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Co-Creation in Automated Public Space Lighting Design: Enhancing Safety and Reducing Light Pollution

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Abstract

Public space lighting in urban areas is a crucial issue linked to climate change in developed environments. It significantly influences aesthetics, functionality, and the sense of safety while also contributing to the problem of light pollution. However, addressing these challenges requires a balance between technical optimization and environmental considerations, which this study explores through an experimental approach. This study examines the application of advanced digital technologies in designing and optimizing public space lighting, particularly in parks. The focus is on presenting a modular algorithm as a foundation for iterative improvements rather than a fully comprehensive lighting design solution. The article presents an algorithm that iteratively determines the optimal number and placement of lamps based on expected lighting levels. While illuminance levels are considered, future extensions could include additional parameters such as glare, uniformity, and color temperature to meet professional standards. This method has significant potential for involving public space users in lighting optimization. The algorithm relies on expected lighting levels, which can be derived from standards and designer decisions. However, user expectations can also be incorporated into simulations. For instance, an interactive application could allow users to highlight under-illuminated or overly bright areas, contributing to a co-created desired lighting map. Lighting levels can be precisely calculated, yet users' subjective perceptions may be crucial in achieving soft, nature-friendly lighting. The article presents the algorithm and discusses the potential of designer-computer and designer-computer-user co-creation for human- and nature-friendly design. This modular framework lays the groundwork for future refinements by integrating professional input and addressing broader lighting parameters.

Keywords
agent-based modeling; co-creation in urban design; digital design technologies; lighting optimization algorithms; parks lighting design; participatory design; public space lighting; sustainable urban planning; urban lighting design

1. Introduction

This research explores the possibilities of co-creation through digital generative techniques, using an algorithm for arranging lighting in public spaces, particularly parks. While professional lighting design typically involves predefined standards and practices, this study adopts an experimental approach to explore modular solutions that can be iteratively refined and extended. As digital design technologies continue to advance, new forms of collaboration are emerging among participants in the design process. This collaboration can occur between designers and users. Generative techniques further enable cooperation between designers and digital tools, fostering innovative solutions to complex urban challenges like lighting optimization. Additionally, generative techniques enable multi-entity collaboration involving users, digital tools, and designers. This article will demonstrate the potential of applying such an approach to lighting design in public spaces, especially parks, to achieve user-friendly and environmentally sustainable solutions. Lighting is a crucial aspect of designing public spaces. It plays a significant role in ensuring safety by enabling obstacle avoidance and mitigating potential criminal risks (Cui et al., 2023). Well-lit public areas contribute positively to safety and night-time social activities (Chen et al., 2024; Rakonjac, Zorić, Djokić, et al., 2022; Rakonjac, Zorić, Rakonjac, et al., 2022). However, poorly designed or excessive lighting can lead to a range of issues, including glare, lack of uniformity, and light pollution. Light pollution is a rapidly increasing alteration to the natural environment that requires urgent attention (Cinzano et al., 2001). It disrupts ecosystems, affects human health, and contributes to unnecessary energy consumption. The correlation between light pollution and environmental changes is a subject of ongoing research (Falchi et al., 2016, 2019; Gallaway et al., 2010; Kocifaj et al., 2023). Addressing light pollution requires a multifaceted approach that considers illuminance levels and parameters such as luminous intensity distribution, shielding techniques, mounting height of luminaires, and color temperature. These factors significantly influence the environmental impact of lighting systems and their alignment with sustainability goals. Despite advancements in professional lighting software such as DIALux (DIAL GmbH, n.d.) and Relux (Relux Informatik AG, n.d.) that allow for detailed photometric simulations, there remains a gap in integrating these tools with participatory design processes (Kubiak, 2024). The proposed framework aims to bridge that gap and emphasizes flexibility through its modular structure while allowing for future extensions to include more advanced qualitative and quantitative criteria. The significance of this study lies in its potential to address two critical challenges simultaneously: enhancing safety in public spaces through optimized lighting design while minimizing environmental impacts caused by light pollution. This study contributes to developing human- and nature-friendly lighting systems that align with contemporary urban sustainability goals by leveraging co-creation processes involving designers, users, and digital tools.

2. Materials and Methods

The research method consisted of multiple steps in the diagram (see Figure 1). Step A1 of the research method involved analyzing algorithmic design and optimization techniques. The authors analyzed the variety of possible approaches to automated design, including evolutionary approaches (Frazer, 1995; Kamaoğlu, 2023; Nessel, 2017; Schumacher, 2015), strict rules approach (Cudzik & Nessel, 2024; Filipowski & Nessel, 2018), agent-based and iterative approaches (Mosteiro-Romero et al., 2024; Rahbar et al., 2022; Zargar et al., 2023), deep learning in architecture (Kafy et al., 2022; Rahbar et al., 2022; Zhao et al., 2022), as well as case studies (Mukkavaara & Sandberg, 2020; Pérez-Martínez et al., 2023; Rodrigues et al., 2015) and other complex approaches and comparisons (Aranburu et al., 2022; Assasi, 2019; Caetano et al., 2020; Cudzik, Nyka, et al., 2024; Cudzik, Unger, et al., 2024; Lee et al., 2014; Oleksy et al., 2022; Reitberger et al., 2024; Romaniak & Nessel, 2019; Schwartz et al., 2021; Sönmez, 2018; Zboinska et al., 2015).

The stages B1, B2, and B3 (see Figure 1) were focused on literature studies and analyses related to public space lighting, including light pollution (Falchi et al., 2016, 2019; Gallaway et al., 2010; Kocifaj et al., 2023), safety topics and correlations between user behaviors and light quality (Zielinska-Dabkowska, 2018). Another crucial aspect of public space lighting is its association with light pollution. Law regulations and studies of existing lighting in urban park area designs were also analyzed, formulating fundamental design problems, principles, and possible simplifications of the design task (see Figure 1, stage B4). One of the fundamental principles in programming is the Single Responsibility Principle (Martin, 2003).

