

Article

Beyond Illumination: Stakeholder Perspectives on Urban Lighting Master Planning for Chiang Mai Old City, Thailand

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Abstract: Chiang Mai Old City, a cultural heritage site and major tourist destination in Thailand, has significant cultural capital but lacks a well-designed urban lighting system, limiting its nighttime development potential. This issue arises from the absence of an urban lighting master plan, a crucial tool for guiding the city's growth. The challenge lies in reconciling the diverse perspectives of stakeholders to create a comprehensive lighting master plan that meets shared goals. This research proposes a system dynamics approach to analyze stakeholder complexity. A qualitative, multi-stage method was employed, through in-depth interviews and focus groups with 60 stakeholders from three groups: government, professionals, and end users, to prioritize critical factors. Causal Loop Diagrams (CLDs) were used to illustrate the interrelations among those factors, leading to alternative scenarios for the lighting master plan's development. The findings demonstrate that safety and security is the top priority, followed by cultural and economic factors. Eleven reinforcing loops and two balancing loops are proposed through CLD visualization. This framework highlights the importance of a participatory process, advocating for a systematic and holistic approach where all stakeholders with diverse perspective collaborate side-by-side in the development of the urban lighting master plan for Chiang Mai Old City.

Keywords: urban lighting master plan; participatory planning; Causal Loop Diagrams (CLDs); systems thinking; sustainable urban design; stakeholder perspectives; lighting design; Chiang Mai Old City



Citation: Navaraj, P.; Inkarojrit, V. Beyond Illumination: Stakeholder Perspectives on Urban Lighting Master Planning for Chiang Mai Old City, Thailand. *Sustainability* **2024**, *16*, 9411. <https://doi.org/10.3390/su16219411>

Academic Editor: Georges Zissis

Received: 27 September 2024

Revised: 26 October 2024

Accepted: 27 October 2024

Published: 30 October 2024



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1. Introduction

Nighttime development has gained global attention as a key strategy to improve quality of life, revitalize the evening economy [1–4], enhance a city's image, and create competitiveness in night tourism [5–10]. Urban lighting, as a core infrastructure element, plays a crucial role in shaping the nighttime environment of cities. It addresses multiple levels of human needs such as providing safety and security that facilitate people to commute around the city [11–19], fosters social interaction [13,15,17,20,21], enhances cultural experiences, and promotes a city's unique identity [13,15,17,22,23]. These benefits stimulate economic activity by attracting tourists, creating jobs, and driving consumption in vibrant nighttime destinations [5–7,13,17,23,24].

As nighttime urban environments become increasingly complex, there has been a shift in urban lighting design from focusing solely on technical performance and aesthetics to adopting a more holistic paradigm [8,17,25]. This new approach incorporates a more complex broader range of considerations, including cultural, social, economic, well-being, and environmental factors [17,25,26]. Consequently, the need for a comprehensive urban lighting master plan has become essential for revitalization of a city.

A comparative study of 12 member cities of the Lighting Urban Community International (LUCI) Association highlights that successful urban lighting master plans share the same key significant element, which is the use of a participatory process involving diverse

stakeholders. This approach ensures more inclusive and informed outcomes by incorporating the knowledge, perspectives, and concerns of affected groups throughout the design, planning, and implementation stages [27]. However, engaging multiple stakeholders is challenging, as each tends to view the system from their own perspective, often overlooking unintended consequences or broader solutions [28]. To overcome these challenges, it is important to provide tools that enable stakeholders to understand the system holistically and recognize interdependencies. Effective methodologies and strong collaboration are crucial for achieving this comprehensive view [26].

In urban research, stakeholder engagement is essential for tackling complex challenges and developing sustainable solutions, especially for infrastructure projects which have a high diversity of stakeholders with conflict interest [29–31]. The participatory process plays a vital role in integrating cross-disciplinary insights by fostering collaboration across diverse stakeholder groups, which in turn offers different role and stages during the entire planning process [28,32,33].

To understand the diversity of the stakeholder perspective, Causal Loop Diagrams (CLDs) have been widely used as effective tools to transform unstructured insights into a systems dynamic approach. They are particularly useful for addressing the complexity of diverse factors and the interrelations raised by multiple stakeholders [28,34–38]. CLDs clarify relationships between key actors and their perspectives, providing a comprehensive understanding of the dynamics within the system [39] and facilitating more effective, holistic problem-solving. However, in urban lighting design, there appears to be limited direct research on applying CLDs specifically to this field. The nighttime urban environment is complex, influenced by factors that fluctuate with changing conditions. This complexity highlights the urgent need for a holistic understanding of the entire system, making the use of CLDs essential for effectively addressing the interconnected challenges of urban lighting design.

Chiang Mai Old City is an important tourism destination in northern Thailand. Its rich cultural heritage presents significant opportunities for enhancing cultural identity, economic development, and tourism [40–43]. Currently, Chiang Mai Old City holds the title of a Creative City for Crafts and Folk Art, recognized by UNESCO, and the city is pursuing a potential nomination as a UNESCO World Heritage Site [42,44]. While previous research has suggested that most visits occur during the evening and nighttime [45], nevertheless, the city's nightscape planning has received less attention. Results from the preliminary survey reveal deficiencies in nighttime lighting infrastructure, particularly in areas such as roads, alleys, and public open spaces (see Figure 1). These deficiencies impact public perceptions of safety and obstruct the visibility of cultural elements and architectural features. As a result, this diminishes the city's ability to foster community pride and fully leverage its nighttime potential [46].

