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Could Neuroscience and Smart Technologies Be the Answer to Inclusive Street Lighting?

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Could Neuroscience and Smart Technologies be the Answer to Inclusive Street Lighting?

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Abstract

This article explores the future of urban environments, highlighting the need for inclusive design strategies to accommodate diverse populations, including those with age-related visual impairments and neurodiversity. It discusses the limitations of current street lighting infrastructure and introduces the concept of environmental affordance to understand how different groups interact with illuminated spaces. The presentation also examines how advancements in neuroscience and smart technologies, such as functional near-infrared spectroscopy (fNIRS), can inform the development of adaptive and responsive street lighting systems, emphasizing a human-centric approach to creating accessible, equitable, and inclusive urban spaces.

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Introduction

Looking ahead to 2039, projections indicate a growing population dealing with challenges in navigating urban environments, particularly after dark. Among these demographics are individuals facing age-related visual impairments and those with neurodiversity, highlighting the urgent need for inclusive design strategies that foster social connectivity and activity outside of residential spaces.

The current state of street lighting infrastructure offers a uniform level of visual access to every road user, regardless of their individual needs and requirements, throughout the entirety of its operational period. This standardized approach aims to ensure safety and visibility for all individuals navigating the roads, regardless of factors such as age, mobility, or visual impairments. By providing consistent lighting conditions, municipalities and urban planners aim to mitigate potential hazards and promote inclusivity within public spaces. The lack of adaptability of street lighting to accommodate a broader spectrum of individuals in society stems from two primary reasons. First, there is a challenge in comprehensively understanding the diverse needs of different demographic groups. Second, there is difficulty in modifying street lighting systems to cater to these varying needs effectively. This paper aims to explore how advancements in neuroscience and smart technologies offer promising solutions to address these challenges.

Street Lighting and Environmental Affordance:

In 1977, James J. Gibson introduced the groundbreaking concept of environmental affordance, which revolutionized the understanding of human-environment interactions [1,2]. Gibson defined environmental affordances as the opportunities and possibilities that the environment presents to individuals, enabling them to engage in specific actions or behaviors. These affordances encompass a wide range of perceptible features within the environment, from physical objects to spatial layouts, that facilitate various activities and interactions. Central to Gibson's theory is the idea that individuals perceive and interact with their surroundings not merely as static entities but as dynamic resources that offer opportunities for action and engagement. Moreover, Gibson emphasized the role of perceptual processes in the perception of environmental affordances. He proposed that individuals build internal cognitive models of their surroundings, which he referred to as "internal models," to represent the structure and features of the environment. These internal models serve as mental maps that guide spatial navigation and inform decision-making processes, allowing individuals to

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effectively navigate and interact with their surroundings. By integrating the concepts of affordance and internal modeling, Gibson provided a comprehensive framework for understanding how individuals perceive, interpret, and act upon their environment to achieve their goals and objectives.

The concept of environmental affordance offers valuable insights into the relationship between urban lighting, spatial navigability, and Pedestrian Visual Diversity (PVD) [3]. In the context of urban lighting, affordances are the perceptible features and characteristics of illuminated spaces that influence how pedestrians perceive, navigate, and interact with their surroundings after dark. When considering the impact of street lighting on spatial navigability and the perception of public spaces, it's essential to acknowledge the diverse visual needs and experiences of individuals, encompassed by PVD. Different demographic groups, such as the elderly, individuals with visual impairments, or neurodiverse individuals, may have distinct requirements for navigating illuminated environments. These varied needs create a spectrum of affordances within urban spaces, where certain lighting configurations may enhance accessibility and safety for some groups while presenting barriers or challenges for others. By integrating principles of environmental affordance into the design and planning of street lighting systems, urban planners and designers can tailor illumination strategies to accommodate the diverse visual capabilities and preferences of pedestrians. This approach involves identifying and leveraging the affordances that support safe and inclusive navigation for all user groups, while also addressing potential barriers or limitations within illuminated environments. Ultimately, by aligning urban lighting design with the principles of environmental affordance and considering Pedestrian Visual Diversity, cities can create more welcoming, accessible, and equitable public spaces for nighttime activities and mobility.

