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# A Comprehensive Exploration of Smart Lighting Aspects: Area of Use, Methodologies and Purposes

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**Abstract-** This paper aims to identify the essential purposes for smart lighting development including areas of application, methodologies, objectives, potential disruptions, and ethical considerations. Smart lighting can enhance citizens' quality of life and ensure safety in outdoor environments. Lighting is a critical factor in sustainable development, and the convergence of lighting and ICT industries is rapidly evolving. The paper evaluates the impacts of a complex intelligent lighting system, including the behavior of end-users and its effects on energy, environment, and resources. By combining innovation with overall system objectives, such as service continuity, energy-saving, and protection of people's health, smart lighting can contribute to a minimally adequate quality of life in underdeveloped economies.

**Keywords:** Smart Lighting, Energy Saving, Automation, Sensors, AI, IoT.

## I. INTRODUCTION

In the context of smart lighting, for the purposes of a possible roadmap, this paper aims to identify the purposes that are identified as essential, from various horizons and disciplines, in order to help analyzing their development. Essential elements appear to be the areas of use, methodologies adopted, objectives pursued, interferences, and ethical aspects. Lighting consumes huge amounts of energy and resources and is a primary factor of sustainable development. Smart lighting as an urban service has a particular influence and enriches the experience and quality of life of citizens.

It is now evident that in the right to safety and in the right to economic and social well-being, a basic component is lighting which, if it acquires smart characteristics, becomes more effective but also more invasive. Smart lighting even better satisfies the need for communities to guarantee freedom and safety of nighttime traffic in urbanized outdoor environments and the right to privacy and correct use of night and day data.

Lighting can increase citizens' trust in the city and in the people who live there. In any case, lighting also helps to satisfy the need to guarantee a minimal quality of life in community environments, it is now an indispensable requirement for communities with underdeveloped economies, given the unstoppable globalization which, in order to be fair, cannot disregard conditions of at least minimally adequate life.

Based on the objectives, it was possible to identify various contributions in the existing literature in order to constitute a reference document to understand the interactions between the components of a complex intelligent lighting system including the behavior of the

end user and evaluating the impacts on energy, environment and resources.

The lighting industry and the ICT industry are now rapidly evolving and converging. In any case, the comparison between the various objectives is important because it is necessary to combine the innovation of the components with the overall system, the general objectives of service continuity, energy saving and protection of people's health.

Smart lighting performs many functions and therefore requires continuity of service, not only for safety lighting and installations in buildings and critical outdoor areas, but also for many other uses with signaling, communication and control services.

This paper presents an overview of the various aspects on area of use, methodologies and purposes covered on smart lighting in recent publications (figure 1).

## II. SMART LIGHTING: AREA OF USE

Smart lighting refers to the use of technology to control and automate lighting in homes and buildings. This can include using connected devices such as smart bulbs, smart switches, and smart hubs to control lighting remotely, using voice commands, or through a mobile app. Smart lighting can also involve using sensors to automatically adjust lighting levels based on occupancy, ambient light, or other factors, as well as integrating with other smart home systems such as security cameras and thermostats. Some of

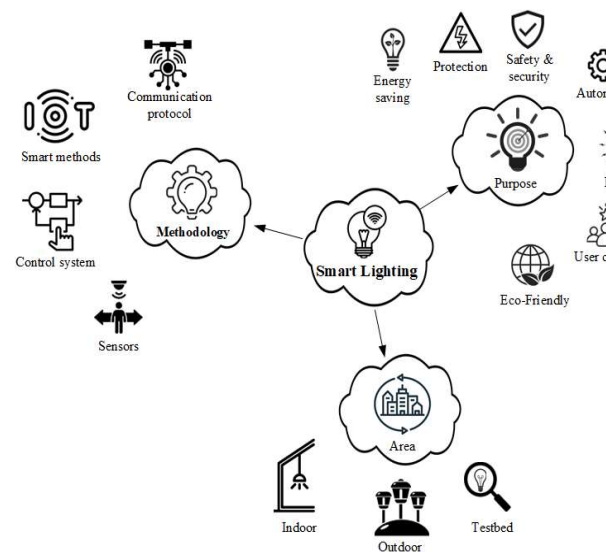


Figure 1 A roadmap of topics of recent published papers on Smart Lighting

the benefits of smart lighting include energy efficiency, convenience, and increased security.