On the other hand, solving design problems is instead a complex process. Therefore, a primary objective at stage B4 was to simplify the design task to the absolute minimum. While such an approach involves accepting certain shortcomings, it enables transparent testing that yields reliable results, even in the early stages of algorithm development. Many parameters should be evaluated when analyzing public space lighting quality. Based on analyses and the Polish norm, the required minimum illuminance level was identified as the most critical (Polski Komitet Normalizacyjny, 2007). Legal standards often specify different minimum illuminance levels for various uses of space (Polski Komitet Normalizacyjny, 2007). Therefore, in the context of public parks, the algorithm should accept at least two values of minimum illuminance level: for pathways and squares and separately for green areas. The authors stated that by operating on these parameters, the algorithm should suggest lamp positions so that the minimum illuminance criteria are achieved throughout the park. Critical parameters for calculating illuminance levels were identified as the luminous intensity and height of the light sources. To simplify the design problem, a uniform height and brightness were set for all light sources. Additional constraints and simplifications included assuming point light sources with uniform emission, ignoring shadows, and excluding light sources outside the study area.

At stage A2 (see Figure 1), based on the analyses and assumptions formulated in stages B4 and A1, it was decided that the algorithm would be developed using an agent-based approach. The algorithm was developed using industry-standard 3D design software, McNeel's Rhinoceros 8, and Grasshopper visual algorithm editor (Version Friday, 17th May 2024, Build 1.0.0008). Specific components were implemented using the C# programming language to enhance the algorithm's flexibility and functionality. The programming process was facilitated by Microsoft Visual Studio 2022, enabling real-time debugging and streamlined code maintenance. Subsequently, the algorithm was developed and cyclically tested to improve its functionality during stages C1 and C2 (see Figure 1). Initially, tests were conducted on hypothetical outlines. Later, the tests were conducted using actual, existing park locations to make the results more realistic. After analyzing potential test locations, Park Grechuty in Krakow, Poland, was chosen for further tests (see Figure 1, stage C3; Zachariasz, 2018). This selection was based on several factors: it is a publicly accessible urban park; it includes both green spaces and paths and squares; it has an irregular layout; it was

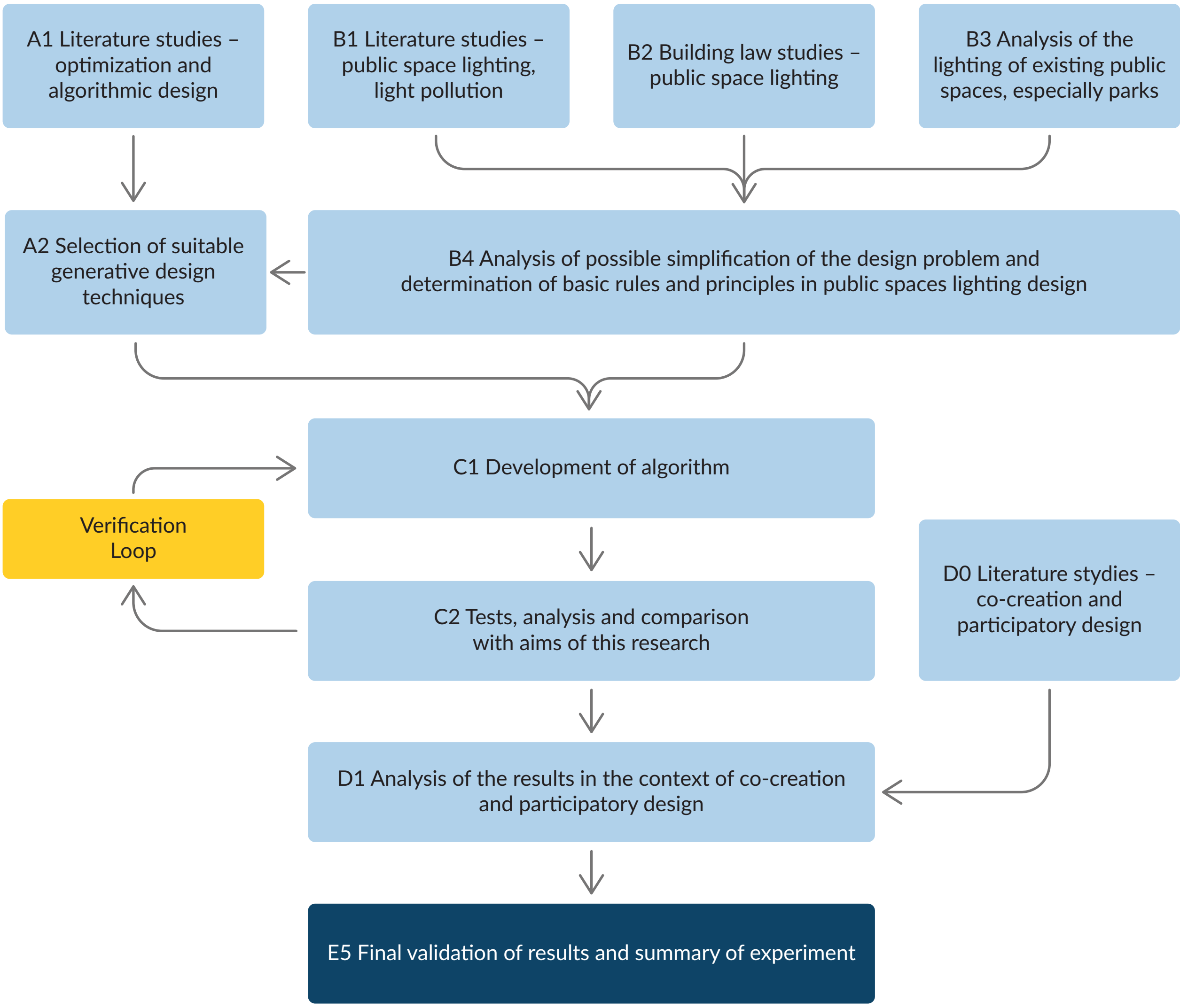

Figure 1. The research method diagram.

recently renovated, including the replacement of lighting; and it features relatively uniform lighting. This enabled the algorithm to compare its results with the park's existing lighting.

