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Research paper

doi: 10.30822/arteks.v10i3.4442

Assessing artificial lighting performance using DIALux in heritage buildings:

The case of the PLN building, Kayutangan heritage area, Malang City

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ARTICLE INFO

Article history:
Received June 02, 2025
Received in revised form Aug. 16, 2025
Accepted October 22, 2025
Available online December 01, 2025

Keywords:
Artificial lighting
DIALux simulation
Heritage buildings
Kayutangan heritage

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ABSTRACT

This study aims to turn on artificial outdoor lighting in the State Electricity Company (PLN) Building as a cultural heritage building in the Kayutangan Heritage Area using DIALux Evo simulation with input measurements and observations in the field. This simulation assesses the average lighting level, lighting uniformity, and energy efficiency, with comparisons to national and international standards. The focus of the study includes the average illumination value, lighting uniformity, and glare assessment which will later be developed into the principle of intelligent lighting in preserving cultural heritage buildings. Based on the simulation results, it was found that most areas of the building have lighting levels below SNI standards, especially in outdoor/pedestrian areas (horizontal elements) and facades (vertical elements). The overlay graph shows a significant disparity in light distribution. These results indicate the need for lighting design interventions in pedestrian areas and building facades. The development of lighting design can later be in accordance with considering aspects of surface materials, functionality, energy efficiency, and most importantly, it can support aspects of preserving cultural heritage buildings. This research is expected to be the basis for developing sustainable lighting strategies in cultural heritage buildings, especially in the Kayutangan Area.

Introduction

The Kayutangan Heritage Area in Malang City is a strategic area with high historical and architectural value. A critical element in preserving this area is natural and artificial lighting, which not only supports the function but also strengthens the visual value and identity of the area (Susanti, Pratiwi, and Wulandari 2021). The Kayutangan PLN Building, as a cultural heritage building designated through the Decree of the Mayor of Malang No. 188.45/244/35.73.112/2019, is an essential subject in developing this area (Wahjutami, Laksmianni, and Winansih 2025; R Wikantiyoso and Santoso 2025). For this reason, analysis of artificial lighting performance is critical for improving the visualization and preservation of heritage buildings. Artificial lighting is crucial in highlighting heritage buildings' architectural and aesthetic elements. According to Sholanke, Fadesere, and Elendu (2021), artificial lighting not only functions as a source of light but also as a visual communication tool that can strengthen the character and identity of the building. In the context of heritage buildings, artificial lighting can highlight important architectural features, such as columns, cornices, and ornaments, thereby increasing visual appreciation of the building. Recent studies emphasize the need for more ecologically responsible illumination strategies for heritage zones, integrating aesthetic, functional, and environmental concerns (Méndez et al. 2024; Galindo, Borge-Diez, and Icaza 2022). Additionally, facade lighting can significantly influence the emotional experience of visitors, helping shape perception and atmosphere through architectural storytelling (Balafoutis 2024).

Prihatmanti and Susan (2017) emphasized that in adapting the use of heritage buildings, artificial lighting must be designed so as not to damage the original character of the building. They suggest using artificial lighting that can improve visual comfort without changing the original structure or elements of the building. This is important to ensure that lighting interventions do not interfere with the historical integrity of heritage buildings. Furthermore, research by Mohammadrezaei et al. (2024) shows that a digital twin-based lighting design approach can be used to evaluate the visual impact of lighting configurations on heritage buildings. By using a virtual model that replicates the real conditions of the building, designers can test various lighting scenarios and choose the most appropriate one to highlight architectural features without damaging the historical value of the building. A similar simulation approach was also employed in the At-Turaif district study, where material reflectance and aesthetic qualities were analyzed to support both function and heritage value (Hameedaldeen, Altassan, and Kotbi 2023).

Figure 1. Location of the Kayutangan PLN building as a case study

In the context of the Kayutangan PLN Building (figure 1), artificial lighting performance analysis can include an evaluation of the light intensity, lighting distribution, and color temperature used. The goal is to create lighting that not only meets functional needs but also strengthens the architectural and aesthetic character of the building. Thus, artificial lighting can be an effective tool in preserving and developing heritage areas such as Kayutangan. However, artificial lighting in heritage buildings is often neglected or does not meet standards, thus affecting visual comfort, energy efficiency, and visual perception of historical architectural elements (Nassrollahi et al. 2019). Therefore, this study integrates lighting simulation using DIALux software to evaluate existing conditions and provide recommendations based on bright lighting and energy efficiency principles.

This simulation was meticulously executed with the primary objective of thoroughly assessing and analyzing the quality and effectiveness of artificial illumination within the external environment surrounding the PLN Malang City Building, with particular emphasis placed on the facade area, the pathways designated for pedestrian use, as well as the various elements of outdoor furniture that contribute to the overall ambiance. This comprehensive assessment holds significant importance, as it aims to ascertain that the existing lighting infrastructure can provide visual comfort and safety for individuals traversing the area and enhance and support the architectural aesthetics of the structure during the nighttime hours (Salata et al. 2015). The findings derived from this evaluation are intended to inform future lighting design strategies and improvements, fostering a more inviting and secure public space for residents and visitors alike. Examples from other historic areas, such as Slovenia and Spain, have demonstrated how strategies like silhouette lighting or optimal luminaire placement using DIALux can significantly reduce glare while enhancing the architectural expression of heritage buildings (Kobav, Bizjak, and Eržen 2023; Cantizani-Oliva, Bullejos, and Dorado 2024).

Therefore, based on the issues above, the research question addressed in this study is:
"Does the current artificial lighting of the PLN Building facade and pedestrian area meet the visual comfort and heritage lighting standards?"
It is hypothesized that the current artificial lighting system applied to the PLN Building's facade and pedestrian pathways in the Kayutangan Heritage Area does not yet meet the

visual comfort and heritage lighting standards established in national (SNI) and international guidelines (CIE).

The purpose of this study is to evaluate the performance of the current outdoor lighting system using DIALux Evo 12.1 simulation, focusing on light intensity, uniformity, and glare potential.

The findings are expected to contribute to the development of context-sensitive lighting designs that support both energy efficiency and heritage preservation in urban environments like Kayutangan.The novelty of this study lies in the combination of simulation-based analysis (DIALux Evo 12.1) with heritage lighting evaluation, which is still rarely done in Indonesia.

Literature review

This literature review discusses various theories and research related to architectural lighting in heritage areas, especially in the context of the Kayutangan Heritage Corridor. The primary focus of this study covers aspects of lighting performance, visual architecture of building facades, and lighting in the context of urban preservation and design. Various theories on lighting design, visual perception, and place-making are used for the analysis. In addition, this study also reviews relevant research on a global and local scale to understand the best practices that can be applied in designing lighting that enhances the visual quality and heritage value of the Kayutangan area.

Lighting performance

This dimension encompasses various technical lighting parameters essential for shaping the visual comprehension of architectural facades. Light intensity (illuminance) determines the brightness level, ensuring adequate visibility while reducing excessive glare. Light distribution impacts the consistency of illumination across surfaces, thereby effectively highlighting architectural subtleties (Lam 1992). The hue of light (color temperature) is crucial in creating the ambiance and the interaction between artificial and natural light, consequently influencing the perception of texture and materiality. Moreover, the cumulative effect of lighting on building facades can either augment or obscure architectural features, thus impacting aesthetics, historical authenticity, and the evening character of urban heritage locations. Intentionally conceived lighting promotes visual harmony and functional effectiveness. The technical aspects of lighting include parameters such as illuminance, light distribution, color temperature, and the effect of lighting on the visual portrayal of the building facade. Light intensity establishes the necessary brightness level to ensure optimal visibility without causing glare. Consistent light distribution is vital for effectively accentuating architectural elements. Light color significantly affects the atmosphere and the perception of construction materials.