Smart Technologies and Smart Cities

Smart city initiatives are seen as avenues to explore future urban scenarios through emerging technologies. However, the translation of these visions into physical manifestations has faced criticism [4,5]. While the aim of smart cities is to enhance urban life quality, technology often dominates, focusing on optimization and performance rather than human-centric approaches[6,7]. This technocentric perspective can lead to overestimations of technology's capabilities and disconnect from citizens' needs [8].

Critics argue that techno-utopian solutions may divert attention from real societal issues [9]. Moreover, a technology-driven approach can face social resistance and fail to evolve citizens' capabilities as expected. Such challenges highlight the need for a human-centric perspective in smart city development, considering the interconnectedness of social and technological spheres[10].

Human Centric Smart City

A human-centric smart city is an urban environment where technology is deployed with a primary focus on enhancing the well-being and quality of life for its inhabitants. In contrast to purely technocentric approaches that prioritize optimization and efficiency, human-centric smart cities place people at the center of urban development and innovation [11]. By fostering inclusive, sustainable, and resilient urban environments, these cities aim to create thriving communities where everyone can flourish. One of the key characteristics of human-centric smart cities is accessibility and inclusivity [11]. Human-centric smart cities prioritize accessibility for all residents, including those with disabilities or special needs. They strive to create inclusive environments where everyone can access services, infrastructure, and opportunities.

A design-oriented approach offers an alternative, bridging the gap between strategic visions and tangible interventions [12].

Adaptive and Responsive Street Lighting and Inclusive Design:

The concept of adaptive and responsive street lighting represents a paradigm shift in urban design, moving beyond fixed infrastructures towards dynamic, user-centered solutions [11]. By integrating sensing and automation technologies, street environments become adaptable over time, blurring the traditional boundaries between different modes of mobility, public spaces, and illumination. This approach challenges the hierarchical division of urban infrastructures, introducing 'chronotopical' boundaries that evolve in real-time to accommodate changing traffic patterns and pedestrian needs [13].

Moreover, inclusive design principles are integral to the implementation of adaptive and responsive street lighting. Consideration of diverse user groups' needs, including those with visual impairments, mobility challenges, or neurodiversity, ensures that street lighting solutions are accessible to all. For example, adaptive illumination options can be tailored to provide sufficient visibility and safety for individuals with different levels of visual acuity, while responsive urban lighting can enhance feelings of security for vulnerable populations such as elderly or disabled individuals navigating public spaces at night by responding to their perceived needs at the time.

This approach is in line with WHO’s Global report on assistive technology [14]. It outlines measures adopted worldwide to improve access to assistive technology, thereby enabling, empowering, and promoting the inclusion, participation and engagement of persons with disabilities, ageing populations, and people living with chronic conditions or temporary impairments. It emphasises that enabling environments – whether age- or disabled friendly, smart cities or villages, barrier-free or accessible, universally or inclusively designed – benefit everyone.

While the concept of an adaptive and responsive environment appears plausible in theory, transforming this concept into a functional prototype necessitates careful consideration and comprehensive studies. Implementing such a system involves a multidisciplinary approach, integrating insights from fields like design, engineering, psychology, and human-environment interaction. Factors such as user preferences, environmental conditions, technological feasibility, and cost-effectiveness must be meticulously evaluated to ensure the effectiveness and practicality of the prototype. Additionally, research studies are vital to assess the impact of the adaptive environment on user experience, well-being, and productivity. These studies may involve user trials, usability testing, and long-term monitoring to refine the design and optimize its performance. By addressing these considerations and conducting thorough studies, we can move closer to realizing the vision of adaptive environments that seamlessly respond to the needs and preferences of their occupants.

Neuroscience and Street Lighting Design

Before exploring how neuroscience can inform street lighting design, it's important to examine the concept of neuroarchitecture and also new technologies that can inform the design of environment.

Neuroarchitecture

Neuroarchitecture is an interdisciplinary field that explores the interaction between architecture and neuroscience. While it is called neuroarchitecture, its principles applied on different form of built environment including urban design. It seeks to understand how the design of environment and spaces affects the human brain, behavior, and well-being. Neuroarchitecture incorporates principles from neuroscience, psychology to inform the design of environments that promote health, productivity, and overall quality of life.

