emitters that produce uniform light, not light sources such as LEDs, which often contain numerous small, high-intensity light emitters

that produce non-uniform light. Lighting professionals and the lighting industry are also using equipment and methods that do not accurately measure the unique properties of LEDs, so metrics, methods and standards all need to be updated to take into account these differences to improve the user's experience at nighttime [79].

7.4.6. Equipment to Measure and Evaluate Light Pollution from a Spatial and Temporal Perspective

Remote sensing methods and sometimes GIS has been used to monitor light pollution from a spatial and temporal perspective. Several approaches have been currently applied, such as: the use of available satellite data [80], the use of images taken by astronauts from the international space station [81], and the use of stratospheric balloons observation platforms [82] along with airborne platforms such as drones [83] or aeroplanes [84].

8. Discussion

The 21st century has been considered a time of significant urban transformation due to the migration of people from rural areas to urban agglomerations, rapid technological developments and innovation, as well as globalisation. Concurrently, the increasing ecological awareness of entire societies, fostered by researchers from various fields, has had a noteworthy impact on the development of urban ecosystems. A new urban model has emerged in response to the above issues—to help enable healthier and environmentally responsible sustainable cities.

Due to the challenges facing humankind, there is an ongoing debate about new ways of working with outdoor lighting at night and how to responsibly shape the image of a nocturnal city [85]. Whilst people need artificial light so society, as we know it, can function after dark, it is essential the environmental and health impacts that ALAN generates are taken into consideration and accounted for as well because humanity needs to decrease energy consumption, light pollution, and ecological harm. For cities and communities to be truly sustainable at night, the use and application of lighting require a paradigm shift, hence the necessity for a new design framework and planning approach for urban illumination. Responsible urban illumination can provide a win/win outcome that meets the various requirements of a sustainable city, including well-executed and appropriate lighting that provides safe, beautiful, enjoyable nightscapes and experiences after dark.

In the presented research, a new environment-centred design framework and planning approach for urban illumination have been proposed based on the latest research, which includes health and environmental aspects. These practical high-level recommendations to minimise the negative effects of ALAN and light pollution should help to inform the urban planners, architects, landscape architects and other professionals who are involved in the planning of sustainable cities and communities. When these professionals are better educated about the impact of improperly designed urban lighting, and they take steps to mitigate it, the benefits of doing so will extend to everyone by improving the present situation that exists for cities after dark.

Sustainable cities and communities at night still face a number of challenges in the future due to recent political, economic, and environmental developments. For example, a forthcoming global energy crisis, along with gas shortages, should change our perspective on energy, so it is treated as a valuable resource. Although LED lighting, on its own, has been promoted in the past to save energy, it is also necessary to integrate smart technologies to control the light levels and operation of LED lighting. This includes both functional and decorative, such as illumination for street lighting and area lighting, building and nonbuilding structure lighting, and industrial and commercial lighting; sports field facility lighting, advertisement lighting, park and garden lighting, safety and security lighting, and lastly, event lighting. The light which is not useful is wasteful light, so turning it off during off-peak hours, e.g. from 12 pm to 5 am, as a standard practice (not just as a temporary measure during a crisis) is a simple solution cities can integrate. This solution can be adjusted according to the days of the week/weekend, seasons and special events.

Often this important step has not been implemented in cities and towns due to various reasons, one being the cost involved in integrating a controlling central management system. Recently, a number of countries have been driven to adopt strategies to reduce their energy consumption which includes switching off decorative and advertisement lighting. Certain cities in Germany have already begun to switch off the decorative illumination of monument and landscape architectural features, such as fountains [86], but from the 1 September 2022, it will be mandatory to apply these measures not only for monuments and public buildings but also for illuminated advertisements and shop window lighting. In France, a number of communities outside of Paris are testing energy reduction measures by switching off all public lighting at night, including street lighting for a few hours [87], and illuminated advertising in all cities will be banned between 1 a.m. and 6 a.m. [88]. In Austria, some communities decided to dim their street lighting by 50% [89], Italy also intends to reduce its street lighting at night [90], and in parts such as South Tirol, measures are even more extreme [91]. In Spain, a mandatory measure has been made until November 2023 to switch off the illumination of shops, supermarkets and public buildings, including popular tourist attractions such as churches and cathedrals [92]. These energy savings measures that European countries are going to apply should not return us to the Middle Ages, where according to the historical sources of that time, there were no urban illuminations at night [93]. Rather, this current situation is an unprecedented opportunity for cities to stop the unnecessary waste of electric lighting and to improve attitudes towards its responsible use and application by including nighttime solutions that support sustainability, safety and life quality. In this context, well-informed lighting professionals seem to be well-equipped to implement these new design approaches for urban illumination in cities.