Azis, Santosa, and Ernawati (2019) conducted a comprehensive study that demonstrated how meticulously designed facade lighting can significantly enhance the visual perception of heritage buildings, thereby reinforcing the identity and character of the surrounding area. Furthermore, supplementary investigations have indicated that an effectively executed facade design can optimize the distribution of natural light within indoor environments, consequently leading to a marked reduction in the reliance on artificial lighting sources and simultaneously promoting greater energy efficiency (Kurniawan 2020).

In the realm of research focused on the parametric optimization of horizontal blade facades about their ability to harness natural lighting, findings reveal that variations in both the rotation angles and the widths of the blades integrated into the facade play a crucial role in determining the indoor distribution of natural light, thereby influencing both the efficiency of the lighting system and the overall visual comfort experienced within the space (Atthaillah and Mangkuto 2020). By meticulously taking into account the various technical parameters associated with lighting as well as the principles of effective facade design, it becomes possible to significantly elevate the visual quality of the building's facade, thereby fostering the creation of an environment that is not only aesthetically pleasing but also highly functional in its utility.

In Light and Color in the Minnaert (1993), Marcel Minnaert discusses how the color of light affects the perception of the shape and texture of buildings. Variations in the wavelength of light can highlight or obscure surface details, thus affecting one’s spatial experience. Lighting with a warmer color temperature tends to have a softer effect and enhance texture, while more intense lighting can highlight details more sharply and increase contrast. Recent research supports this theory by showing that the light spectrum and color temperature significantly affect visual perception. A study by Zhang (2019) found that different lighting levels significantly impact the perception of two-dimensional objects, with the color temperature of light (correlated color temperature, CCT) affecting the clarity of texture and color. These findings can be applied to building facades to create specific visual effects (Zhang 2019).

Furthermore, a plethora of empirical research has substantiated the notion that the chromatic quality of illumination can initiate distinct emotional reactions, which, in turn, significantly influence the dynamics of human interactions within various architectural environments. For instance, the comprehensive investigation conducted by Li et al. (2022) revealed that individuals exposed to red-hued light experienced a spectrum of emotional reactions that ranged from a profound sense of tranquility to an acute feeling of tension, thereby underscoring the intricate and multifaceted nature of the interplay between the color of light and human psychological responses. In the realm of architectural design, the implementation of well-considered lighting strategies not only serves to accentuate critical features of a building's facade but also plays a pivotal role in cultivating the intended ambiance while simultaneously elevating the overall aesthetic appeal of the constructed environment, thereby contributing to the holistic experience of the space.

Architectural Visual of Building Facades Lighting plays an essential role in shaping the visual perception of architectural elements, especially in displaying the composition, proportions, and details of colonial building facades. Well-placed light can highlight decorative elements and material textures and strengthen the historical identity of the building.

According to research, lighting with warm color temperatures can give a classic impression and emphasize the beauty of colonial facade ornaments. At the same time, cool lighting tends to display lines and structures more sharply (Zhang 2019). Even light distribution also affects visual balance and clarity of form. In addition, Li et al. (2022) emphasized that the intensity and direction of lighting can create shadow effects that strengthen the depth and dimension of building facades. Lam (1992) in Perception and Lighting as Formgivers for Architecture discusses how lighting functions as a utility element and a significant factor in shaping the perception of architecture Light affects how humans perceive a space's scale, proportion, and atmosphere, so effective lighting design can enhance the quality of the architectural experience.

Research by Boyce (2014) shows that lighting affects the legibility of architectural details and the perception of the texture of a building facade. Another study by Veitch and Newsham (2017) highlights that dynamic lighting with the correct distribution and color can improve visual comfort and create a more attractive atmosphere. In addition, research by Linhart et al. (2020) found that variations in illumination can change the perception of space, where direct lighting increases the perception of depth, while diffuse lighting creates a broader and more comfortable impression of space.

In the context of colonial buildings, lighting designed with the interaction between light and shadow in mind can strengthen the architectural character and enhance the visual appeal of the facade. Thus, understanding the relationship between lighting and architectural perception is essential in creating a better built environment.

Urban nightscape and the visual identity of historic areas

The Urban Nightscape concept, developed by Schielke and Leutz (2015), emphasizes how lighting shapes the visual identity of historic areas at night. Well-designed lighting can highlight architectural character, improve the readability of building forms, and create an atmosphere that supports urban space users' visual and emotional experience. Research by Amini (2022) shows that the intensity and distribution of lighting affect the visibility and readability of historic buildings at night. This study highlights that the right combination of color temperature and lighting techniques can enhance the visual appeal and increase public cultural awareness of historic buildings.

Zielinska-Dabkowska (2018) explore how LED lighting in historic urban environments can affect nighttime perception and cultural heritage identity. They found that energy-efficient LED lighting provides efficiency and can enhance the visual appearance of historic building facades without reducing their original aesthetic value. In addition, research by Nardelli (2021) highlights that nighttime lighting that adapts to the social context can create a more interactive city experience and increase public engagement in urban spaces. Therefore, lighting design that considers cultural, historical, and social aspects is essential in shaping the night image of a historic city.

Lighting in the context of heritage and urban design

Lighting plays a vital role in strengthening the visual identity of a heritage area without losing its historical value. The right lighting design can highlight architectural elements, improve the readability of building details, and create an atmosphere that supports the public's spatial experience. Fisher-Gaertner (2011), in Lighting for Historic Buildings, emphasized that lighting strategies for historic buildings must consider the balance between aesthetics and conservation. The use of light sources that follow the characteristics of the material and the intensity of lighting that is not excessive are key to maintaining the architectural integrity of historic buildings.

A study by Bakker et al. (2017) shows that excessive lighting can obscure the original details of a building and create visual distortion, while adaptive lighting can maintain the readability of the building facade optimally. Lighting should promote the process of place-making by building a distinct sense of location and identity, known as Placemaking, which will strengthen the narrative, and add to the overall atmosphere of the site (Rastegari, Pournaseri, and Sanaieian 2023; Zeini Aslani, Dugar, and Mozaffar 2023), in the concept of Place-making in Urban Lighting Design, highlights how lighting can create an atmosphere that supports the spatial experience and enhances social interaction. A study by Boyce (2014) found that lighting with the correct distribution and color can improve the perception of safety and comfort in historic public spaces.

In addition, research by Borisuit et al. (2015) shows that lighting that considers psychological factors can enhance the appeal of urban areas at night without reducing their historical value. Research by García-Hansen et al. (2021) highlights that lighting with a warm color spectrum is more effective in maintaining a historical atmosphere than lighting with a more modern blue or white spectrum. By implementing the right lighting strategy, lighting design enhances the aesthetics of cultural heritage areas and strengthens the visual identity and community engagement with its architectural heritage.

Relevant similar research

Architectural lighting is essential in maintaining and highlighting the historical character of buildings in heritage areas. In addition to enhancing aesthetics, lighting clarifies architectural details that may be difficult to see during the day and creates an atmosphere that follows its historical context. Several studies have discussed effective lighting strategies for historic areas worldwide, including Europe, Asia, and Indonesia. Schielke (2018), in his research on the lighting of historic building facades in Europe and Asia, emphasized the importance of choosing the right light color, intensity, and lighting distribution to highlight architectural character without reducing its historical value. This study shows that carefully designed lighting can improve public perception of historic buildings, create a more attractive atmosphere, and strengthen the area's identity as part of the cultural heritage. With an approach that considers the interaction between light and building texture, lighting can be utilized to maintain a historical impression while providing a more dynamic visual experience.