Smart lighting implementation can be applied to both indoor and outdoor areas. Indoor smart lighting systems can improve energy efficiency, convenience, and personalized lighting experiences in homes, commercial buildings, industrial facilities, healthcare facilities, educational institutions, hospitality, and entertainment venues. Outdoor smart lighting systems can enhance safety, reduce energy consumption, and provide remote monitoring and control in public spaces, streets, and parks. Both indoor and outdoor smart lighting systems can incorporate a range of intelligence methods, such as motion detection, ambient light detection, geolocation, voice control, machine learning, app control, energy monitoring, automation and scheduling (figure 2). Apart from commonly used indoor and outdoor areas for smart lighting, testbed laboratories are also suitable for implementing smart lighting systems. Implementing smart lighting in a testbed laboratory can lead to increased energy efficiency, improved convenience and safety, and opportunities for automation and customization.

Let us consider the specific case of street lighting. The adoption of smart lighting can make a significant contribution to energy saving and high performance. It is well known that designing street lighting is an interesting methodological application of how to approach a plant project in general. In particular, to design street lighting, the following lighting engineering categories must be identified: - the reference category, - the project category, - the operating categories.

Once the type of road has been identified which allows for the definition of the reference lighting category, a preliminary analysis is carried out aimed at identifying the significant influencing parameters, such as the intensity of vehicular flow and the presence of road intersections, to define through an evaluation of the risk and functionality the project and operating categories.

The risk assessment leads to dividing the road into study areas with homogeneous conditions of the influencing parameters. Considering that the main geometric and functional elements making up a road are the types of lanes and intersections with other roads, it is convenient to define a compositional procedure for the configuration of any typical area with or without intersection.

By analyzing functional elements, it is possible to identify several typologies that can be used as a reference to configure elementary zones. This enables the

identification of different study areas, for which lighting calculation evaluations can be carried out as a reference.

These typologies constitute the basic elements with reference to which the lighting system is configured for each zone or intersection.

Once the composition of the installations with pole reinforcements and lighting towers has been identified, the expected performance verification calculation must be carried out with reference to each actual configuration.

In summary, when designing the layout of a road divided into study areas, the following lighting categories must be identified:

The operating categories describe the immediate and possible seasonal/daily conditions of a lighting system based on varying influencing parameters. The relevant parameters determine if a particular area needs a reference category with higher or lower performance requirements. Risk analysis and energy consumption considerations help in implementing smart features in the system components for a seasonal/daily operation plan with multiple lighting categories that correlate with the system's effective operating conditions.

### III. METHODOLOGIES IN SMART LIGHTING

Smart lighting systems utilize various methodologies to provide efficient, flexible, and personalized lighting solutions. These methodologies include both standard protocols, intelligent methods, control systems and sensors (figure 3).

Standard protocols such as KNX and DALI are widely used in smart lighting systems to ensure compatibility between different devices. These protocols define the communication between lighting devices and control systems, enabling them to work together seamlessly.

Intelligent methods such as artificial intelligence, internet of things, and neural networks are used to enhance the performance and functionality of smart lighting systems. These methods enable smart lighting systems to learn from user behavior, environmental factors, and other inputs, and adjust lighting levels and patterns accordingly.

Control systems are also a critical component of smart lighting systems, allowing users to monitor and adjust lighting levels, color, and other settings. These systems can be accessed through mobile apps, voice commands, or other interfaces, providing users with flexibility and convenience.

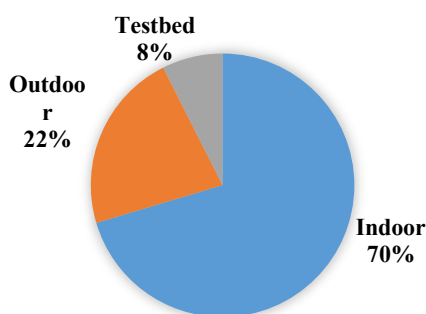


Figure 2. Smart Lighting Area of Use by percentage.

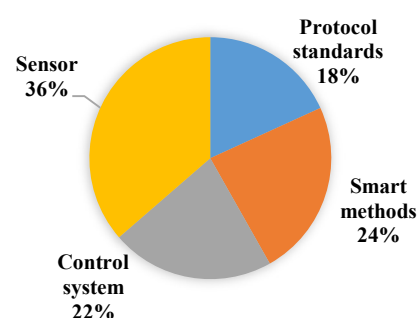


Fig 3. Used methodologies in Smart Lighting by percentage.