Tests were conducted with varying parameters, light source luminous intensity, lamp height, and the desired illuminance of surfaces. The algorithm's performance was analyzed through simulations based on the existing lighting solution. Both graphical and numerical data were collected for subsequent analysis during the tests. This facilitated the evaluation of the algorithm's results, its potential for automating the lighting design process, and its implications for sustainable design and light pollution. The analyses conducted at stage C4 indicated that the algorithm could be used in participatory design. This insight led to an expanded review of the literature and analysis in this area (Buongiorno Sottoriva et al., 2022; Jung & Kang, 2023; Kashem & Gallo, 2023; Lorens & Zimnicka, 2023; Rodriguez Müller et al., 2024; Smith et al., 2024; Zidar et al., 2017). The research findings were then discussed, and conclusions were formulated.

All literature studies (stages: A1, B1, B2, D0) were conducted using state-of-the-art methods combined with elements of the systematic search review methodology (Grant & Booth, 2009). As shown in Figure 2, they

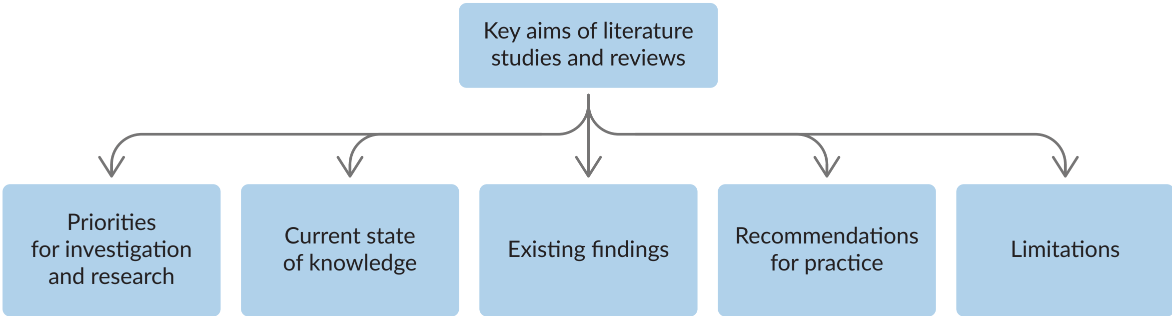

Figure 2. Key aims of literature studies and reviews.

focused on the current state of knowledge, priorities for investigation and research, existing findings, recommendations for practice, and limitations.

3. Algorithm

The algorithm developed in this study is designed to optimize the placement and luminous intensity of light sources in urban parks, ensuring that lighting conditions meet specific safety and usability standards. While the current implementation focuses on minimum illuminance levels, future iterations could incorporate additional parameters such as glare control, uniformity, and energy efficiency to align with professional lighting practices. The central concept of the algorithm is illustrated in Figure 3. It revolves around an iterative process that dynamically adjusts lamp positions based on real-time feedback from various test points distributed throughout the park.

The initial phase of the algorithm is of utmost importance as it lays the foundation for the entire simulation process. It involves preparing the fundamental data required for the simulation. This preparation includes generating a list of test points evenly distributed within the park boundary to measure illuminance levels at key locations (see Figure 4b). Each test point is assigned a minimum expected illuminance level based on its functional classification—whether it is located on pathways, squares, or green areas. This differentiation ensures that lighting requirements are tailored to specific park zones, reflecting real-world design standards. Concurrently, the initial positions of the lamps are uniformly generated within the park boundary (see Figure 4a). These lamps and test points are placed using a pseudorandom distribution, ensuring no direction is favored, thus allowing for a more organic and realistic simulation process.

However, this approach assumes uniform lamp characteristics (e.g., height and luminous intensity), simplifying initial testing but limiting its applicability to more complex scenarios involving diverse luminaires. Notably, the initial number of lamps is set to be lower than the anticipated final number, allowing the algorithm to add more lamps as needed during optimization. The core operation of the algorithm takes place within its main loop, where it iteratively refines the lamp positions to achieve the desired lighting conditions. Initially, the algorithm calculates the illuminance levels at all test points by applying the inverse square law of light attenuation, considering the contributions from all existing light sources (see Figure 4c). This calculation assumes point light sources with uniform emission patterns and does not account for factors such as shadows or variations in luminous intensity distribution. These simplifications will be addressed in future iterations to enhance accuracy. The calculated illuminance levels are then compared against the minimum