Neuroarchitecture comprises four main interrelated pillars: neuroscience, architecture/environment, physiology, and psychology (emotions and behaviour). Other fields related to neuroscience may also indirectly relate to neuroarchitecture [15].

Researchers in neuroarchitecture study various aspects of environmental design, such as lighting, spatial layout, materials, and their impact on human cognition, emotions, and physiological responses. By applying insights from neuroscience to design practice, neuroarchitects aim to create environments that are more supportive of human needs and experiences.

Examples of neuroarchitectural research topics include the effects of natural light on mood and circadian rhythms, the influence of spatial layout on wayfinding and navigation. Ultimately,

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neuroarchitecture seeks to bridge the gap between the built environment and human biology, leading to the creation of healthier, more engaging, and more sustainable spaces for people to live, work, and play.

Neuroscience Technologies and Design of Environment

New technologies in neuroscience have created new avenues for researchers to conduct more in-depth research into how people experience their environment. One of the latest technologies is functional near-infrared spectroscopy (fNIRS), which reveals brain activity in real-world settings. fNIRS is a non-invasive optical imaging technique that measures changes in oxygenated and deoxygenated haemoglobin (Hb) concentrations within the brain by means of their characteristic absorption spectra of the wavelengths range of 700–1000 nm [16]. For instance, it could monitor the prefrontal cortex and thus reports on 'cognitive load' while a person walking in streets [17]. Unlike functional magnetic resonance imaging (fMRI) fNIRS offers the advantage of being portable and suitable for use outside of traditional laboratory settings. This portability allows researchers to study brain activity in naturalistic environments, providing insights into how individuals interact with their surroundings in real time. Additionally, fNIRS has a higher temporal resolution than fMRI, making it well-suited for capturing rapid changes in brain activity associated with dynamic tasks such as walking in urban environments. Furthermore, fNIRS is less susceptible to motion artifacts compared to electroencephalogram (EEG), a test that measures electrical activity in the brain using small, metal discs (electrodes) attached to the scalp, making fNIRS particularly useful for studying brain activity during movement-related tasks. Overall, fNIRS offers unique advantages for studying the neural correlates of behavior in real-world contexts, complementing traditional neuroimaging techniques.

Eye-tracking during fNIRS allows simultaneous monitoring of eye movements and brain function, and advanced analytical techniques similar to fixation-related fMRI[18] can be employed. In the context of inclusive street lighting, these methodologies can help understand whether and how different groups of people experience the night time environment differently.

Another advantage of fNIRS and fMRI lies in the ease of analyzing and interpreting their data objectively, especially when compared to traditional behavioral study methods. These neuroimaging techniques offer a direct window into the functioning of the brain, allowing researchers to observe neural activity in real-time with a high degree of spatial and temporal resolution. Unlike behavioral studies, which often rely on subjective observations and interpretations, fNIRS and fMRI provide quantitative measurements of brain activity, making it easier to draw concrete conclusions and identify patterns. Additionally, these imaging modalities offer the ability to localize brain activation with precision, enabling researchers to pinpoint specific regions involved in various cognitive processes or tasks. This objectivity and precision not only streamline the analysis process but also enhance the reliability and reproducibility of findings, thereby advancing our understanding of the complex workings of the human brain.

Conclusions

In conclusion, the integration of neuroscience and smart technologies holds tremendous potential for enhancing the inclusivity of street lighting design in urban environments. By leveraging insights from neuroarchitecture and advancements in neuroscience technologies such as fNIRS, researchers can gain a deeper understanding of how different groups of people experience the nighttime environment. This knowledge can inform the development of adaptive and responsive street lighting systems that cater to the diverse visual needs and preferences of pedestrians, including those with age-related visual impairments and neurodiversity. Furthermore, the human-centric approach to smart city development emphasizes the importance of prioritizing the well-being and quality of life of urban inhabitants. By considering the interconnectedness of social and technological spheres, cities can create more accessible, equitable, and inclusive environments for nighttime

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activities and mobility. Ultimately, the fusion of neuroscience, smart technologies, and inclusive design principles offers a promising path towards creating safer, more welcoming, and more inclusive urban spaces for all individuals.

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