Urban lighting design is widely recognized as a powerful tool for celebrating and enriching the nighttime environment [47], creating placemaking and city characterization [48–50], and evoking emotional connections that strengthen the bond between people and the city [11,51]. The absence of a comprehensive urban lighting master plan represents a significant gap in Chiang Mai's ability to fully utilize its nighttime potential. This gap presents a valuable opportunity for this study to explore and address the complex lighting issues from the perspective of stakeholders, using Chiang Mai Old City as a case study.

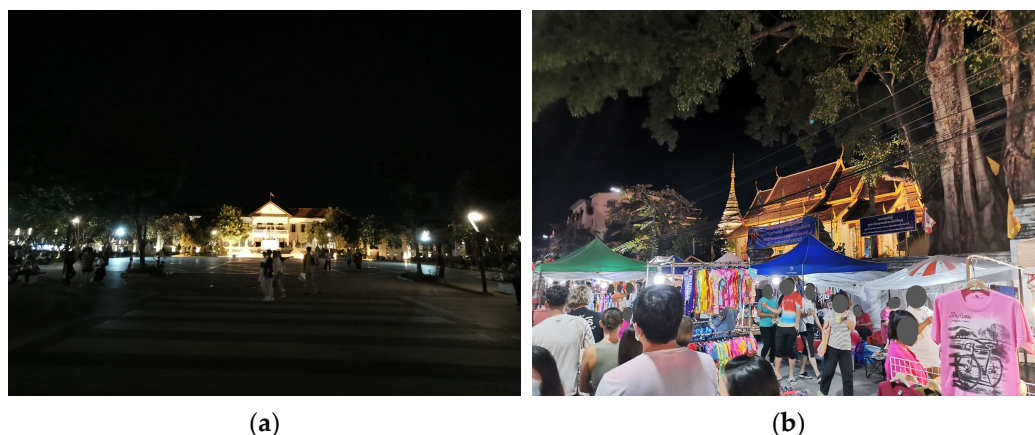


Figure 1. Examples of current urban lighting condition in Chiang Mai Old City: (a) Three Kings Monument Plaza, a civic space of Chiang Mai Old City, and (b) Rachadamnoen Road weekend walking street, the main axis of Chiang Mai Old City. (Images were taken by authors on 15 October 2023).

This study has three objectives. Firstly, it aims to identify and prioritize the critical factors for developing an urban lighting master plan for Chiang Mai Old City by using a qualitative multi-stage method to collect diverse stakeholder perspectives from in-depth interviews and focus groups. Secondly, it seeks to visualize the complex interrelationships between various factors from stakeholders by using CLDs for a deeper understanding of the cause-and-effect interrelation to propose possible thematic clusters and initial scenarios as a strategic model for an urban lighting master plan towards sustainable development. Lastly, the study will discuss the broader applicability and flexibility of this approach to other cities by offering a framework for developing urban lighting master plans in cultural heritage contexts.

Overall, this research offers a holistic approach to urban lighting master planning by utilizing CLDs for systemic analysis. The study provides a comprehensive framework for addressing the complex dynamics of lighting design in cultural heritage cities like Chiang Mai Old City. Moreover, it presents a flexible solution that can be adapted to other cities, promoting sustainable urban development through inclusive stakeholder's participatory process.

2. Literature Review

2.1. The Paradigm Shift in Urban Lighting Master Planning

In the early stage of urban lighting design, the focus was primarily on technical considerations. Urban lighting handbooks and standards have long been approached primarily from a technical perspective. Early editions of lighting handbooks and standards often focus predominantly on technical aspects such as light quantity, visual performance, and infrastructure durability. This technical approach aimed to ensure adequate illumination and performance but often overlooked aesthetic that enhances a city's attractiveness and stakeholder engagement.

Over time, lighting practice has shifted from a focus on engineering illumination to more emphasis on lighting design, moving away from illuminance calculations towards aesthetic considerations and quality of lighting [52–56]. As argued by the International Commission on Illumination (CIE) [57], functional lighting, designed primarily for safety and utility, often lacks visual appeal. The focus evolved to include expressive elements such as beautification, harmony, and identity creation. This transition began in the early 1990s when French lighting designers, notably from the Association des Concepteurs Lumière et Éclairagistes (ACE), began integrating cultural and aesthetic considerations into their designs [26].

Strategic urban lighting master plans emerged, aimed at enhancing the urban nightscape atmosphere contributing to city beautification [52,57]. These master plans, which were widely

adopted across the UK, Europe, North America, and Asia, not only addressed future lighting needs but also served as marketing tools to attract funding for their implementation. For example, the Edinburgh Lighting Vision Plan aimed to boost the Scottish capital's tourism economy beyond the busy summer season by focusing on key visual elements such as gateways, nodes, skylines, topography features, vistas, and historical zones, all of which helped create a coherent nighttime identity for the city, create a sense of arrival, and prioritize visual performance [52].

Nevertheless, criticisms arose regarding the narrow focus of earlier plans, which either emphasized functional lighting or highlighted architectural landmarks without considering the broader context [58]. This critique highlighted the need for a more holistic approach to urban lighting master planning, one that integrates nocturnal landscapes, pedestrian-friendly environments, and environmental considerations such as energy consumption and ecological impact [17,57,58].

The most recent shift in urban lighting design places people and social dynamics at the center. This human-centric paradigm extends beyond technical performance and aesthetic considerations, incorporating a broader interdisciplinary perspective that integrates lighting engineering with urban design and architecture to enhance human experiences [17,25]. Zielinska-Dabkowska and Bobkowska [17] highlight this shift towards prioritizing human needs over traditional factors such as infrastructure and city mobility. This shift emphasizes improving pedestrian experiences and fostering environmentally responsible, sustainable urban environments [20] as a more holistic approach to urban lighting master planning [59]. The CIE [57] supports this broader approach, advocating for comprehensive lighting master plans that harmonize all lighting elements within the urban nightscape. These plans balance visual objectives with legislative, managerial, and economic considerations while addressing energy consumption and light pollution, aiming to achieve an optimal balance between functionality and aesthetic appeal.