TABLE 1. SMART LIGHTING ASPECTS: AREA OF USE, METHODOLOGIES AND PURPOSES

Area of Use		Methodology				Purpose				
		Protocol	Smart	Control system	Sensor	Energy saving	Safety & Security	Automation	User comfort	Eco friendly
Outdoor	[1,3,8,11,14,15]	✓				✓				
	[4,5,6,12]		✓			✓				
	[2,7,9]				✓	✓				
	[13,15,56,57,59]			✓		✓				
	[10, 58]			✓			✓			
Indoor	[12,36,37,38,49,55]		✓			✓				
	[18,23,24,31,32]	✓				✓				
	[16,20,21,25,34,41,42,48]				✓	✓				
	[19,26,27,29,44,45]			✓		✓				
	[28,39,47]		✓				✓			
	[43,53]			✓		✓				✓
	[17]				✓	✓		✓		
	[22]				✓	✓	✓			
	[46]	✓				✓			✓	
Testbed	[2,9]				✓	✓				
	[51,52]	✓	✓		✓	✓	✓	✓		
	[30]					✓				
	[54]				✓		✓			

Sensors are used in smart lighting systems to detect and respond to changes in the environment. For example, motion sensors can detect when a room is occupied and turn on the lights accordingly, while light sensors can adjust lighting levels based on ambient light levels. Overall, the main methodologies in smart lighting systems involve a combination of standard protocols, intelligent methods, control systems, and sensors to provide efficient, flexible, and personalized lighting solutions.

The various smart systems applied to lighting systems can make a significant contribution to safety and energy saving. An important example is the absorption of electricity and the planning and management of road tunnel lighting which require the application of the criterion of a design aimed at the operation of the systems. To this end, it seems appropriate to resort to flexible and modular configurations for the plants and management criteria that allow operation with programmable electrical power. During service, the luminance entering tunnels is generally controlled automatically by sensors, in correlation with the external luminance. The objective of regulating the internal luminance is to maintain its value in a safe relationship with the external luminance, so as to always guarantee the speed of the lighting design as safe. Considering that a tunnel can be located in remote sites, a high-power value can be critical and unsustainable. In fact, the local electricity distribution could be inadequate to supply it and the cost-benefit criterion could prove inconvenient to adopt the aforementioned value for the sizing of the equipment and for energy consumption. It should be noted that the global electrical power required depends both on the luminance that the lighting system must guarantee, and on the penetration of its extension. With the same power

engaged, if a decrease in traffic speed compared to the design speed is imposed in critical conditions compared to those at high frequency, which various vehicle signaling systems such as variable message panels can communicate to users. Reducing the speed of the vehicles allows for a reduction in the stopping distance and thus a quota of the electric power is made available to be used with greater density in the entrance area, to make available a higher power density which is suitable for critical situations that the legislation with general nature cannot predict.

IV. SMART LIGHTING OBJECTIVES

Smart lighting systems have multiple objectives, including energy efficiency, safety and reliability, room design, user comfort, environmental effects, protection, and automation (figure 4).

Energy efficiency is a primary objective, as smart lighting systems use advanced technology to optimize energy consumption, reduce waste, and lower costs. Safety

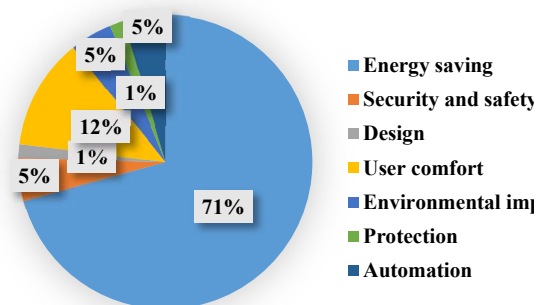


Figure 4 The main goals of Smart Lighting by percentage.

and reliability are also essential, as smart lighting systems offer better illumination, reducing the risk of accidents, and improve security, increasing the safety of people and property.

Room design and user comfort are equally important, as smart lighting systems can create a more pleasant and adaptable ambiance, improve productivity, and enhance the user experience. Additionally, smart lighting systems minimize environmental effects by reducing carbon footprint, using renewable energy sources, and decreasing light pollution.

Protection is another critical objective, as smart lighting systems can detect and prevent hazardous conditions, such as overheating or electrical malfunction. Automation is the final objective, as smart lighting systems can be programmed to adjust lighting according to time, occupancy, or environmental conditions, providing seamless and efficient operation.

Smart lighting systems offer multiple objectives that aim to improve energy efficiency, safety and reliability, room design, user comfort, environmental effects, protection, and automation.