In recent decades, cities have often been applying lighting wastefully and carelessly, and this attitude needs to be addressed. Once responsible lighting (along with curfews, dimming, etc.) is in place—then such extreme measures should not be necessary. After all, the purpose of sustainability is to provide well-thought-through and carefully executed quality services that respect resources and take into account the "cost" and consequences of their use. This means sustainability also needs to apply to all uses of urban lighting. As certain functional illumination is necessary, cities need to prioritise which lighting is truly required and then for that lighting to be executed in the best possible way to mitigate its impact and costs. Furthermore, perhaps it is time for humanity to reassess permanent nighttime lighting that is solely for entertainment purposes, and considering its adverse impacts on health and well-being, that far more restrictions are placed on it.

Even with low-carbon LEDs, the massive investment spent removing conventional functioning street luminaires and replacing them with glary, white LEDs—has resulted in errors; instead of improving lighting conditions, they have often worsened. Despite using shielded and directed downward luminaires, light pollution has increased because the LEDs are much brighter, and the shorter blue wavelengths of light scatter more readily, bouncing off the ground into the atmosphere. Furthermore, the transition to LED lighting technology has, in fact, not reduced energy consumption, as more light has been used than before [94].

Additionally, it is crucial to provide the necessary guidance to help educate stakeholders about safety and security and to also provide reassurance that switching off urban lighting due to the energy crisis will not make cities feel less safe [95], nor will less lighting will contribute to increased crime and burglary [96]. It is important for decision-makers to know that recent research from France highlights the fact there is no substantial evidence that shows a decrease in public lighting increases crime; in fact, just the opposite, and there are urban communities which demand less lighting because new LED light sources are considered too bright [97]. Furthermore, a study performed in the city of Zurich, Switzerland (with the help of satellite night data), compared the effect of replacing older street lighting with LED technology that involved much less lighting than before, confirming no

increase in crime. Moreover, in darker places with less outdoor illumination, there was no confirmed increase in traffic accidents as well [98].

This work brings to attention, also the need for local participation and community engagement in the design process of urban illuminations to achieve "health for all" by reducing inequalities, improving social justice, and sharing responsibility towards designing sustainable cities after dark. Even organisations such as the World Health Organisation considers the involvement of this group essential to address health-related issues and promote well-being [99]. Repeatedly, decision-making processes about the development of sustainable cities at night are made without consulting citizens. These key stakeholders can propose ideas, voice their concerns, and positively influence decisions. Their participation can benefit municipalities by finding innovative sustainable lighting solutions, strengthening local action, and gaining support for the implementation of new ideas.

Lastly, a sustainable city should meet the basic needs of its inhabitants and promote economic growth whilst creating sustainable living conditions for all [100]. Therefore, in order to enable the development of sustainable cities and communities at night, three fundamental aspects have been identified and described in detail, namely: environmental, public health and well-being, plus regulatory and legal. These aspects require further transdisciplinary research and for this research to then be translated into practice. The last action should involve LUCI (Lighting Urban Community International), a nonprofit organisation created in 2002 [101], which has since formed an international network of over 70 cities that use light as a tool for social, cultural and economic development. For the past decade and a half, LUCI has played a significant role in the shaping of public lighting policies in cities.

Combining research with the practical realities and challenges that exist will ensure a better future and experience not only for all human dwellers of cities but also for non-human species that inhabit or visit urban environments.

8.1. Future Research

While this study offers an essential understanding of numerous challenges involving research, additional associated issues are likely to remain unanswered.

8.1.1. The Need for Clear and Accurate Definitions and Terminology

In order to reduce light pollution and ecological light pollution and to enable communication across all disciplines and stakeholder groups involved in designing cities at night, it is necessary to have a commonly agreed vocabulary with clear and accurate definitions and terminology. Unfortunately, in the International Lighting Vocabulary, published in 2020 [102] by the International Commission on Illumination (CIE), the international authority on light and lighting, light pollution is only defined as the "Sum total of all adverse effects of artificial light" [103]. The term ecological light pollution does not even exist in their vocabulary. Therefore, how can the problem of light pollution and the adverse impact of incorrectly designed urban lighting be solved if the issue is not properly defined?