Recently, Peña-García et al. [60] identify a gap in recognizing how contextual factors interact with lighting to influence outdoor lighting outcomes. They propose the Basic Process of Lighting (BPL) framework, which integrates human factors by assessing the effects of public lighting on well-being and emotions. Their research indicates that social factors have a significant impact on well-being compared to physical and visual factors, highlighting the need for a deeper understanding of how lighting design affects human experiences and social dynamics.

To understand the relation of human perception and expectations towards the urban lighting, the Society of Light and Lighting (SLL) [56] integrates Maslow's hierarchy of needs [61] to evaluate how lighting contributes to various needs, from basic physiological requirements to higher-order psychological and self-fulfillment needs. Recent research has applied this framework to lighting design. For example, Boyce [13] utilized Maslow's hierarchy to demonstrate that nighttime lighting addresses fundamental human motivations, arguing that urban lighting should not only fulfill basic needs but also evolve in alignment with the ascending levels of Maslow's pyramid.

Frutos et al. [11] explored how lighting design fosters a sense of belonging, identifying lighting as a generator of atmosphere. Properly designed lighting can create optimal conditions for social interaction, making spaces more attractive and encouraging people to return and spend more time. Moreover, lighting can serve as a symbol, reflecting collective memories through personal, group, and cultural processes. Additionally, Turekulova et al. [12] assessed how lighting correlates with human needs and emotions using a morphological analysis with a cross-consistency assessment method. Their evaluation criteria, based on Maslow's pyramid, considered the effects of light on different levels of needs. This approach highlights the importance of integrating lighting design with a comprehensive understanding of human needs, enhancing both functionality and emotional impact in urban spaces.

Despite an increasing use of the Maslow's hierarchy framework in lighting design, its application to large scale urban lighting master planning remains underexplored. Figure 2

illustrates the connection between Maslow’s hierarchy framework and urban lighting design, which could provide a comprehensive framework for urban lighting master plans.

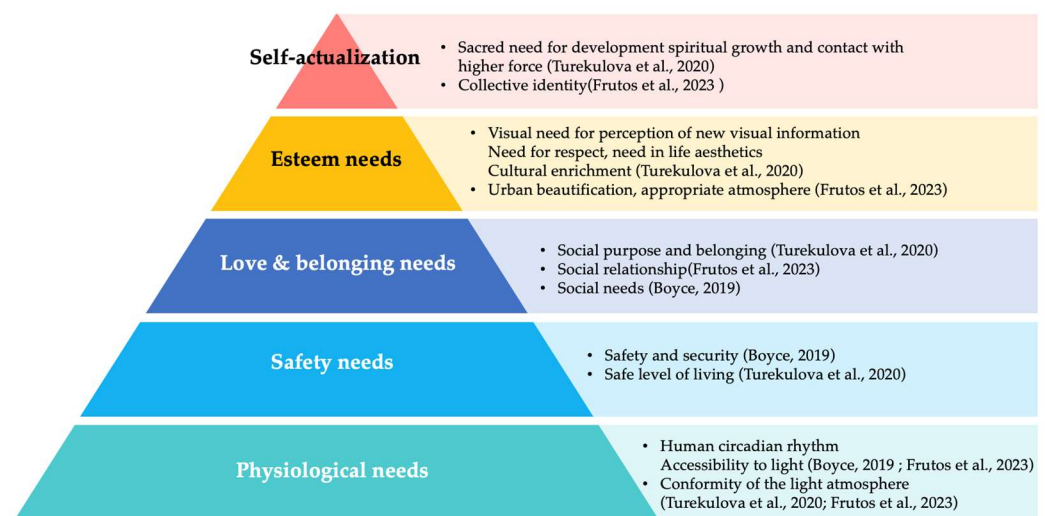


Figure 2. The connection between Maslow’s hierarchy of needs framework [61] and previous studies on urban lighting design [11–13]. Source: Authors.

2.2. Factors in Urban Lighting Master Plan Development

Regarding the current shift towards a human-centric paradigm in urban lighting master planning, Zielińska-Dabkowska and Bobkowska [17] identified eight key aspects of urban lighting in sustainable cities. In this research, these eight aspects serve as the base framework for analysis. A literature review is conducted to expand upon these aspects, providing a deeper understanding and detailing their scope. Table 1 provides a summary of urban elements and lighting benefits for each factor.

Table 1. The various factors identified by different lighting researchers.

Factor	Researcher	Urban Element	Lighting Benefits
Safety and security	Johansson et al. [16,62] Böhme [15] Boyce [13]	Movement (motorized and pedestrian) Footpath	Detection of obstacles or surfaces Visual orientation Wayfinding
	Zielinska-Dabkowska and Bobkowska [17] Portnov [18] Himschoot et al. [19]	Social activity (Public space) Property Signage	Facial recognition Lighting comfort Reassurance Universal design Brightness and darkness contrast
Social	Boyce [13] Entwistle and Slater [20] Zielinska-Dabkowska and Bobkowska [17] Böhme [15] Bille [21]	Public space (Civic space and park)	Perception Space population Usage Experience Atmosphere
Economy	Boyce [13] Schulte-Römer et al. [24] Zielinska-Dabkowska [63] Giordano [23]	Public space (Civic space and park) District	Attraction Experience Convivial
	Zielinska-Dabkowska and Bobkowska [17] Böhme [15] Huang and Wang [9]	Streetlighting Private property	Entertainment Festival

Table 1. Cont.