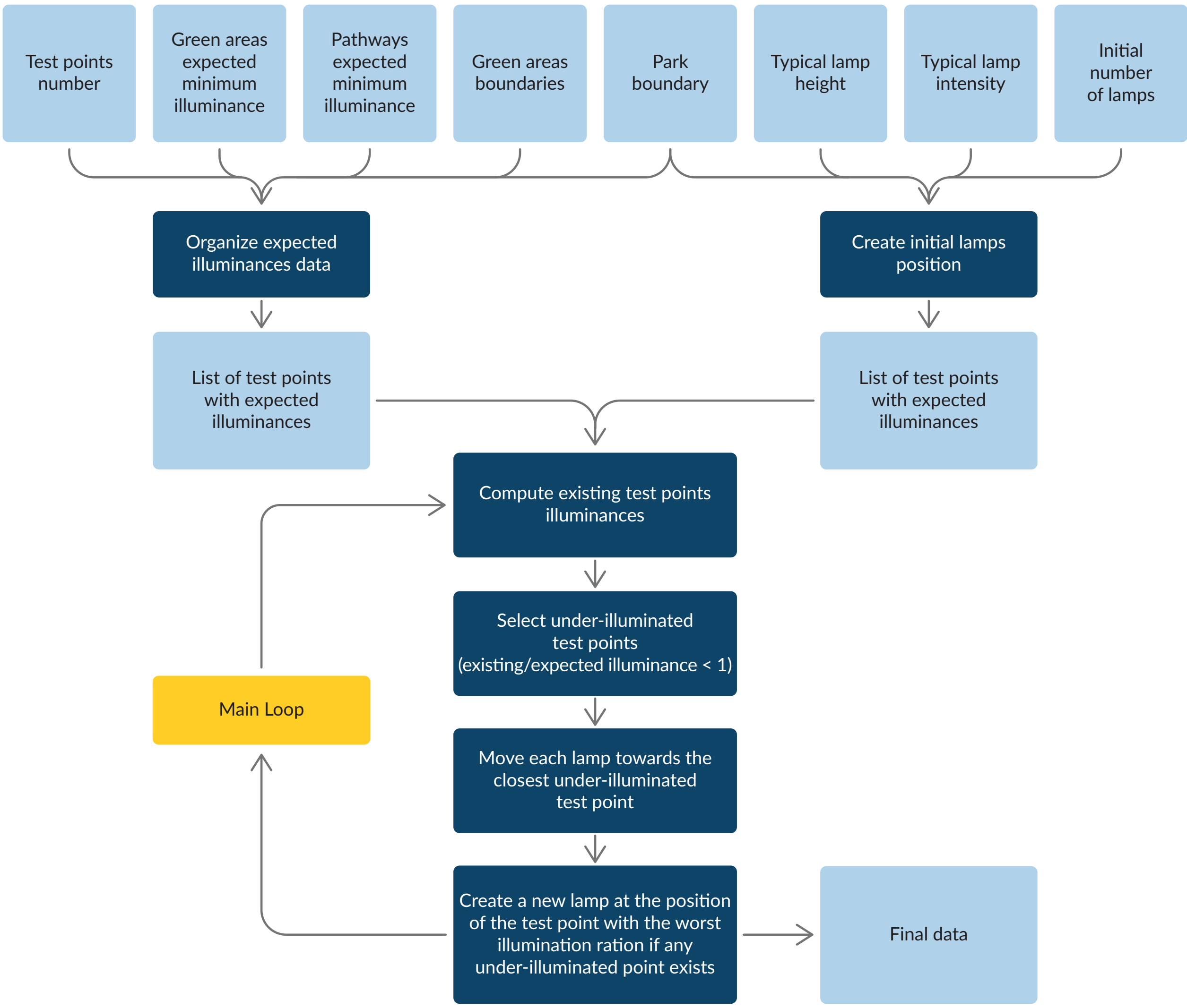

Figure 3. The algorithm diagram.

required levels at each test point to identify under-illuminated areas (see Figure 4b). Once under-illuminated points are identified, the algorithm adjusts the lamp positions. Each lamp is moved horizontally towards the nearest under-illuminated point, ensuring light is distributed more effectively across the park.

Additionally, the algorithm periodically introduces new lamps at strategic locations, specifically at test points where the disparity between actual and expected illuminance is most significant. The placement of new lamps considers their proximity to under-illuminated areas and their potential overlap with existing light sources to avoid redundancy and excessive energy use. However, adding new lamps is controlled and does not occur in every iteration; instead, it is performed at specific intervals to maintain a balanced and efficient increase in lighting coverage. The iterative loop continues until the algorithm achieves a state where no further test points remain under-illuminated, indicating that the park's lighting conditions meet or exceed required standards.

At this point, the algorithm outputs the final positions of the lamps along with computed illuminance values for all test points (see Figure 6). This output includes graphical representations such as false color maps and numerical data tables for detailed analysis. These results allow for secondary metrics to be computed—such

Figure 4. The initial state of simulation: a) initial positions of lamps, b) visualization of test points meeting the minimum illuminance criteria (orange samples) and being under-illuminated (dark grey samples), c) visualization of test points computed illuminance levels.

as average illuminance levels, uniformity ratios, and energy consumption estimates—to evaluate and compare different lighting configurations (see Table 1). Including these metrics provides a more comprehensive assessment of lighting performance beyond meeting minimum illuminance requirements. The entire process demonstrates the algorithm's capability to create a lighting design that is both functional and adaptable, capable of addressing diverse urban park environments' complex needs. While this study focuses on foundational principles and simplified scenarios, it establishes a framework that can be expanded in future research to include more advanced parameters and professional input from lighting designers or urban planners.

4. Results

The results of this study provide a comprehensive and nuanced analysis of the proposed algorithm's performance and effectiveness in optimizing public space lighting within an urban park setting. This analysis evaluates the algorithm's ability to meet minimum illuminance requirements. It explores its potential to address broader urban lighting objectives, such as reducing light pollution, improving energy efficiency, and enhancing user safety. Specifically, the study examines the algorithm's ability to balance multiple factors, including safety, energy efficiency, and environmental impact, while adhering to regulatory standards.

The results underscore how the algorithm's modular framework allows for iterative refinements and adaptability to different urban contexts. The analysis, structured around a series of carefully designed tests, compares the algorithm's outputs with the existing lighting configuration and delves into a range of alternative scenarios. These scenarios involve systematically adjusting parameters such as lamp height, luminous intensity, and expected illuminance levels. For example, variations in lamp height were tested to assess their impact on uniformity ratios and glare control, while adjustments to luminous intensity were

Table 1. Tests results.