Also, it is a misnomer to call any artificial light at night "friendly" because it implies it is harmless or benign, and as recent environmental research shows, it is not. While such descriptions may help in the marketing of artificial lighting that is less harmful and light polluting, it is important to use language and terms that are more accurate such as: "ecologically responsible", "ecologically sensitive", or "dark sky compliant", instead of "turtle-friendly", "insect-friendly" or "night sky friendly", to help educate people across all disciplines and groups, including the lighting industry, decision-makers and the general public.

There is also the need to re-write the current definition of a sustainable city to take into account the entire span of each 24 h day. A sustainable city at night also needs to consider social, environmental and economic aspects that include: (1) protecting the natural night for current and future generations to come, (2) supporting human health and well-being, (3) preserving and restoring nocturnal biodiversity in urban and natural

ecosystems and (4) reducing the city's energy footprint by applying intelligent lighting solutions and technology.

8.1.2. The Need for Innovation and Smart Technologies in Lighting

Given the rapid development of the smart city concept that is being widely used in various fields, the application of smart technologies, such as lighting management systems in urban lighting, should be further researched as an option for sustainable urban illumination.

8.1.3. The Need for a Tested and Validated of Environment-Centered Design Framework with a Real Case Study That Provides Empirical Data

This concept paper presents new perspectives on the design approach of urban illumination, and it is hoped that there will be stakeholders involved in city planning who recognise the immense value and numerous benefits of putting it into practice, whether for the entire city or parts of it, such as a neighbourhood, street or green space. This would then present an opportunity to test and validate empirical data from a real case study.

It is likely that in a couple of years, several reports will appear in the literature, perhaps with suggestions for improving some elements of this approach.

9. Conclusions

It is expected that this work will assist in resolving the oversight of not addressing urban illumination and its impact on SDG11: Sustainable Cities and Communities. It is critical that the politicians and city authorities who are willing to adopt the goals of SDG11 are made aware of this gap, and that appropriate actions are taken to minimise the phenomenon of light pollution and its negative effects. Thus, this work proposes that the responsible urban illumination needed for cities to be sustainable, healthier and environmentally responsible after dark might be achievable if the following actions for responsible urban illumination are incorporated into planning documents:

1. Every city resident deserves access to darkness and quality lighting, and both should be used and distributed fairly without discrimination. The design process for responsible urban illumination should start with darkness, and any light that is added should not prevent a view of the stars, nor should it ignore the importance of nocturnal placemaking and safety;
2. In all projects involving urban illumination, the social benefits of outdoor light at night should be optimised while simultaneously, its costs in environmental and financial terms should be limited;
3. Collaboration with lighting professionals (urban lighting designers, architectural lighting designers, illuminating engineers) should be undertaken at the appropriate early stages of the design process for urban, building and landscape design projects;
4. Collaboration with researchers/experts from different disciplines and specialities (e.g., astronomers, ecologists, biologists, etc.) is desirable in order to have access to evidence-based information on contemporary issues involving sustainable cities;
5. Public and private clients should be educated about the importance of responsible urban lighting to make well-informed decisions on the environment and the health and well-being of the city's residents. They should also take an active role in the application of existing regulatory lighting frameworks as well as the establishment of local regulations that are absent or lacking;
6. The local community should be an active stakeholder and participant in all urban lighting projects. It is crucial to involve citizens in the decision-making process, so they can voice their concerns, propose new ideas, and influence decisions;
7. The Five Principles of Responsible Outdoor Lighting should be applied to lighting projects of urban illumination: All light should have a clear purpose, it should be directed only to where it is needed, it should be no brighter than necessary, dimmed

down or turned off when not required, and warmer colour lights should be used where possible;
8. An Environmental Lighting Impact Assessment (ELIA) and Health Lighting Impact Assessment (HLIA) should be performed for permanent, existing and new developments that require urban illumination, as well as temporary events such as festivals, music concerts, etc., investigating the possible adverse effects on threatened and endangered wildlife, as well as humans and their quality of life;
9. Lighting technology should be embraced by asking for support and direction from the lighting industry (luminaire, light source and lighting control manufacturers) in order to sustain nighttime biodiversity and reduce energy consumption;
10. A circular economy should be a central aspect of the urban illumination project brief, design, specification, manufacturing, and installation process to reduce the use of natural resources, electronic waste and energy and to lower the carbon footprint;
11. After the project completion, the site should be visited at night with all community stakeholders to verify that the urban lighting design was fully implemented and that it meets the agreed principles.

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