Factor	Researcher	Urban Element	Lighting Benefits
Cultural and heritage	Böhme [15]		Sense of place
	Edensor and Milington [22]	Historical place	Sense of belonging
	Edensor [64–66]	Architectural feature	Narrative
	Giordano [23]	Privilege social space	Storytelling
	Zielinska-Dabkowska and Xavia [67]	Heritage and commercial centers	Sensation
	Boyce [13]	Façade	Carving and texture
	Schulte-Römer et al. [24]	Monument	Place identity
	Zielinska-Dabkowska and Bobkowska [17]	Structures	Atmosphere
		Artefacts	Ambience
			Light phenomena
			Relative proximity
			Viewed from a distance
Well-being	Veitch [68]		
	Boyce [13]		
	Entwistle and Slater [20]	Streetlighting	Circadian lighting
	Zielinska-Dabkowska and Bobkowska [69]	Private property (Façade and advertisement)	Lighting pollution
	Zielinska-Dabkowska and Xavia [70]	Historical place	Responsible lighting
	Zielinska-Dabkowska and Bobkowska [17]	Architecture	
	Pérez Vega et al. [71]	Community	
Environment	Pérez Vega et al. [71]		Lighting pollution
	Schulte-Römer et al. [24]	Night sky	Responsible lighting
	Hölker et al. [72]	Landscape	Light source
	Zielinska-Dabkowska and Xavia [70]	Streetlighting	Lighting level
	Zielinska-Dabkowska and Bobkowska [17]	Public space (Civic space and park)	Curfew
			Sensor and timer
Technology	Böhme [15]		LED
	Ebbensgaard [73]		Smart system
	Giordano [23]		Public space
	Entwistle and Slater [20]	Streetlighting	(Civic space and park) Control system
	Zielinska-Dabkowska et al. [74]	Private property (Façade and advertisement)	Big data
	Zielinska-Dabkowska and Xavia [70]		Human-centered lighting
	Cellucci et al. [75]		Curfew
	Pérez Vega et al. [71]		Sensor and timer
	Zielinska-Dabkowska and Bobkowska [17]		
Regulation	Pérez Vega et al. [71]	Movement (motorized and pedestrian)	Lighting pollution
	Zielinska-Dabkowska et al. [74]	Private property (Façade and advertisement)	Participatory Organization
	Zielinska-Dabkowska and Bobkowska [17]		
	Dufner et al. [25]		

2.2.1. Safety and Security

Urban lighting's primary function is widely recognized as ensuring safety and security for both motorists and pedestrians by enhancing visual performance [52,53,55]. Adequate lighting fosters a sense of safety and boosts confidence for individuals venturing outdoors after dark [13,16,19,76]. Previous studies [16,62] identified four critical objectives of pedestrian lighting: detecting obstacles such as uneven surfaces, facilitating visual orientation for reading street signs, enhancing facial recognition for social comfort, and ensuring overall pedestrian comfort.

The preference for lighting plays a crucial role in enhancing a sense of safety [18]. Himschoot et al. [19] suggested that higher light intensity generally enhances feelings of safety more than light color does, recommending amber lighting as a balance between safety benefits and minimizing negative impacts on wildlife, night vision, and circadian rhythms. Böhme [15] supported that well-lit areas promote feelings of security and freedom, as illuminated spaces create a sense of safety by clearly defining boundaries and reducing

exposure to potential hazards. In contrast, darker, undefined areas can be perceived as dangerous, heightening the perceived risk.

This foundational aspect of urban lighting extends to various additional benefits for the city. Boyce [13] also emphasized that effective urban lighting not only improves safety but also offers social and economic benefits.

2.2.2. Social

Lighting is not only a functional tool but also plays a vital role in shaping social spaces, enhancing urban livability, and fostering social connections among diverse communities. Entwistle and Slater [20] emphasize how light influences social diversity and interactions by shaping spaces through both technical and aesthetic design, highlighting its transformative role in urban environments. Böhme [15] expands on this, suggesting that space is not merely defined by physical structures such as walls, balconies, or stone cornices, but by the interplay of light, alignment, and perspective. Illumination significantly affects how individuals perceive and experience space, with light actively creating environments that shape our social interactions. Bille [21] supports this by framing light as an ambient quality that surrounds and defines space, rather than merely illuminating it. Boyce [13] emphasizes the social value of lighting, noting how it extends daily activities by enabling social interactions after dark.

2.2.3. Economy

Urban lighting plays a pivotal role in driving the nighttime economy by extending business hours and fostering social engagement in public spaces, particularly in tourism, retail, and hospitality sectors, contributing to a city's overall liveliness and economic resilience. Boyce [13] emphasizes that effective lighting not only enables businesses to operate around the clock but also encourages people to gather and participate in social activities after dark. This aligns with Schulte-Römer et al. [24], who highlight how lighting creates vibrant and dynamic environments that draw in shoppers, diners, tourists, and nightlife enthusiasts, thereby boosting economic activity. Giordano [23] further stresses the strategic use of urban lighting in revitalizing nighttime economies and promoting tourism.

The second scope relates to temporary or event-based lighting, such as in the context of light festivals. Böhme [15] highlights how illumination can enhance features such as public art, tourist attractions, and light festivals, adding a crucial dimension to space and creating an atmosphere of spectacle and engagement. This approach aligns with Zielinska-Dabkowska's [63] previous study that lighting festivals, such as the Fête des Lumières in Lyon or the Biennale of Lighting Culture, Frankfurt, serve not only as cultural events but also as economic tools to attract tourists, using advanced lighting technologies like 3D mapping and projection.

2.2.4. Cultural and Heritage

In the context of cultural and heritage aspects of urban lighting, Böhme [15] emphasizes that the phenomenology of light significantly influences how spaces are perceived, contributing to emotional experiences tied to urban environments. Edensor [64] suggests that defamiliarization through illumination can transform familiar places, making them seem both new and profound. This approach enhances the sense of place by offering diverse sensory and symbolic experiences that connect people with historical narratives and cultural contexts.