In Indonesia, research by Azis, Santosa, and Ernawati (2019) highlighted the optimization of street and building lighting in cultural heritage areas. This study emphasizes the importance of integrating street and building lighting to create a harmonious and functional environment. The survey results indicate that illumination that considers aesthetics, safety, and comfort for pedestrians can improve the overall quality of public spaces. Adequate lighting in historic areas must be able to direct attention to critical architectural elements without causing excessive visual distortion or light pollution that can disturb the surrounding environment.

Another study by Santosa and Antariksa (2020) evaluated lighting in colonial buildings in Malang. This study found that many colonial buildings had not received appropriate lighting, so their architectural details were less than optimal at night. In addition, the imbalance between street lighting and building lighting causes visual disturbances that can reduce the historical impression of the area. This study recommends a lighting approach that considers the character of colonial architecture, the use of energy-efficient lighting technology, and adjustments to light intensity to highlight essential elements without causing adverse impacts on the environment.

Moreover, many academic investigations have provided evidence suggesting that the hue of illumination plays a pivotal role in eliciting distinct emotional reactions, significantly influencing how individuals engage with various architectural environments. In their comprehensive study, Li et al. (2022) discovered that individuals' exposure to red light could provoke an extensive spectrum of emotional responses, ranging from feelings of tranquility to heightened states of tension, thereby illustrating the intricate and multifaceted nature of the interplay between the color of light and human psychological processes. Within the realm of architectural design, the implementation of well-considered and strategically devised lighting techniques can serve to accentuate critical features of a building's facade, thereby not only establishing the intended ambiance but also contributing to the overall enhancement of the aesthetic appeal and visual quality of the constructed environment.

Lighting quality analysis through DIALux simulation

In the analysis of artificial lighting performance in cultural heritage buildings, a visual simulation-based approach is essential to understand how lighting affects the function of space and the architectural character of the building. DIALux Evo is one of the lighting simulation software programs widely used to model and simulate lighting systems in architecture and lighting engineering.

The main advantage of DIALux is its ability to monitor artificial lighting in three dimensions, considering light intensity and distribution, as well as its effects on visual comfort and conservation of building elements (Aksamija 2016). In the context of building heritage, such as the PLN Building in the Kayutangan area, Malang, the use of DIALux allows researchers to analyze the diversity of existing lighting against visual comfort standards without directly changing the physical building. This simulation also plays a vital role in the conservation process because excessive or inappropriate lighting can accelerate the damage to building materials (Cassar 2009). Thus, DIALux is a technical tool and instrument for making design decisions sensitive to historical values and cultural heritage.

The use of a quantitative approach with DIALux simulation provides objective data related to illumination levels, light distribution, and energy efficiency, which can be compared to lighting standards such as SNI or international recommendations, such as from CIE (Commission Internationale de l'Éclairage) (Cuttle 2015). Therefore, integrating lighting simulation in cultural heritage architecture studies is a strategic step in developing data-based designs and preserving the values of historic buildings. Lighting simulation using DIALux software is essential to analyzing artificial lighting performance in cultural heritage buildings such as the PLN Building in the Kayutangan area (Wahjutami and Winansih 2025). Through this approach, researchers can emit sufficient lighting in each room, identifying whether the available lighting meets visual comfort standards according to regulations such as SNI or international recommendations from CIE.

The simulation results allow for the visualization of light distribution evenly or unevenly in space so that areas that experience excess or lack of lighting can be identified, which has the potential to interfere with user activities. In addition to the visual comfort aspect, the simulation also provides information on the energy efficiency of the existing lighting system. With this data, the potential for energy savings can be explained through alternative, more efficient lighting systems, such as LED technology. This is important in conserving cultural heritage buildings that require lighting systems that are not only technically effective, but also energy efficient and friendly to building elements sensitive to excessive light exposure.

Furthermore, the simulation results help to identify lighting risks to historical materials, such as wood, ornaments, or documents, easily damaged by high light intensity. Thus, DIALux analysis not only functions as a technical tool but also as a conservation instrument that can maintain the visual and material integrity of the building in the long term. Based on the overall findings from this simulation, recommendations can be formulated for redesigning the lighting system that considers the suitability of the space function, energy efficiency, and preservation of the building's historical values, while strengthening the data-based approach in the conservation of cultural heritage architecture.

Luminance (Surface brightness)

The background luminance is significantly influenced by various factors, notably including the specific positioning of the luminaire in question and the observer's line of sight, which may encompass a range of environments, such as a serene pathway within a park or a bustling footpath in a commercial shopping street. In the initial phase of Spieringhs' comprehensive study, the average surface luminance of the roadway was utilized as the baseline for defining the background; however, the research also considered alternative backgrounds to provide a more nuanced understanding. In the illustrative representation displayed in figure 2, one can observe a purely demonstrative luminance measurement aimed at highlighting the diverse areas that may be categorized as contributing to background luminance; it is important to note that this representation does not adhere to the stringent requirements stipulated by CIE 232:2019 (i.e., a maximum of ⩽12 mm/pixel), and consequently, it is not deemed appropriate for the calculation of the average luminance across the designated luminance area.

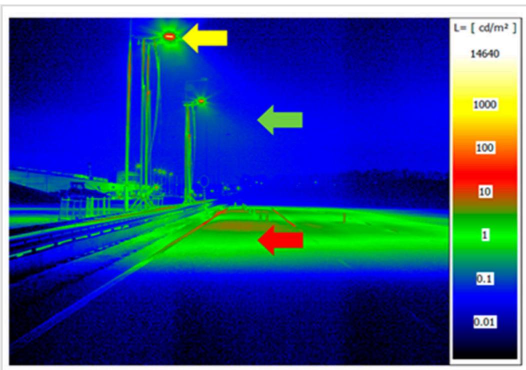

Figure 2. An illustrative luminance image of a regulated street lighting system showcasing various luminaires, elevations, and separations; the yellow arrow denotes the luminaire background, the green arrow refers to the urban nocturnal sky, and the red arrow represents the road surface
Source: (Spieringhs et al. 2022)

This study by Spieringhs et al. (2022) sheds light on the complexities of accurately measuring and interpreting luminance in various contexts. Thus, it becomes evident thats determining background luminance requires careful consideration of several variables that can affect the observer's perception of light and the overall visual experience in different settings. Ultimately, the insights garnered from this research serve as a critical foundation for future investigations into luminance characteristics and their implications for environmental design and urban planning (Spieringhs et al. 2022). CIE 115:2010 in Fotios and Gibbons (2018) recommends horizontal lighting for residential areas, an average of 20 lux, and the commercial regions, 30 lux; the AS4 guideline recommends the use of vertical lighting at a height of 1.5 m, with a range of 10 lux to 20 lux, depending on pedestrian density. In Indonesia, SNI 7391:2008 (Indonesian National Standard) regarding street lighting specifications in urban areas. According to the SNI standard, the illumination or uniformity value is within the standard range of 3 - 7 lux (National Standardization Agency 2008). CIE 94: 1993 and CIE 234: 2019 (Skarżyński and Żagan 2022) recommend Luminance on façades in a rural area (E1); the luminance should be around 4 cd/m² /m². In urban areas (E4), the luminance can be as high as 12 cd/m², similar to CIE 94, but with more emphasis on the context of the surrounding environment.