Test Id	0	1	2	3	4	5	6
Lamp height [m]	10	10	6	6	6	6	15
Lamp light source luminous intensity [cd]	720	720	300	300	300	720	720
Lawn expected illuminance [lx]	1	1	1	2,5	1	1	1
Pathways expected illuminance [lx]	5	5	5	5	3,5	5	5
Total number of lamps	78	81	153	183	127	91	81
Average illuminance	4,864	5,152	4,378	5,151	3,627	6,291	4,776
Illuminance of brightest test point	14,697	12,164	14,406	13,667	11,961	24,998	8,426
Illuminance of brightest test point without top 20 samples (0,4%)	12,360	10,810	11,505	11,328	9,889	21,984	7,857

analyzed for their influence on energy consumption and light distribution. By exploring these variations, the study reveals how different configurations can influence the overall lighting quality, distribution of light across different areas, and the balance between brightly and dimly lit zones.

This approach highlights how professional lighting considerations—such as luminous intensity distribution curves and shielding techniques—can be integrated into future algorithm iterations for enhanced performance. This approach allows for a thorough evaluation of the algorithm's flexibility and robustness in addressing the complex challenges of urban lighting design, with direct implications for practical urban planning and lighting design. Furthermore, the study considers the implications of these adjustments for urban planning goals, such as reducing light pollution, enhancing nighttime visibility, and ensuring that public spaces are welcoming and secure. For instance, scenarios focusing on minimizing upward light emissions demonstrated how the algorithm could reduce light pollution metrics such as the Upward Light Ratio and Upward Flux Ratio.

The results highlight how the algorithm can be adapted to different urban contexts, catering to specific needs and preferences while maintaining compliance with established lighting standards. By providing a detailed breakdown of each test scenario, the study offers valuable insights into the practical applications of the algorithm in real-world urban environments, demonstrating its potential to significantly improve the design and management of public space lighting. This includes its ability to serve as a decision-support tool for planners by offering visualizations (e.g., false color maps) and numerical metrics that facilitate informed decision-making. The table presents the results of the final tests conducted in this research, including key input parameters and primary and secondary numerical data (see Table 1). Test 0 shows the illuminance levels computed by the algorithm using the current lamp positions (see Figure 5).

The emitter's luminous intensity, height, and expected illuminance levels are consistent with those in Test 1 (see Figure 6). In these two tests, minimum illuminance values reflect the Polish norm (PN-EN 13201:2007). This ensures that comparisons between existing solutions and algorithm-generated configurations are grounded in established regulatory standards.

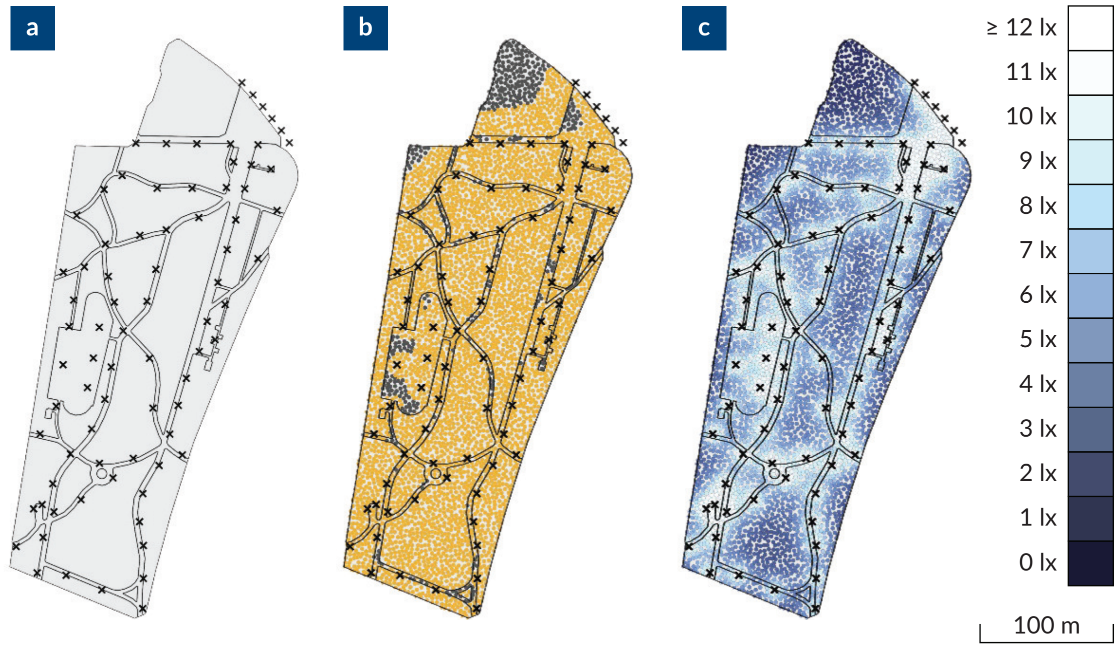

Figure 5. The visualization of theoretical illuminance using the existing position of lamps and the same settings as in Test 1: a) positions of lamps; b) visualization of test points meeting the minimum illuminance criteria (orange samples) and being under-illuminated (dark grey samples); c) visualization of test points computed illuminance levels.