Zielinska-Dabkowska and Xavia [67] highlight the importance of nighttime illumination in enhancing the visual and cultural identity of urban settings, particularly in cities dependent on heritage tourism. Effective lighting not only showcases architectural and historical elements but also enriches the spatial experience for residents and visitors. They advocate for the use of appropriate lighting technologies and professional expertise to ensure that the unique character of a place is highlighted harmoniously and sensitively.

This includes maintaining and preserving monuments, archaeological sites, and historic urban settings to retain their cultural significance during the night.

Zielinska-Dabkowska and Bobkowska [17] further argue that decorative urban lighting should enhance the appreciation of built heritage by sensitively illuminating facades, monuments, and other structures, thus giving them distinct identities after dark. Giordano [23] points out the growing emphasis on sustainable and innovative lighting designs in cultural-led regeneration strategies. This approach aims to foster a renewed commitment to adopting technologies that support the cultural and economic vitality of cities. Overall, the integration of lighting into cultural heritage strategies requires a balanced consideration of aesthetic, emotional, and functional aspects to create vibrant and meaningful authenticity.

Urban lighting plays a vital role in shaping the identity and atmosphere of a place. Edensor [64,65] emphasized that the interplay between light and darkness not only defines how we perceive space but also shapes how we experience it, as lighting reveals various dimensions of space. Color and illumination can alter perceptions, creating distinct sensory experiences.

Böhme [15] described urban atmospheres as being “staged” by designers and advertisers, much like scenes in a theater. This staging is reflected in how cities use lighting to balance attractions, control their image, and enhance beauty and entertainment. Meanwhile private property lighting, such as from facades and advertisements, plays a significant role in this balance, influencing the city’s overall aesthetic [13]. Media displays and glass facades further contribute to the visual appeal of cities at night, helping to highlight architecture and skylines in ways that reinforce urban identity and branding strategies. This strategic use of lighting not only beautifies urban spaces but also contributes to the process of “place-making” [9,24], where lighting helps define a city’s character and its appeal to both residents and visitors.

2.2.5. Well-Being

The relationship between light and human health, particularly in relation to the circadian system, has led to a growing concern in lighting design, where the focus is shifting beyond vision to include human well-being [68]. Entwistle and Slater [20] highlight the impact of artificial lighting on circadian rhythms and overall health. Artificial illumination can disrupt sleep and contribute to health problems such as unwanted light trespass and spill light from outdoor sources infiltrating homes which can lead to insomnia and hormonal imbalances [17,67,69,72]. As cities transition from sodium lamps to LEDs, the extent of our exposure to artificial light is increasing. This shift emphasizes the need for new strategies and technologies to address these issues. Raising public awareness about lighting problems is crucial, and both researchers and lighting professionals must communicate these challenges effectively.

Veitch [68] emphasizes that effective lighting should address not just visual performance but also spatial aesthetics, safety, and overall human well-being. This perspective marks a significant shift from earlier lighting design principles, which primarily prioritized visual performance. According to the IESNA [54] lighting handbook and discussions from the First CIE Symposium on Lighting Quality in 1998 [77], modern lighting design now encompasses three key dimensions: visual performance, spatial appearance, and individual well-being.

Lighting plays a crucial role in well-being; for example, excessive glare and flicker can disrupt eye movements, reduce visual comfort, and lead to headaches and eyestrain. Conversely, insufficient lighting can also negatively impact health, potentially contributing to mood disorders. This evolving understanding pointed out the importance of designing lighting solutions that cater to the diverse needs of individuals and promote both functionality and health [68].

2.2.6. Environment

In recent decades, lighting professionals have significantly altered nighttime environments by illuminating streets, buildings, landscape, advertising lighting, and skyglow continuously [72]. This shift has prioritized visual appeal for visitors over the preservation of natural nightscapes. Consequently, this had led to unnatural brightness and color changes, which are now recognized as environmental pollutants which affect terrestrial and aquatic habitats; for example, this affects places like New Zealand where preserving natural nocturnal landscapes is crucial due to the unique native flora and fauna [67,71].

Schulte-Römer et al. [24] highlight the growing awareness of lighting as an environmental issue affecting both humans and animals. The negative impacts of ALAN, such as reduced visibility of starry skies, are often subtle and challenging to prove. The shift to energy-efficient LED lighting, particularly those emitting cold-white light with higher blue wavelengths, exacerbates these issues. Zielinska-Dabkowska and Xavia [70] also proposed effective strategies, including using fully shielded fixtures, selecting appropriate light sources with safer color temperatures, and implementing controls such as curfews and automatic sensors. These measures can enhance urban safety, improve environmental quality, and protect natural areas. Moreover, the built environment can gain from emphasizing nocturnal placemaking by intentionally leaving some areas unlit as dark sanctuaries for wildlife.

2.2.7. Technology

The rapid evolution of lighting technologies has led to increased unnatural brightness and varied light colors across urban landscapes [71]. This proliferation of artificial light has significant implications for both the environment and public health. Many cities are adopting new technologies in their lighting strategies and master plans to reduce costs and emissions while fostering the development of “smarter” cities [73]. Technological advancements in lighting have dramatically expanded the range of options and effects available. As noted by Entwistle and Slater [20], innovations such as LEDs, advanced control systems, and big data applications have enhanced human-centered lighting design. Böhme [15] highlights that modern light-generating and control technologies offer a diverse array of lighting possibilities and effects.