Measuring pedestrian luminance using Fusion Optix involves utilizing digital tools to assess lighting conditions in outdoor environments (Childs et al. 2005; Krizek 2010). Fusion Optix software provides a precise and efficient method for luminance measurement, which is essential for designing well-lit public spaces. This approach is beneficial when combined with traditional tools to understand the lighting environment comprehensively. Incorporating both digital and conventional methodologies guarantees precise evaluations of pedestrian safety and comfort regarding luminance. Presented below are the pivotal elements of luminance quantification utilizing Fusion Optix. Digital instruments for luminance quantification are exemplified by Fusion Optix software, which provides a contemporary approach to luminance assessment, yielding accurate and effective outcomes when contrasted with traditional lux meters (Mery-Ruiz 2023). Digital instruments possess the capability to swiftly analyze extensive data collections, thereby rendering them appropriate for expansive outdoor settings such as parks and metropolitan locales (Mery-Ruiz 2023). The amalgamation of digital and traditional methodologies is advocated to attain the most reliable and thorough luminance evaluations, as the integration of digital instruments and conventional devices enhances the overall accuracy (Mery-Ruiz 2023). Traditional instruments, including lux meters, aid in fostering a more comprehensive understanding of the illumination environment, thereby complementing the accuracy offered by digital tools (Mery-Ruiz 2023).

The glare effects

Unpleasant illumination from a light source or luminaire is characterized by the International Commission on Illumination (CIE) as "illumination that induces discomfort yet does not obstruct the perception of the object." Given its significance in formulating aesthetically pleasing lighting designs, discomfort glare has been the subject of extensive research. Numerous glare indices have been proposed, including the CIE Glare Index (CGI), the British Glare Index (BGI), Visual Comfort Probability (VCP), Glare Control Sign (Glare), Cumulative Brightness Effect (CBE), Daylight Glare Index (DGI), and Daylight Glare Probability (DGP).

Various discomfort glare prediction models have been established for outdoor settings, introducing the Discomfort Glare (DG) value, which forecasts the glare sensation for outdoor lighting installations based on the luminance of the luminaire, the surrounding context, and the ambient conditions. The suggested glare metrics for LED lighting within pedestrian areas are computed based on the luminance of the luminaire's light source, the background, size, and viewing angle. Unpleasant glare in automotive lighting is also considered in the model that Schmidt Clausen and Bindels proposed. Concurrently, Lin introduced a model addressing discomfort glare from LED street lighting and assessed various glare rating scales, revealing that the de Boer scale may vary significantly across different levels of glare source luminance, solid angle, and background luminance. The role of spectral sensitivity on glare perception in outdoor lighting has been examined and incorporated into the glare model presented by Sweater-Hickcox. Within road and vehicle lighting contexts, CIE 243:2021 and Funke assert that the distribution of glare source luminance influences the glare rating based on LED luminance, inter-LED distance, and background luminance.

In the domain of external illumination apparatus, it is essential to recognize that the immediate context in which these light sources are evaluated is primarily characterized by the average ambient luminance. This luminance can demonstrate significant fluctuations, varying from a relatively low 0.06 candela per square meter (cd/m^2) to a considerably higher 20 cd/m^2, or even by the extensive urban night sky that may exhibit an even lesser luminance level, generally oscillating between a minuscule 0.0002 cd/m^2 and a peak of 0.05 cd/m^2. Such variability frequently results in heightened Unified Glare Rating (UGR) values requiring further inquiry. Thus, exploring the specific parameters and methodological frameworks essential for thoroughly assessing glare becomes increasingly crucial, particularly in quantifying UGR within pedestrian domains by leveraging the sophisticated functionalities of DIALux Evo software. Although UGR is predominantly acknowledged as a quantitative indicator for evaluating discomfort glare in primarily indoor environments, it is important to note that this measure can be adapted and utilized in pedestrian areas, contingent upon the appropriate contextual considerations and adjustments to ensure its precision and applicability.

DIALux Evo is a sophisticated commercial lighting simulation software tool that can calculate UGR by meticulously simulating various lighting conditions and thoroughly evaluating the contributing glare factors inherent in those environments. To successfully compute the UGR within the DIALux Evo framework, it is essential to utilize a set of specific input variables, which include, but are not limited to, light source illuminance (L), background illuminance (Lb), light source solid angle (ω), and the position index (P), each of which plays a pivotal role in determining the overall glare impact.

This particular parameterization is not merely a technical necessity. However, it is crucial to ensure that the UGR calculations yield accurate and reliable results, as highlighted in the research conducted by Son et al. (2015), which elucidates the importance of methodological rigor in glare assessment. Ultimately, the ongoing exploration of glare evaluation methodologies will likely enhance our understanding of visual comfort in varying lighting environments, thereby contributing to developing more effective and aesthetically pleasing outdoor illumination solutions.

In each simulation, the user must set up the simulation environment in DIALux Evo to reflect the pedestrian area accurately. This involves defining the field of view for the background lighting and the luminous part of each luminaire (Son et al. 2015). The capabilities of the DIALux Evo Software allow modification of the UGR calculation model to accommodate different input conditions, which is essential for adapting UGR measurements to the pedestrian environment (Son et al. 2015).

Color temperature

The color temperature of lighting significantly affects various aspects of human perception and environmental interaction. It affects visible light communication, road visibility, driver alertness, indoor thermal perception, and biological responses. Adjusting color temperature is essential in various settings, from residential to commercial environments, where different activities may require different lighting conditions. The color temperature of lighting significantly affects pedestrian behavior and comfort in heritage sites. It influences visual perception, psychological preferences, and the overall atmosphere of the environment. Lighting choices can improve pedestrian paths' livability and aesthetic appeal, especially in urban heritage settings. The color temperature of street lighting significantly influences pedestrians' visual and psychological perceptions. Higher correlated color temperatures (CCT) increase perceptions of safety and comfort, providing better visibility and a sense of security. A study conducted in Beijing found that pedestrians preferred moderate to high CCT lighting, especially at higher ambient temperatures, as it was associated with warmer light colors and increased comfort.

In the heritage context, appropriate lighting design is critical to improving the livability of pedestrian paths. A study in Batroun, Lebanon, highlighted the importance of harmonizing lighting with urban heritage settings to improve nighttime perceptions and mental safety (Traboulsi et al. 2023). Using artificial lighting in heritage areas can significantly impact the perceived quality of urban design, contributing to a more livable and aesthetically pleasing environment (Traboulsi et al. 2023). Lighting significantly influences occupants' perceptions of comfort in pedestrian environments. This suggests that appropriate lighting, including color temperature considerations, can improve pedestrian comfort levels in heritage cities (Shi et al. 2024).

Methods

This study uses a quantitative descriptive approach using DIALux Evo 12.1. Simulations are carried out based on input data from lighting specifications in the field, direct measurements using physical devices such as luxmeters at several points to support compliance with existing data, then re-modeled to obtain valid data. This method was chosen because it is effective in visualizing and evaluating lighting performance in historic buildings while maintaining their physical integrity (figures 3 and 4). This approach ensures an evidence-based simulation that mirrors the actual lighting conditions on site and allows a comprehensive assessment without physical intervention, thereby supporting heritage-preservation goals (Valencia Pavón et al. 2024).

Figure 3. 3D model of the PLN Kayutangan building

Figure 4. Simulation modeling of existing lighting conditions

The main parameters analyzed are: (1) Average illumination value (lux); (2) Uniformity (lighting uniformity); (3) Power efficiency and total lamp power. The simulation considers the specifications of the lamps used in the field and compares them to the lighting standards of SNI 6197:2011 and international references (IESNA, IBSE). Overlay graphs and isolux distributions are used to show the quality of light distribution (Beccali et al. 2019).