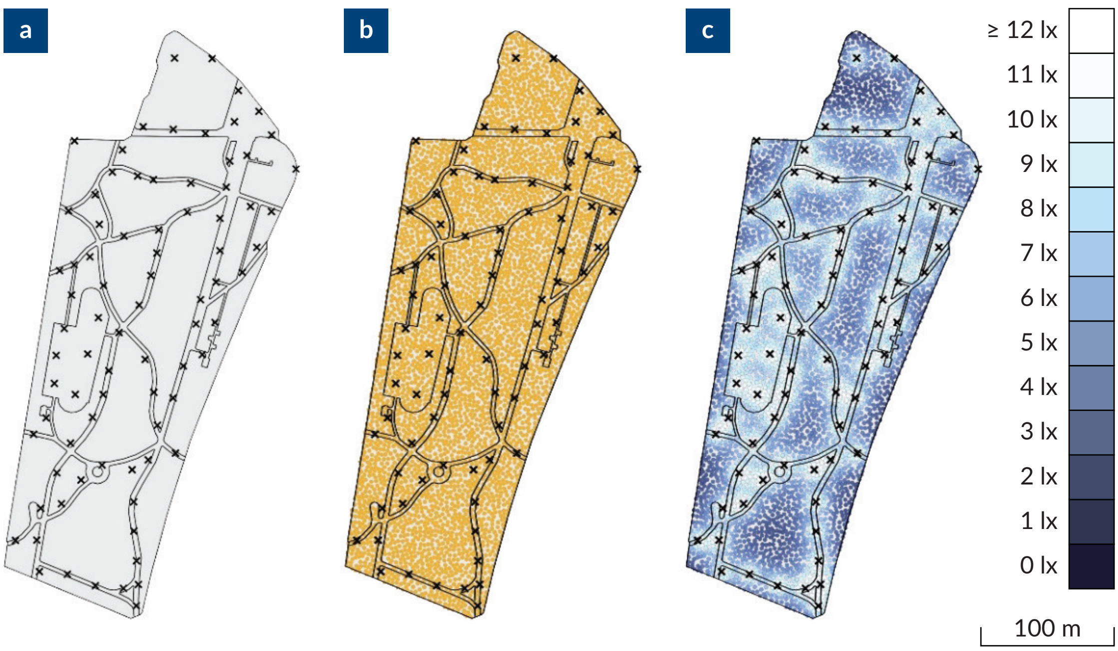

Figure 6. The final state of Test 1: a) positions of lamps; b) visualization of test points meeting the minimum illuminance criteria (orange samples), no occurrence of under-illuminated test points (dark grey samples); c) visualization of test points computed illuminance levels.

However, it is essential to consider the algorithm's limitations and resulting simplifications during these comparisons. For instance, assumptions such as uniform lamp characteristics (e.g., height and luminous intensity) or exclusion of shadows from obstacles may affect how closely test results align with real-world conditions. Additionally, to simplify testing, external light sources outside the park boundaries and the impact of park lighting on the surrounding area were excluded from calculations. However, these aspects could be incorporated into future iterations for greater accuracy. Despite these limitations, the results provide a strong foundation for further development of this approach.

As shown in Figure 5, some lamps in the existing solution are positioned outside the park boundary. They were included in Test 0 because they are essential for achieving the appropriate illuminance levels in the square in the park's northern part. Additionally, a pond within the park was omitted from the tests to simplify the problem. Although the existing lamps are similar, they are not identical; therefore, the height and luminous intensity values used in the computations are approximations of the actual conditions due to the algorithm's limitations.

Tests 2, 3, and 4 (see Figure 7) illustrate the algorithm's results using lower lamp heights and reduced luminous intensity values compared to Tests 0 and 1. The first version (see Figure 7a) achieves the minimum illuminance levels specified by the Polish standard (PN-EN 13201:2007). Test 3 (see Figure 7b) raises the minimum illuminance level for green areas to 2,5 lx, compared to Test 1, to reduce the disparity between the brightest and darkest areas. Similarly, the minimum illuminance for pathways is reduced to 3,5 lx in Test 4 (see Figure 7c).

The next set of tests investigates variants related to lamp height (see Figure 8). All other parameters remain the same as in Test 1 (see Figure 6 and Figure 8a). Test 5 shows the algorithm's results with higher lamps set at 15 m, while Test 6 presents the results with lower lamps set at 6 m.

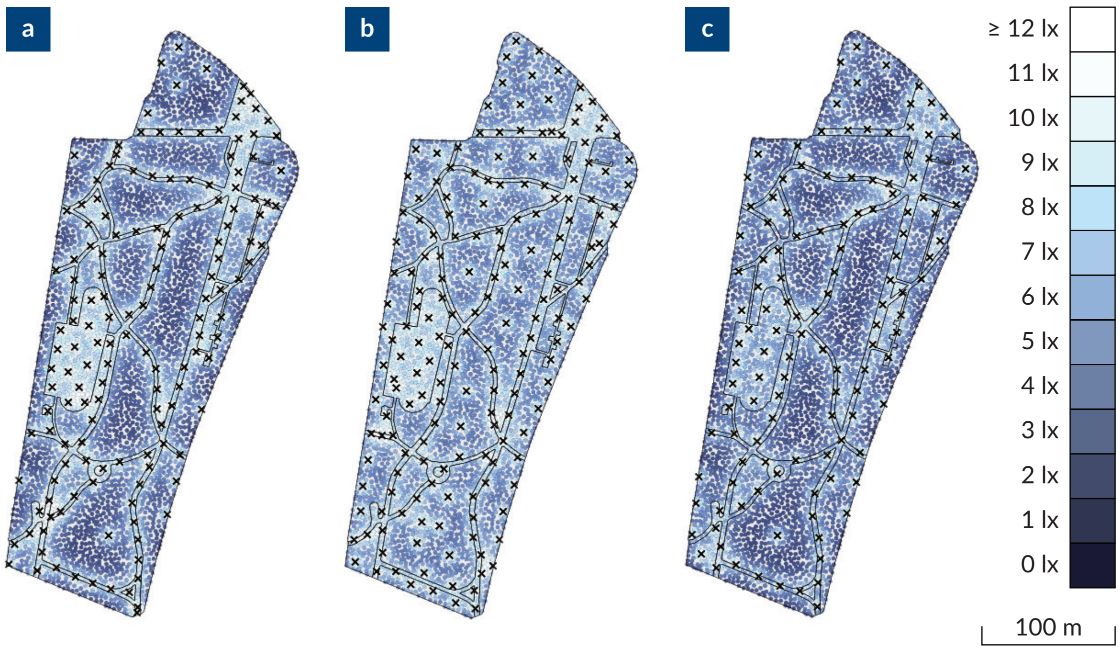

Figure 7. The results of the algorithm with reduced height and luminous intensity of lamps: a) Test 2, b) Test 3 (higher expected illuminance of lawn: 2,5 lx), c) Test 4 (lower expected illuminance of pathways: 3,5 lx).