It is apparent that urban lighting should prioritize energy efficiency by using energy-saving light sources, luminaires with optimized optical design, appropriate light spectra, and smart control systems. Pérez Vega et al. [71] emphasize the collaboration between researchers and industry professionals, including those in remote sensing and lighting technology, is crucial for developing and implementing effective lighting control measures. These collaborations often occur through new platforms such as conferences and technical committees, which facilitate the exchange of knowledge and the advancement of lighting technologies.

It should also support circular economy principles by reusing and recycling lighting equipment. Additionally, incorporating renewable energy sources, such as solar power, is vital for urban illumination. Furthermore, Zielinska-Dabkowska et al. [74] note that the rise of digital tools, like online petitions, has sparked a new wave of citizen action aimed at reducing the impacts of light pollution. Results, in terms of energy efficiency and lighting quality, show that approaches could be feasible and environmentally friendly at the same time [75].

2.2.8. Regulation

Effective regulation of urban lighting is becoming increasingly important as it intersects with a range of environmental, health, and social concerns. Pérez Vega et al. [71] highlight the critical role of collaborative frameworks involving key stakeholders such as urban planners, landscape designers, policymakers, and environmental experts in creating and enforcing comprehensive urban lighting regulations. These collaborative efforts help

set sustainable short- and long-term goals for lighting master plans, ensuring that lighting strategies are not only functional but also environmentally and socially responsible.

Current policies and regulatory frameworks should be reassessed to support prototyping, innovation, and human-centered design. Lighting design considerations must be integrated early in project planning to ensure alignment with broader city development goals. As it becomes more complex, the need for sustainable, inclusive, and contextually sensitive development grows [25].

Zielinska-Dabkowska [69] points out that healthy lighting design is becoming an ethical concern, with legal actions, such as those in Monterey, California, challenging inappropriate LED lighting practices. Consequently, Zielinska-Dabkowska and Bobkowska [17] emphasize the need for urban lighting to be regulated through both soft and hard laws, with ongoing monitoring to mitigate artificial light pollution and its adverse effects.

In conclusion, the eight factors are commonly mentioned by lighting researchers as key elements for developing urban lighting master plan. The literature review reveals the interrelated nature of these factors, demonstrating the complex cause-and-effect relationships that influence urban lighting design. Each factor affects the others, reinforcing the need for a holistic approach to developing an effective urban lighting master plan. Understanding these dynamics is crucial for creating comprehensive and impactful urban lighting strategies that address functional, aesthetic, and societal needs. However, prioritizing these factors requires active stakeholder engagement throughout the design and planning process. Both CIE [57] and ILE [52] emphasize the importance of balancing lighting requirements for various user groups, which is crucial during the development of urban lighting master planning.

2.3. Stakeholders in Urban Lighting Master Planning

Stakeholders refer to individuals, groups, or organizations that have an interest in, or are affected by, the decisions, actions, or outcomes of a project. Effective management of stakeholders is critical to a project's success, as inadequate strategies, plans, methods, and processes for stakeholder engagement can result in project failure [29].

In the urban design and planning process, the analysis of stakeholders' being used as a research tool in the development of the urban decision-making process [31], it is crucial to involve stakeholders to ensure that their needs and preferences are considered [29,30,78]. Various stakeholder groups each responsible for different roles and stages throughout the planning process [28,32,33] have distinct short-term and long-term expectations, with different beneficiaries receiving value at each stage [31]. However, a significant challenge is that each stakeholder views the system from their own unique perspective. Stakeholders may overlook unintended consequences outside their limited view of the system, and they may only consider solutions within these perceived boundaries [28]. This occurs because decisions are often shaped by narrow viewpoints.

In an urban lighting master plan, the dynamics of urban life after dark must be tackled within a broader social, economic, and environmental framework. Lighting must be integrated as a core component of urban planning policy rather than treated as a separate initiative or strategy. This integration should recognize the significant impact lighting has on the nighttime experience and the interconnectedness of lighting with urban design, human experience, and other practices [8,25]. As lighting becomes more complex, the need for sustainable, inclusive, and contextually sensitive development grows. Stakeholders, defined broadly as individuals or groups with an interest or stake in the outcome of a project, are essential to the urban design process and bring diverse perspectives that contribute to more balanced and effective planning outcomes [25,57].

The role of stakeholders in urban nightscape has gained increasing recognition in recent years since the rapid pace of urbanization [8,25]. A successful urban lighting master plan is impossible without effective stakeholder collaboration and a shared vision to create a vibrant urban space for its users [74]. Collaboration is essential for generating innovative and suitable lighting solutions for urban areas after dark. Planning a cohesive urban

nightscape is challenging due to the involvement of multiple actors with varying levels of expertise, cultural influences, and objectives, ranging from government departments to individual property owners [57].

According to CIE [57], the development of urban lighting requires the collaboration of multiple stakeholders who are interested in improving and implementing lighting strategies. These stakeholders may differ depending on the region, but the core principle is to involve and gain the support of any organization, group, or individual that can influence or contribute to the lighting development process. It is essential to anticipate and address potential objections by ensuring the inclusion and consideration of all relevant stakeholders' perspectives, which CIE divided into the consultation group.

The LUCI Association stresses the importance of fostering cooperation between the public and private sectors, ensuring that all stakeholders, including light producers and citizens, understand the significance of the nightscape's quality and identity, as well as their shared responsibility in shaping it [27]. This awareness could promote the development of a genuine "local culture of light". Similarly, ARUP [25] emphasized the importance of collaboration across disciplines, stakeholder groups, and management systems. Lighting designers should take a more proactive role in creating socially sustainable environments by encouraging stakeholder collaboration, leveraging shared knowledge, and building interdependencies. Meanwhile, a strategy for managing light ownership should harmonize both private and public lighting sources. Additionally, citizens and stakeholders should be involved in the design and decision-making processes to better understand public and business needs.