Based on the DIALux simulation 12.1, the assessment is divided into two main parts: (1) For façade lighting, the evaluation refers to CIE 94:1993 and CIE 234: 2019, applicable for urban areas with high activity levels and heritage buildings. These standards guide the vertical illuminance and visual comfort criteria for building façades in complex urban environments (Cantizani-Oliva, Bullejos, and Dorado 2024; Żagan and Skarżyński 2020). (2) For the yard and pedestrian way, the criteria used are CIE 115:2010 (Class P3) and SNI 7391:2008, which address outdoor lighting requirements for pedestrian pathways and environmental comfort in public spaces (Burattini, Bisegna, and De Santoli 2025) (figure 5).

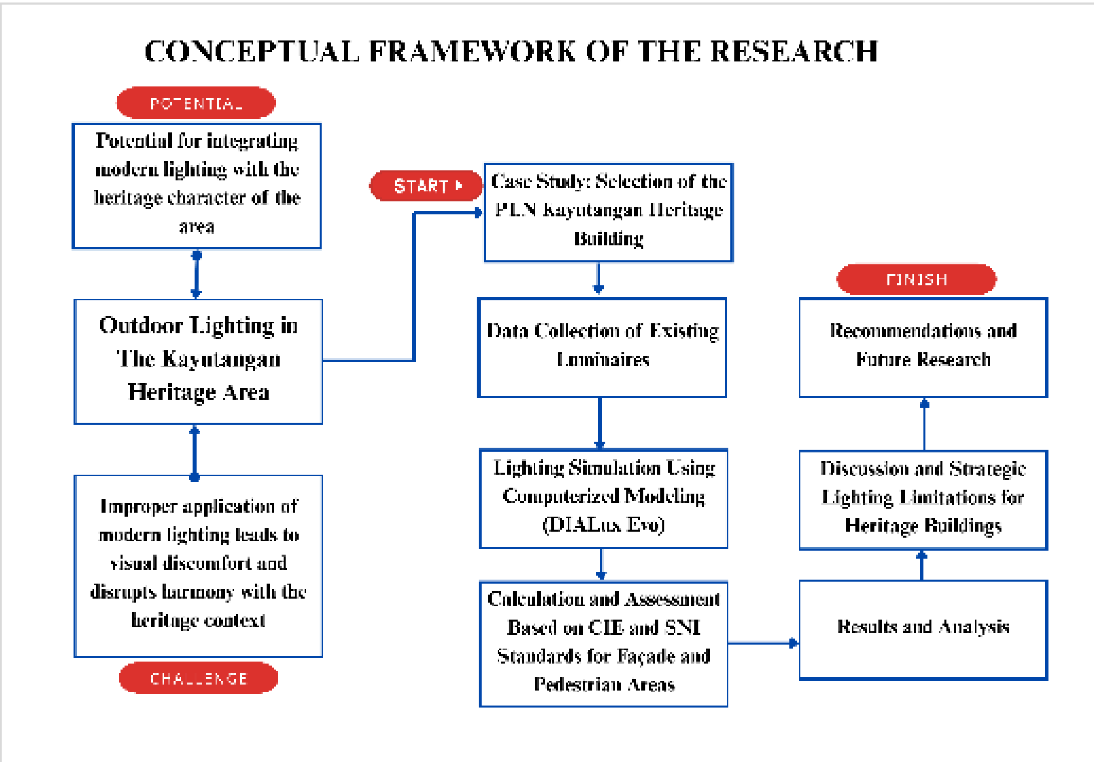

Figure 5. Conceptual framework of the research

Results and discussion

The PLN Kayutangan edifice, located at Jalan Basuki Rahmat (Kayutangan) No. 100, Klojen District, Malang City (R Wikantiyoso and Santoso 2025), represents a significant historical structure that epitomizes the opulence of the Dutch colonial era architecture within Indonesia (figure 6). This particular building was initially constructed in 1930 to serve as the headquarters for the Dutch electricity enterprise, N.V. Algemeene Nederlandsch-Indische Electriciteits Maatschappij (ANIEM), which had previously operated under the name Maintz & Co and was headquartered in Amsterdam. This building is part of an elite European residential area during the colonial period, which is now known as the Kayutangan Heritage Area. As a form of protection for cultural heritage, the PLN Kayutangan Building has been designated as a cultural heritage by the Malang City Government (Respati Wikantiyoso and Poerwoningsih 2025).

Figure 6. Kayutangan heritage area, PLN building location

This determination refers to Malang City Regional Regulation Number 1 of 2018 concerning Cultural Heritage and Law of the Republic of Indonesia Number 11 of 2010 concerning Cultural Heritage. This building is included in the list of 32 official cultural heritage buildings in Malang City. In terms of architecture, the Kayutangan PLN Building represents a modern colonial architectural style known as Nieuwe Bouwen, a style that developed in the Dutch East Indies after 1920.

These elements give this building a strong visual character and significantly contribute to the identity of the Kayutangan area. In a study of visual perception of the facades of cultural heritage buildings in this area, the Kayutangan PLN Building received the highest aesthetic score from professionals and non-professionals (figure 7). This shows a consensus regarding the visual and architectural quality of this building (Ramli, Santosa, and Antariksa 2019). Although most of the buildings in the Kayutangan area do not fully meet the golden section principle, the proportions of the PLN Building facade can still present visual balance and are aesthetically attractive (Aprillianto 2014).

Overall, the Kayutangan PLN Building not only holds historical value as a symbol of the development of the electricity network during the colonial period, but also represents modern colonial architecture's aesthetic and technical achievements. Its determination as a cultural heritage is an important step in preserving the city's architectural heritage, which has high historical, educational, and aesthetic value.

Figure 7. Night photo of PLN Kayutangan building, Malang. Photo Technique: Camera Setting (EXIF): ISO 50, F/10, 3.2 seconds, tripod. Camera: Sony A7CII + 20mm

Through comprehensive visual analysis and precise measurements, it has been determined that the illumination within the PLN edifice exhibits a greater degree of complexity due to the presence of multiple layers of lighting, specifically: (1) Illumination provided by vintage street lamps (traditional three-branched fixtures); (2) Uplighting from the base that accentuates certain sections of the columns and portions of the structure on the second level; (3) Lighting designated for the PLN building's signage (in the representation of the PLN emblem) serving as an indicator of the building's purpose and as a notable landmark; (4) Vertical illumination on the tower and upper facade displays a washlight effect, characterized by gentle lighting that enhances the visibility of the tower and upper wall. The facade lighting in the PLN building has provided a layering of lighting on the building facade, and the fence has actually been given additional yellow lighting to support the heritage impression, but it is rarely turned on.

The color of light (color temperature) exposed to the PLN building and the dominance of warm lighting (around 2700K–3000K) on heritage street lights provide a heritage, friendly feel, and are suitable for historical areas. The yellow and blue "PLN" neon signage contrasts sharply with the lighting on the facade (figure7). Several uplight lighting points use neutral white lighting, giving a striking impression, but still look harmonious. Although contrasting light is used, the lighting on the facade of the PLN Building still looks like it can create a harmonious atmosphere.

The existing lighting configuration of the PLN Kayutangan Building is illustrated in (figure 8). The diagram shows the spatial arrangement and types of luminaires used across various exterior zones of the building, including the fence, façade, pedestrian pathways, and yard. The table embedded in the figure provides detailed specifications for each lighting type, such as lamp model, power consumption (Watt), correlated color temperature (CCT in Kelvin), and quantity. This data, obtained through field observation and measurement, served as the primary input for the DIALux Evo simulation to evaluate lighting performance, including illuminance, uniformity, and energy use.

Based on the study of light distribution and visual effects on heritage buildings in the Kayutangan corridor, the lighting in the PLN Building is one of the best of several buildings that are not used at night because they function as offices. So, this building is a case study that is expected to be able to represent other cultural heritage buildings in the Kayutangan corridor.