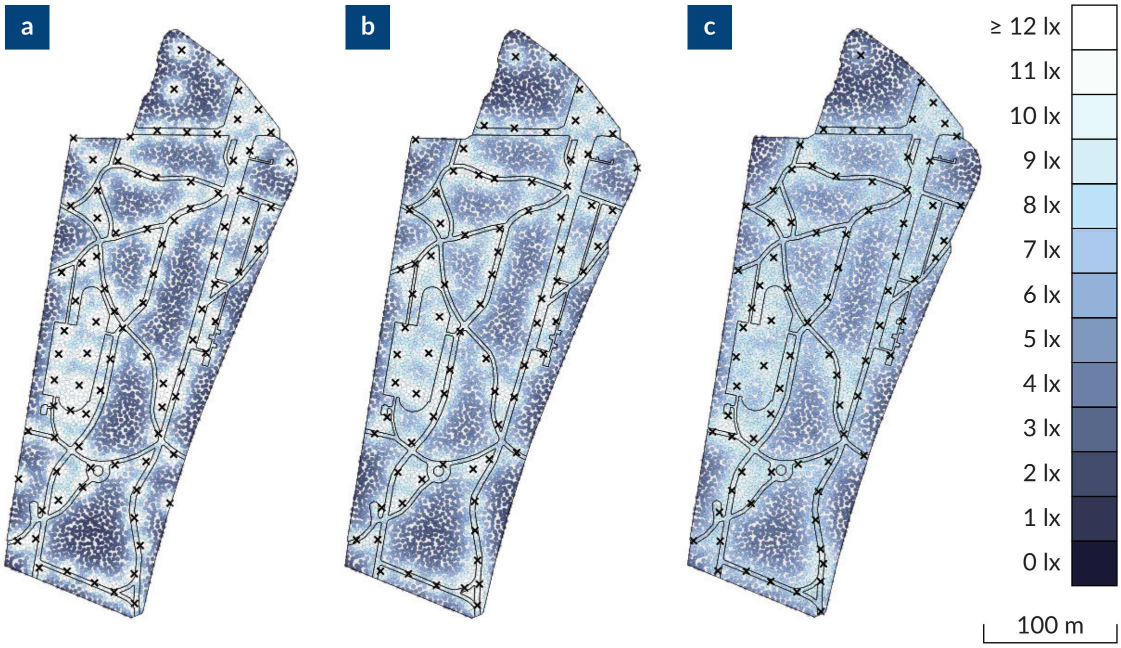

Figure 8. The algorithm results with the original luminosity of lamps but different heights: a) Test 5: 6 m, b) Test 1: 10 m, c) Test 6: 15 m.

5. Discussion

The results illustrate how the algorithm can influence the design process, effectively acting as an additional participant in the design workflow. By dynamically adjusting lamp positions and intensities based on input parameters, the algorithm introduces a level of automation that complements traditional design practices. Based on the given parameters, the algorithm creatively positions the lamps to achieve the desired minimum illuminance across various parameter variations. This unique capability ensures the desired illuminance levels and expedites the development of design variants, complete with visualizations of the resulting illuminance levels and the generation of quantitative data. These visualizations, such as false color maps, provide designers with actionable insights into light distribution patterns and areas requiring further refinement.

During the tests, it was observed that a key challenge in this design task is achieving the minimum illuminance levels while simultaneously minimizing one or more of the following factors: the number of lamps, the total lamp brightness, the average illuminance level, and the brightness of the brightest points, to reduce the contrast between dark and light areas. This balance is critical for meeting sustainability goals such as reducing light pollution, lowering energy consumption, and improving safety perception by avoiding overly bright or excessively dark zones. These factors are critical for various aspects of sustainability, including safety perception, light pollution, and energy consumption. Analysis of the tests' results indicates that reducing both the height and brightness of the lamps in Test 2 could lower overall luminous intensity and average illuminance while still meeting the required minimum illuminance levels (Figure 7a). Among the tests conducted, Test 6 achieved the lowest contrast of light—the difference between the darkest and brightest test point (Figure 8b).

This result demonstrates how parameter adjustments can optimize lighting configurations to minimize glare and improve uniformity while complying with regulatory standards. This data can be valuable for assessing solutions regarding light pollution, energy consumption, and overall well-being and safety. Ultimately, the algorithm-generated results can support critical design decisions, especially during the early stages of a project. Notably, with appropriately selected parameters, the algorithm produced results similar to the existing solution (see Figures 5 and 6). This similarity validates its potential as a decision-support tool for urban planners and lighting designers while highlighting its adaptability to real-world conditions. This outcome is particularly significant considering the nature of agent-based methods (Cudzik & Nessel, 2024) and the relatively simple set of rules governing agent behavior. This observation justifies the use of an agent-based approach for such tasks. The algorithm presented in this study uses expected illuminance data to generate designs. For example, such data might be represented by a grayscale bitmap (see Figure 9). In this experiment, the algorithm primarily operates on data regulated by legal standards. However, such a bitmap can also be created based on the designer's subjective decisions or to reflect public space users' expectations. This adaptability allows the incorporation of user feedback into lighting design processes through participatory approaches. Such flexibility aligns with contemporary urban planning trends emphasizing co-creation and stakeholder engagement (Jung & Kang, 2023). Such interaction could be facilitated through a web-based application combining location data with user feedback, such as opinions on whether an area is too dark or bright. For example, like how noise pollution data is used in tools like the Hush City App (Buongiorno Sottoriva et al., 2022), user-generated feedback on lighting conditions could create open-access maps reflecting localized illuminance expectations. Such a map can reflect co-creation expectations at a localized urban scale (Kashem & Gallo, 2023; Lorens & Zimnicka, 2023; Zidar et al., 2017). Leveraging the presented algorithm, these maps of illuminance expectations can be seamlessly converted into multiple design alternatives. Additionally, such a map would provide valuable geospatial data that could support long-term strategies in sustainable big-scale urban planning (Casiano Flores & Crompvoets, 2023),