Continuity of service requires different power sources such as power supplies from UPS, Generating Sets or, at least, a couple of independent connection points and an intelligent distribution structure to overcome fault situations and allow maintenance activities. Lighting systems with a large number of uniformly distributed luminaires need a modular concept to facilitate installation, maintenance and control procedures. A smart design criterion of the power distribution of many LED luminaires is to arrange them in clusters and to configure an AC main distribution and a DC branch distribution connecting the groups of luminaires with twin wire ballasts with double power supply and double type of control, digital and analog.

In this way, the lighting system of institutional, congress or entertainment venues, but of road intersections, as well as tunnels, can satisfy the need for continuous availability of the system.

The diffusion of street luminaires in urban and industrial areas offers an important opportunity to improve the performance of ground systems since it allows, even if only de facto, the interconnection between contiguous ground systems and their integration into a single system with higher performance since a global grounding system is an intrinsically safe grounding system.

## V. SMART LIGHTING INTERFERENCES

The proper functioning of smart lighting systems can be affected by various interferences, including the harmonic contribution in the power supply, the flicker phenomenon, and electromagnetic interferences.

Harmonic contribution in the power supply refers to the distortion in the power supply waveform caused by non-linear loads, such as electronic devices and lighting systems. This distortion can cause additional heat and energy loss, leading to decreased efficiency and higher costs.

The flicker phenomenon is another interference that can negatively impact the performance of smart lighting systems. It refers to the visible and rapid changes in light

intensity, which can cause discomfort, eye strain, and even trigger neurological disorders in some individuals.

Electromagnetic interferences (EMI) can also affect the proper functioning of smart lighting systems. EMI is a disturbance that affects the electromagnetic fields of electrical and electronic devices, potentially leading to malfunctions or data loss [54].

To mitigate these interferences, smart lighting systems need to be designed with proper power management, waveform correction, and filtering capabilities. Additionally, advanced control algorithms and monitoring systems can help to detect and respond to interferences in real-time, ensuring the proper functioning of the system.

As a possible cause of disturbance on the mains power supply, it must be considered that LED lighting fixtures require switching power supplies. These power supplies have high starting currents and in systems with many devices, their simultaneous insertion can cause the protections to trip and overload components such as power UPSs. In addition to the solution of inserting the devices in sequence, their common power supply can be provided in groups by adopting a common AC/DC power supply of adequate power. A common power supply not only allows limiting the current on insertion but can manage the switching off of the devices which, remaining powered, do not require a new insertion. The adoption of ac/dc three-phase power supplies makes it possible to balance the load made up of numerous appliances and to inhibit the third harmonics on the power supply lines with a better quality of the distribution network.

## VI. SMART LIGHTING ETHICAL ASPECTS

Smart lighting, as a commodity, significantly enriches the quality of life for inhabitants in urban environments. Increased economic and social well-being are fundamental outcomes of artificial light, transforming neighborhoods by providing security in habitat and safety in freedom of movement. However, as lighting systems become more effective by acquiring smart characteristics, they also become more invasive in their collection of data. The information acquired to deliver this service must be securely protected against invasion of privacy and misuse. Ethical problems, arising from the deployment of smart lighting systems, will become of immense importance and must be freely and openly discussed to reach shared, communal solutions.

The ethical considerations surrounding smart lighting are focused on ensuring that the data collected on indoor and outdoor activity is used appropriately and that every individual has the right to a minimum level of lighting. It is essential to consider the privacy implications of data collection and to ensure that individuals' rights are respected. Additionally, the use of smart lighting should not discriminate against any group of people, and access to this technology should be made available to all. Ultimately, the ethical aspects of smart lighting aim to promote social justice and fairness while ensuring that technology is used to improve the quality of life for all.

## VII. CONCLUSIONS

This paper has emphasized the crucial aspects of smart lighting as an urban service, including areas of application, methodologies, objectives, potential disruptions, and

ethical considerations. Smart lighting has the potential to enhance citizens' quality of life and safety in outdoor environments while also contributing to sustainable development. As the convergence of lighting and ICT industries continues to evolve rapidly, it is important to evaluate the impacts of complex intelligent lighting systems, including end-user behavior and effects on energy, environment, and resources. Integrating innovation with system objectives, such as service continuity, energy-saving, and protection of people's health, can help achieve a minimally adequate quality of life in underdeveloped economies. A comprehensive approach that respects fundamental human rights and ensures the correct use of collected data is necessary for the proper development of smart lighting.

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