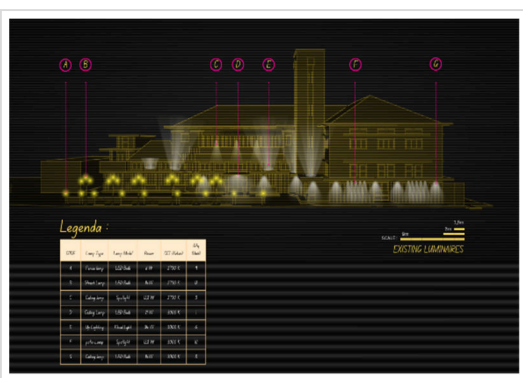

Figure 8. Configuration and technical specifications of existing outdoor lighting at the PLN Kayutangan heritage building, Malang

However, there are several notes for visual landmarks, (1) The building can display the shape of the building at night, especially the provision of special lighting on the vertical tower makes it a visual landmark at night, this effect strengthens the sense of place and visual navigation of the area; (2) The visual composition between the low building and the high tower can be read clearly. Facade lighting has a lighting hierarchy principle in the visualization of buildings at night, where not all parts must be evenly lit. However, iconic parts need to be emphasized to emphasize the facade landmark.

Analysis of average lighting intensity values

The outcomes derived from lighting simulations conducted with DIALux Evo 12.1 software on the heritage structure known as the PLN Building, located in the Kayutangan District of Malang, indicate that the majority of the examined areas fall short of the minimum standards for artificial illumination mandated for public outdoor environments The luminance assessment was conducted across five facade and tower zones (F1, F2, F3, T1, and T2). The results were compared against the standard references outlined in CIE 94:1993 and CIE 234:2019. These references provide minimum, average, and maximum luminance levels for urban and heritage environments to ensure visual comfort and spatial legibility.

The line graph (figure 9) illustrates the values of L.avg (average luminance), L. Max (maximum luminance), and L. Min (minimum luminance) for each zone, with dashed lines representing the standard benchmarks (L.avg = 25 cd/m², L. Max = 150 cd/m², L. Min = 12 cd/m²).

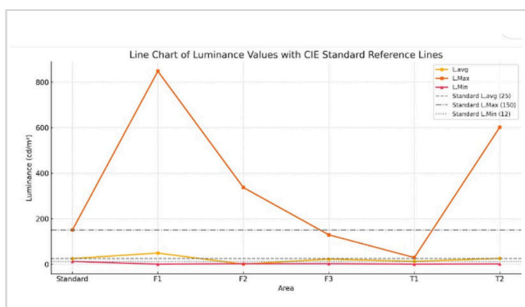

Figure 9. Overlay graph of DIALux lighting simulation results, façade zone

Key observations for the area facade include: F1 significantly exceeds the standard maximum luminance, reaching 848 cd/m², which may cause glare and reduce visual comfort for pedestrians. F2 and T1 demonstrate luminance levels far below the recommended averages, indicating poor illumination and potential under-lighting. T2 achieves values closest to the standard for average luminance, suggesting a more balanced lighting condition. The inconsistencies in luminance levels across the zones highlight the lack of uniform lighting design and the need for standard-based optimization. This comparison reinforces the importance of applying established lighting standards, especially in heritage areas where modern lighting installations must align with contextual sensitivity and visual coherence.

Illuminance Assessment for Yard and Pedestrian Zones, to evaluate the lighting performance of the yard and pedestrian areas in the Kayutangan Heritage Corridor, a comparison was made with SNI 7391:2008 and CIE 115 standards. These standards outline recommended thresholds for average illuminance (E.avg), minimum illuminance (E.min), and uniformity ratio (Uo) in outdoor environments, particularly pedestrian zones (P class).

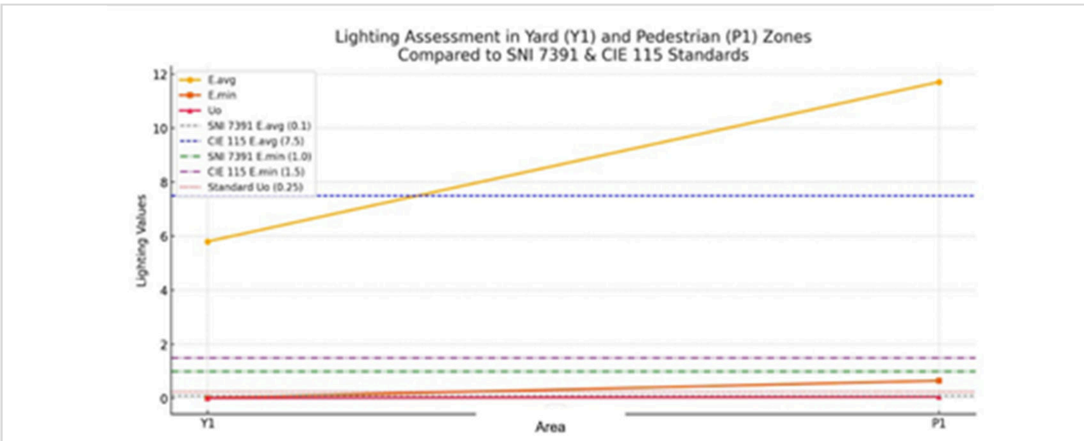

Figure 10. Overlay graph of DIALux lighting simulation results, pedestrian and yard surface zone

The line graph (figure 10) presents the performance of two measured zones, Y1 (yard) and P1 (pedestrian way), against the standard benchmarks. Notable insights include: In the Y1 zone, the E.avg value is 5.8 lux, which falls below the CIE 115 standard of 7.5 lux. The minimum illuminance is critically low (0.017 lux), and the uniformity ratio (Uo) is only 0.003, far below the standard threshold of 0.25. This suggests severe lighting inconsistency and potential safety concerns in both zones. In heritage areas such as Kayutangan, ensuring proper light distribution is essential not only for visibility and safety but also for preserving the visual coherence of the urban nightscape for heritage.

Furthermore, an extensive array of scholarly investigations has yielded substantial evidence indicating that the specific hue of illumination has a crucial influence on eliciting a diverse range of emotional responses, which play a significant role in determining how individuals interact with and perceive various architectural settings. In a thorough and meticulous study conducted by Li et al. (2022), it was revealed that the exposure of individuals to red light can incite a wide array of emotional reactions, which can span from profound feelings to concerns. P1 zone performs relatively better, with an E.avg of 11.7 lux, exceeding both standards. However, its minimum illuminance (0.65 lux) and uniformity ratio (0.056) still fail to meet the minimum requirements, indicating that lighting is not evenly distributed, despite sufficient overall brightness.

These findings emphasize the need for a more balanced and regulation-compliant lighting of tranquility to more pronounced states of tension and anxiety, thereby highlighting the complex and multifaceted dynamics between the color of light and the intricate psychological processes that govern human emotions. Within the discipline of architectural design, the thoughtful application of meticulously planned and strategically implemented lighting techniques can effectively enhance and emphasize key elements of a building's facade, which not only aids in the establishment of the desired atmospheric quality but also significantly contributes to the overall enhancement of both the aesthetic appeal and visual integrity of the constructed environment, underscoring the importance of lighting as a fundamental aspect of architectural practice.

Figure 11. PLN building 3D modeling for DIALux Evo 12.1 simulation

The graph shows all zones below the ideal outdoor lighting threshold. This confirms the urgent need for lighting redesign based on spatial and temporal simulations (figure 11). The advantage of using DIALux Evo 12.1 simulation in this study is its ability to identify weak points in the existing lighting system in detail. This software allows for accurate visual modeling of lighting conditions, including visualizing dark areas, uneven light distribution, and potential glare or inefficient over-lighting.