In the design and planning process, another significant group of stakeholders, the professional group, has been identified. This consists of the designer and technical team, who possess a unique combination of lighting skills and/or project knowledge that enhances the possibility of delivering successful solutions on different levels of responsibility for a public realm in the city. Previous research also pointed out the rising role of designer, stating that it is crucial to recognize the urban designer's position within the power hierarchy of stakeholders who are invested in the implementation of design and urban development, and to understand whose interests the design is intended to serve [79,80]. Rather than imposing solutions, designers are increasingly working alongside communities to create new modes of participation, helping to harness and extend local resources through collaborative initiatives.

Various literature sources provide insights into how these stakeholders are categorized, emphasizing the importance of their engagement at every stage. Table 2 outlines the key stakeholders identified in several important studies on urban lighting master planning.

Table 2. Identification of key stakeholders from previous studies on urban lighting master planning.

Literature and Paper	Group	Stakeholder Details	Focus
A guide to urban lighting master planning CIE 234:2019 [57]	Consultation group	National Government Local Government Local Government Departments Non-Governmental Organizations (NGOs) Building Owners and Associations Professional Institutes or Societies Private Companies	Government sector Professional End user

Table 2. Cont.

Literature and Paper	Group	Stakeholder Details	Focus
Urban lighting master plan—origins, definitions, methodologies and collaborations. Zielinska-Dabkowska [26]	Professional group	Urban planner/designer Architect, Landscape architect, Architectural lighting designer Light artist Engineer Transport planner Consultant/specialist Researcher Cost consultant quality surveyor Manufacturers Contractors User’s representative	Professional End user
Rethinking Sustainable Cities at Night: Paradigm Shifts in Urban Design and City Lighting Zielinska-Dabkowska and Bobkowska [17]	Key actors	Client Designer in the built environment Contractor End user	End user
Exploring Nightscape LUCI Associate [27]	Public-private cooperation	Public stakeholder (Municipality) Private stakeholder Light producer Citizen	Government sector Professional End user
Lighting in the Urban Age Meaningful design for cities, people and place ARUP [25]	Stakeholder groups	Public sector Lighting designer Private sector Citizen	Government sector Professional End user

Table 2 illustrates that while each source of literature focuses on stakeholder engagement from different angles, a consistent pattern emerges across the studies. Stakeholders can be broadly categorized into three main groups: the government sector, professional sector, and end users. The government sector includes national and local governments, and municipal departments, which play a regulatory and policy-driven role in urban lighting development. The professional sector comprises urban planners, architects, lighting designers, engineers, and other technical experts responsible for designing, implementing, and maintaining lighting systems. Finally, the end users group encompasses residents, businesses, tourists, NGOs, and citizens who directly interact with and experience the city’s nighttime environment.

Together, these groups encapsulate the full range of perspectives required to develop a well-rounded urban lighting master plan. Their combined input ensures that the plan addresses regulatory requirements, technical feasibility, and public satisfaction, making them representative of the city’s diverse stakeholder landscape.

Each stakeholder plays a different role and holds varying responsibilities in the collaborative planning process. Stakeholder importance can vary across different stages of the planning process, from design and planning to implementation, monitoring, evaluation, and ongoing maintenance. Although the goal is to involve a broad range of stakeholders throughout all phases, this evaluation helps to understand participants’ varying motivations, levels of willingness to engage, power dynamics, influence, and interests at each stage.

2.4. Participation in Urban Master Planning

Traditionally, urban planning and design followed a top-down approach, where planners, viewed as “the experts”, developed proposals which were then presented to decision-makers. These decision-makers held the authority to approve or reject the proposed urban plan [81,82], which led to the top view implementation that was disconnected from public participation.

Nowadays, this sits in direct contrast to participatory planning, which emphasizes the involvement of concerned stakeholders as a bottom-up approach which has gained increasing popularity as it encourages the involvement of a larger number of stakeholders, allowing for collective decision-making from joint participation [81–83]. However, it also presents challenges, as diverse stakeholders often bring specific concerns and interests, which can lead to conflicts. These conflicts may, in turn, cause delays in the planning and implementation process.

2.4.1. Urban Design and Planning Participation

Arnstein's Ladder of Citizen Participation [84] is a foundational framework in the study of public involvement in decision-making processes. It offers a critical perspective on the varying degrees of citizen engagement and highlights how different levels of participation impact the effectiveness and equity of decision-making. However, its simplistic and linear structure as well as overemphasis of power dynamics have led to criticisms of its limitations and inadequacies for fully grasping the complexities of participation, both conceptually and in practical terms [85,86].

Since then, stakeholder participation has been developed in various theories and frameworks across disciplines, especially in urban design and planning. For example, Friedmann proposed Transactive Planning, which focuses on the interactive process where knowledge is not just transferred from experts to the public but co-created through ongoing engagement. Habermas' Theory of Communicative Action [87] underpins many participatory approaches by emphasizing the role of communication and deliberation in democratic processes wherein stakeholders should engage in discourse free from coercion, leading to the best argument prevailing rather than the most powerful voice.

Freeman's stakeholder theory [88] emphasizes the need for organizations to consider the diverse interests of all stakeholders and recognizes the interconnectedness of their actions and the broader social and environmental systems in which they operate. Supported by Wenger's Communities of Practice [89], it emphasizes stakeholder participation as a process of collective learning with a shared interest in a particular domain that comes together to exchange knowledge, develop new ideas, and build shared practices.

In addition, Innes and Booher's Collaborative Rationality [90] raises an alternative to traditional rational planning models, emphasizing the importance of deliberative processes where stakeholders engage in open dialogue, negotiate differences, and co-create solutions. This suggests that effective planning in complex environments requires the collaboration of multiple stakeholders with diverse perspectives and collective wisdom that leads to more robust and acceptable outcomes.