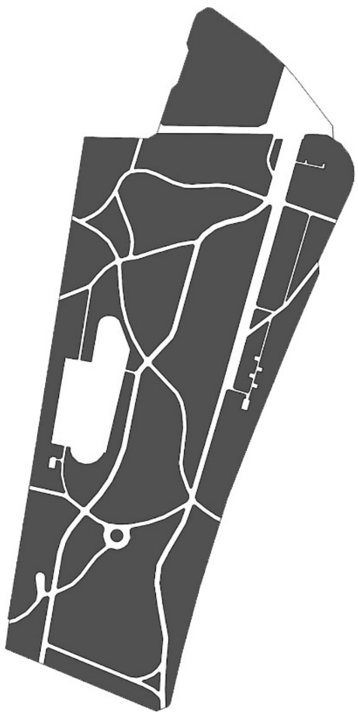

Figure 9. Grayscale bitmap representing expected minimum illuminance levels following the legal standards (white—5 lx, dark grey—1 lx).

potentially incorporating elements of artificial intelligence (AI) at some level (Tan, 2023). For instance, AI could analyze large datasets from user feedback to identify patterns or optimize lighting configurations across entire cities rather than individual parks.

While this concept is promising, challenges remain regarding engaging potential participants (Rodriguez Müller et al., 2024). Another critical issue is whether co-creation participants operate independently or are somehow guided by experts (Smith et al., 2024). Virtual Reality (VR) offers a promising solution to these challenges by providing immersive environments where users can evaluate lighting scenarios interactively. VR allows participants to experience proposed lighting designs in simulated environments before implementation, facilitating public engagement and expert validation (Krupiński, 2020; Kubiak, 2024). While illuminance evaluation may occur in real-world settings for existing spaces, VR enables assessments for spaces that do not yet exist. Utilizing VR for these evaluations can be engaging and informative for designers and users while ensuring expert guidance where necessary. Additionally, VR facilitates co-creation in designing spaces that do not yet exist, making it a valuable tool for revitalization projects and new design initiatives.

6. Conclusions

Algorithms represent a valuable tool in the early stages of lighting design, offering significant advantages such as the automatic creation of design variants that adhere to minimum illuminance criteria and the simulation, visualization, and numerical analysis of illuminance levels. These tools enable designers to explore creative solutions efficiently while ensuring compliance with technical standards, making them particularly useful in addressing complex urban lighting challenges.

These capabilities streamline the decision-making process and significantly enhance creative exploration, enabling designers to evaluate multiple scenarios efficiently. The algorithm's flexibility in accommodating various illuminance expectations makes it well-suited for participatory design processes, a key component in sustainable urban development. The algorithm bridges the gap between technical requirements and user preferences by incorporating user-defined illuminance levels into actionable lighting design solutions. This capability ensures that lighting designs are functional and aligned with community needs.

The algorithm's participatory potential is especially beneficial for urban revitalization projects, where existing public spaces require sensitive reimagining to enhance safety, functionality, and aesthetics while reducing environmental impact. In such contexts, the algorithm's ability to optimize lamp placement while minimizing factors like glare, energy consumption, and light pollution offers a practical solution for achieving balanced outcomes. Integrating VR into this process can further amplify the benefits, providing stakeholders with an immersive experience that supports dynamic generation, real-time visualization, and iterative participatory evaluation. VR enables users to experience proposed lighting designs interactively, fostering better communication between designers and end-users while allowing experts to guide the process effectively. This integration fosters better communication between designers and end-users and empowers communities to shape their environments actively.

Moreover, as introduced in this article, the illuminance expectations map offers significant value as a geospatial data resource. Such maps can be generated based on user feedback or legal standards and adapted for urban contexts. They provide planners with actionable insights into localized lighting needs while supporting long-term strategies for sustainable urban development. This map can be instrumental in guiding urban planners and designers towards more informed, responsive, and nature-friendly lighting solutions that balance the need for safety with the imperative to reduce light pollution. Additionally, these maps can serve as a foundation for integrating AI to analyze large datasets from user feedback or optimize lighting configurations across broader urban areas. By harnessing these advanced digital tools and methodologies, urban planning practices can evolve to become more adaptive, inclusive, and ecologically responsible, ultimately creating more intelligent, sustainable cities. The modular nature of the algorithm also allows for future extensions to incorporate additional parameters such as glare control metrics, uniformity ratios, color temperature adjustments, or energy efficiency considerations—further enhancing its applicability in professional lighting design contexts.

In conclusion, integrating algorithmic tools in public space lighting design advances the technical aspects of urban planning. It promotes a co-creative, user-centered approach that aligns with the broader goals of sustainable development. The synergy between advanced technologies like algorithms and VR, user engagement through participatory processes, and environmental stewardship represents a transformative direction for future urban design initiatives. This approach offers a pathway toward smarter and more sustainable cities that prioritize human well-being and environmental preservation by addressing functional requirements and ecological responsibilities.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Upon request.

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