Based on the simulation, it can be seen that the facade areas of F1, F2, F3, T1, and T2 require comprehensive lighting intervention (figures 12 and 13). Improvement of the lighting system is important from a technical perspective and in the conservation aspect of cultural heritage buildings. Heritage building materials such as natural stone, wood, and stained glass are susceptible to inappropriate light exposure due to excessive intensity or uncontrolled distribution. Therefore, redesigned lighting interventions must simultaneously consider the principles of conservation, energy efficiency, and user comfort (Guerry et al. 2019).

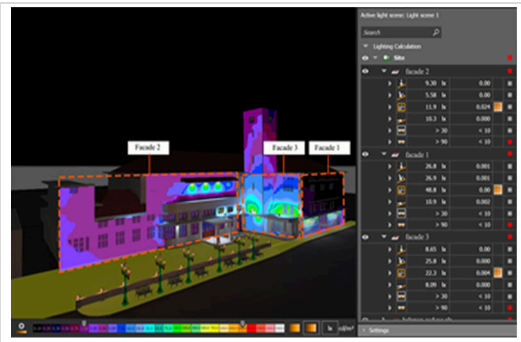

Figure 12. Characteristics of lighting visualization using DIALux Evo 12.1 simulation on facades and surfaces

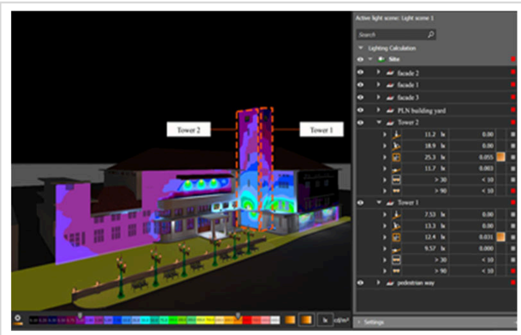

Figure 13. Characteristics of lighting visualization using DIALux Evo 12.1 simulation on a facade tower

In this context, lighting design recommendations include selecting the correct type of armature, using LED lights with lighting angle distribution according to zone needs, and implementing automatic sensors to adjust lighting intensity to the level of environmental brightness. With this approach, heritage buildings can maintain their historical and architectural value and improve their functional engenders the occurrence of what is referred to as "glare contrast," which is characterized by a stark and pronounced differentiation between zones that are excessively illuminated (overlit) and those that exhibit insufficient illumination (underlit); such disparities can severely highlight the urgent requirement for a considerably more thorough and detailed approach to the intricacies of lighting design, particularly within the context of heritage sites, while simultaneously stressing the critical importance of attaining a meticulously balanced and harmonious relationship in the levels of illuminance that not only elevate the architectural significance and aesthetic value of the structures in question but also enhance the overall quality of the experiential journey for individuals navigating through these historically rich and culturally important spaces.

Quality as safe and comfortable public spaces. Compromising the aesthetic integrity of the facade not only compromises the overall visual comfort experienced by individuals occupying the space, particularly in communal areas or transitional zones where movement between different environments occurs, but also results in the ramifications that stem from these significant findings.

Evaluation of light uniformity and distribution

The findings derived from the comprehensive lighting simulation conducted on heritage buildings reveal a significant discrepancy between the recorded maximum illuminance (lux) values and the minimum illuminance levels observed across each designated zone, thereby indicating a pronounced uneven distribution of light throughout the various areas of the structure (figure 14).

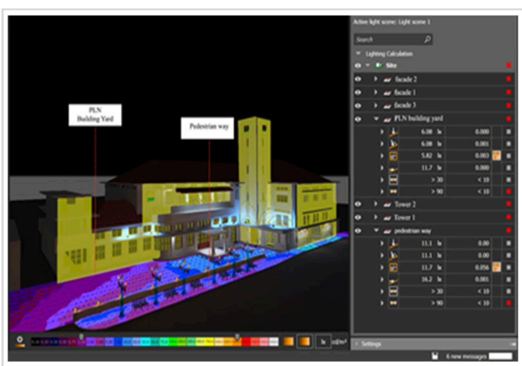

Figure 14. Characteristics of lighting visualization using DIALux Evo 12.1 simulation on pedestrian way and yard

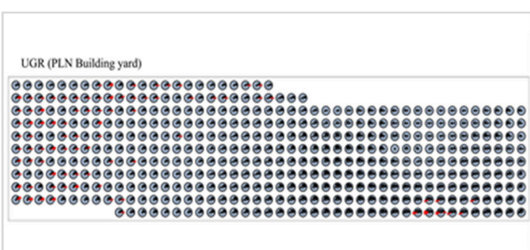

Figure 15. Surface Glare Distribution (UGR)

In this illustration, the eye symbol that is depicted in red signifies a particular region characterized by an elevated intensity of glare. In contrast, the gray symbol denotes an area where the glare intensity remains within acceptable tolerance thresholds, thereby suggesting less potential for visual impairment.

This is a notable imbalance. Figure 15 provides a comprehensive visual representation of the spatial distribution of glare as assessed through the Unified Glare Rating (UGR) methodology, which serves as a standardized approach for quantifying glare levels.

The simulation results of the outdoor lighting at the front yard of the PLN building indicate a significant level of visual glare. The Unified Glare Rating (UGR) in this area shows a maximum value exceeding 30, with the strongest glare detected at a viewing direction of 195°. This value suggests a high level of visual discomfort for pedestrians or visitors, especially when facing the lighting source from that direction. Although UGR is primarily used for indoor environments, it can also be applied in outdoor perception studies to evaluate user experience regarding lighting quality.

Figure 16. Surface Glare Distribution (GR)

Moreover, the Glare Rating (GR), more suitable for outdoor applications, exceeds 90, far above the recommended threshold of 50 based on EN12464 standards. This extreme glare level may result from exposure to intense light sources or improper luminaire orientation, reducing visual comfort and potentially hazardous conditions during nighttime use (figure 16). These findings highlight the necessity for reevaluating the lighting layout and intensity to improve the aesthetic and functional aspects of the PLN building's outdoor space.

Based on the measurement of the illumination value and visualization in figure 16, the average illumination value ($\bar{E}$) is 5.82 lux, with a maximum value of 50 lux, a minimum value of 0.0017 lux, and a uniformity value (Uo) of 0.003 lux. This shows the irregularity of the lighting distribution in the outdoor area of the building. According to the SNI 7391:2008 standard for outdoor transportation areas, the uniformity lighting should not exceed 0,25 lux. Thus, this area needs improvement to achieve the standard value.

The comprehensive analysis and subsequent findings that emerged from the extensive lighting simulation performed on heritage buildings unequivocally reveal a considerable and noteworthy discrepancy between the maximum illuminance (lux) values that were meticulously recorded and the minimum illuminance levels that were observed across each distinct and designated zone within the structure, thereby indicating a profoundly pronounced uneven distribution of light throughout the various areas of the architectural edifice (figure17).

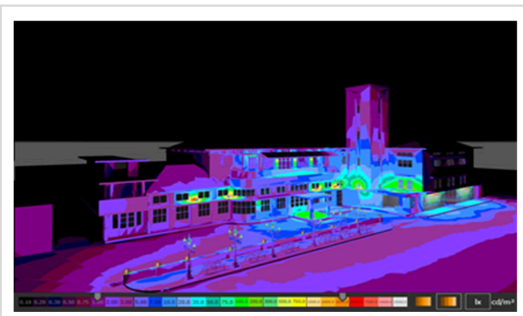

Figure 17. Visualization of simulation of light uniformity and distribution

This significant and notable imbalance not only engenders the occurrence of what is colloquially referred to as "glare contrast," but is also characterized by a stark and striking differentiation between zones that are excessively illuminated, often termed overlit, and those that exhibit a marked deficiency in illumination, which can be classified as underlit; such pronounced disparities can severely compromise not only the aesthetic integrity of the building's facade, but also adversely affect the overall visual comfort experienced by individuals who occupy the space, particularly in communal areas or transitional zones where movement between different environmental conditions frequently occurs.

Consequently, the profound implications of these findings underscore the pressing necessity for a more meticulous and thoughtful approach to lighting design within heritage contexts, thereby emphasizing the crucial importance of achieving a harmonious and well-balanced distribution of illuminance levels that not only enhances the architectural significance of the buildings in question but also significantly improves the quality of experience for users as they navigate and traverse these multifaceted spaces. In light of this analysis, it becomes increasingly evident that a thorough reevaluation of current lighting strategies in heritage sites is beneficial for preserving the historical integrity and the functional usability of such vital cultural landmarks.

In order to effectively tackle the complexities associated with this particular issue, it is of paramount importance to adopt a lighting methodology that is fundamentally centered around the principles of zoning, in conjunction with a meticulous recalibration of the placement of luminaires throughout the designated spaces. This sophisticated methodology necessitates a comprehensive modification of various factors, including but not limited to the quantity, category, and spatial arrangement of luminaires within each specific zone, all aimed at achieving a significantly more uniform and equitable distribution of light throughout the respective area.

Moreover, the strategic utilization of surfaces that exhibit elevated reflectance coefficients, such as ceilings that possess reflectance levels equal to or exceeding 85% and walls that maintain reflectance levels of 80% or higher, can substantially enhance the dispersion of light while concurrently reducing the dependency on additional light sources that may otherwise be required. The implementation of this multifaceted strategy not only serves to augment visual comfort and significantly improve energy efficiency, but it also plays a critical role in the preservation of the historical significance of heritage structures by effectively mitigating the potential for material degradation that could arise from the use of inappropriate lighting techniques. The presence of inconsistent light distribution within any given space strongly necessitates the adoption of a zoning-based lighting strategy coupled with a thorough recalibration of the positioning of luminaires, all in an effort to uphold the foundational principle of uniformity and to avert the occurrence of glare that may adversely affect the visual experience. It is, therefore, imperative to devise a comprehensive lighting system that places a premium on the principles of even light distribution, energy efficiency, and the conscientious conservation of buildings, particularly in the context of the management and preservation of heritage properties.

Towards smart and contextual lighting design: findings from Kayutangan case study

This study reaffirms the significance of integrating lighting simulation tools, particularly DIALux Evo, in evaluating the quality of nighttime illumination in heritage buildings. Simulations based on field measurements provide a valid foundation for heritage-sensitive lighting strategies, aligning with recommendations from (Valencia Pavón et al. 2024; Beccali et al. 2019), who emphasize simulation-based lighting optimization and public safety.

Findings indicate that several facade areas suffer from uneven light distribution and localized excessive glare. These conditions echo the findings of Żagan and Skarżyński (2020), who advocate for layered floodlighting techniques to accentuate architectural details without causing visual discomfort. In particular, the silhouette-based glare mitigation method described by Kobav, Bizjak, and Eržen (2023) can be considered relevant and applicable to the facade zones of the PLN building.

Moreover, for improved pedestrian comfort and wayfinding, the integration of contextual and spatially adaptive lighting is essential. This aligns with the findings of Burattini, Bisegna, and De Santoli (2025); Cantizani-Oliva, Bullejos, and Dorado (2024), who underscore the importance of lighting uniformity and directional control to improve nighttime spatial legibility in public areas. In this context, appropriate lighting contributes not only to user safety and comfort but also to preserving the architectural identity of heritage areas.

Lastly, future lighting interventions should consider sustainable urban lighting policies, such as those advocated by Méndez et al. (2024), which emphasize the need to balance aesthetics, environmental responsibility, and heritage conservation. The integration of smart lighting systems, daylight harvesting, and glare-reduction strategies is key to ensuring both visual quality and energy efficiency in the illumination of heritage sites.

Design implications for energy efficiency and smart lighting

The results of the lighting simulation with DIALux can be integrated into an adaptive and energy-efficient smart lighting design strategy. This system combines automatic sensors and light intensity control algorithms based on actual needs, such as user presence, time, and availability of natural light. This approach enables lighting responsive to environmental conditions, improves energy efficiency, and improves user visual comfort. A thorough study meticulously carried out by Zhao and collaborators in 2019 has provided substantial evidence indicating that deploying and utilizing adaptive lighting technology within various public spaces and environments can drastically reduce energy consumption rates by nearly 40%. This significant reduction in energy usage highlights the efficiency of such advanced technological solutions. It presents a compelling argument favoring their incorporation and integration into the broader framework of urban planning and development strategies. Furthermore, the findings of this investigation underscore the critical importance of embracing innovative energy-efficient technologies, as they can lead to more sustainable urban environments that are both economically viable and environmentally responsible in the long term.

This substantial reduction in energy usage not only contributes to lower operational costs associated with public lighting systems but also plays a pivotal role in promoting sustainability and minimizing the environmental footprint of urban areas. Consequently, the findings of this study underscore the importance of adopting advanced technological interventions in the pursuit of energy efficiency and ecological responsibility in communal spaces. This is achieved by integrating motion and light sensors that adjust the lighting intensity according to needs. Mardaljevic (2016) emphasized that daylight harvesting saves energy and improves the quality of the visual environment. Adaptive lighting systems with sensory control have been shown to simultaneously improve energy efficiency and visual environmental quality. Boyce (2014) stated that integrating presence and light sensors in lighting systems can significantly reduce energy consumption without sacrificing user visual comfort.

The implementation of this system also supports the goals of sustainability and energy conservation in buildings. Thus, the results of the DIALux simulation can be the basis for redesigning intelligent and energy-efficient lighting systems. Integrating motion, time, and natural light intensity sensors allows the lighting system to adapt to real-time environmental conditions and user needs. This approach improves energy efficiency and supports the conservation of heritage buildings by maintaining appropriate lighting quality.

Conclusions

The study concludes that the lighting performance of the PLN Building facade and pedestrian area is not aligned with established standards (CIE 94, SNI 7391), particularly in terms of uniformity and glare control. Simulation data highlights the urgent need for lighting redesign that incorporates zoning, appropriate fixture placement, and adaptive lighting systems for heritage contexts.

Based on the visual and numerical analysis results, it can be concluded that the exterior lighting of the PLN Building in Malang City still needs significant improvement. The average illumination value has not met the minimum standard, and the imbalance in light distribution causes some areas to be too bright while others are dark. In addition, high glare levels (UGR and GR) can cause discomfort to the environment users at several points. So, it can be recommended that: (1) Reposition or adjust the lighting armature to achieve a more even light distribution; (2) Use lamps with glare protection or special lighting hoods; (3) Use adaptive lighting technology or automatic sensors for energy efficiency and visual comfort.

This study shows that artificial lighting in the PLN Building as part of the Kayutangan heritage area is still far from optimal standards. Integrating DIALux simulation in evaluating lighting quality provides a strong basis for technical recommendations and visual conservation of cultural heritage buildings. More careful lighting design interventions are needed, based on the principle of bright lighting, to ensure visual quality and energy efficiency in heritage areas.

Conflicts of Interest

The author declares no conflict of interest.

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