2.4.2. Participation in Urban Lighting Design

In urban design and planning, there has been a clear shift from traditional linear, hierarchical approaches to more co-creative and holistic processes that emphasize communication and deliberation. Similarly, in urban lighting, Zielinska-Dabkowska and Bobkowska [17] introduced a new design approach called "side-to-side", which promotes multidisciplinary and interdisciplinary collaboration to enhance communication among stakeholders. The traditional linear, top-down approach to urban lighting typically involves creating a brief, which is then developed into a document and executed without ongoing communication or checks throughout the process. Moreover, end users are often only involved in the later stages of design, limiting their ability to provide input or influence the project. This approach lacks tools for capturing and communicating user feedback and social satisfaction.

To address these limitations, the Iterative Urban Lighting Design Process, which focuses on collaboration among a wide range of stakeholders who work together towards shared goals and interests, has been proposed. This iterative process gives all participants an equal role, fostering open communication, collective decision-making, and the development of appropriate solutions. The iterative design method involves multiple rounds of analysis and feedback, with each iteration aimed at refining decisions and improving outcomes.

This approach breaks down complex urban lighting challenges into manageable parts, allowing for incremental design, development, and testing until a fully functional and effective lighting solution is achieved and ready for implementation.

However, the recent body of research on participatory processes in urban lighting design remains relatively limited. As public urban lighting is a transdisciplinary field, the complexities of participatory and interactive lighting require expertise and knowledge background [91]. Moreover, the success of urban lighting research must be conducted in real-world settings, allowing for practical application. This approach is critical for developing lighting solutions that are not only technically proficient but also socially inclusive and responsive to the needs of different stakeholders, as it refers to the shifting of the urban lighting paradigm to a more holistic approach [17].

Due to the challenges of complexity on the participatory process with interdisciplinary factors related to urban lighting master planning, it is crucial to employ appropriate tools which can unravel the complexities. Traditional representations like master plans or rendered visualizations can no longer adequately be systematically assessed to ensure they encompass all levels of engagement to see the holistic visualization. Therefore, designers and researchers must leverage new opportunities to capture the dynamic nature, growth, and ongoing transformation of cities by gathering information and incorporating it into iterative urban design processes [92].

2.5. Visualisation Tool for Urban Complexity

With the complexity and uncertainty of the urban context, it is necessary to unwind the unstructured problem before proposing the design solution. Sterman [93] suggests that to effectively address an issue, it is vital to understand the entire system. Any intervention without this comprehensive understanding is likely to create additional problems.

Recently, there have been many research methods and tools used to tackle the complexity and uncertainty of urban design and planning with a systematic approach, especially the research on the diversity of stakeholders' perspective. For example, the structural analysis–MICMAC method was created to structure decision-making in a hierarchical manner [94] while the science–design loop was created as Iterative and Participative Action Loops [95]. Stakeholder Mapping to identify relevant stakeholders seems to be crucial to enable higher planning efficiency, reducing bottlenecks and the time needed for planning, designing, and implementing projects [33]. The Analytic Hierarchy Process (AHP) developed a model by using stakeholder participation [96]. Problem structuring methods (PSMs) are used widely in urban participatory research such as intervention strategies for urban project [97–99] to enhance the understanding of decision problems and to foster a productive environment where individuals and processes can effectively structure key elements.

Finally, the Participatory System Dynamics (SD) Model is a conceptual framework used to understand and simulate the behavior of complex systems over time. It allows for a deeper understanding of how different elements within the system interact. This approach is particularly valuable for studying dynamic, non-linear problems that evolve over time and are influenced by multiple interacting factors. This approach supports decision-making on a strategic, system-wide scale and allows for the examination of the long-term effects of different strategies [34].

However, to understand a complex system, it is often described in terms of three key dimensions: the number of elements involved (quantity), the extent of interrelationships between these elements (connectivity), and the functional connections among the system's elements (functionality) [93]. SD was first introduced by Jay W. Forrester in 1969, and is used to illustrate the system in the mind of the individual, which is called a mental model. This modeling approach captures people's perceptions of real-world systems by focusing on causal relationships and feedback loops which is a system structure where outputs from a process or action are fed back into the system as inputs, influencing future behavior, particularly combined with influence diagrams like Causal Loop Diagrams (CLDs) and Cognitive Maps (CMs) [93,97,100].

Causal Loop Diagrams (CLDs) and Cognitive Maps (CMs) are popularly used as tools to visualize the mental model. However, it is important to clarify [28] that CMs are typically organized in a hierarchical structure, often represented as a means/ends graph, with goal-oriented statements positioned at the top of the hierarchy. CLDs focus on mapping the feedback structures within systems [101], as opposed to emphasizing hierarchical organization [102]. Moreover, CLDs are composed of variables linked by causal connections, each with a designated polarity that indicates the direction of influence between the variables. These diagrams highlight reinforcing and balancing feedback loops and are frequently utilized to illustrate critical feedback mechanisms that contribute to a particular issue within a decision-making process [28]. Creating CLDs involves pinpointing stakeholders and internal variables as well as establishing the causal relationships among those variables. Typically, CLDs are constructed using qualitative methods such as literature reviews, observations, and stakeholder interviews [39].

In summary, CLDs are a vital part of the System Dynamics methodology, serving as a bridge between qualitative understanding to quantitative modeling of complex systems which normally are illustrated by using thematic analysis of CLDs. Now there are many research studies using CLDs to unwind the various urban un-structured problem, as CLDs have been used widely as a visualization tool in recent urban research. For example, Tomoaia-Cotisel et al. [36] use CLDs to help policymakers identify and implement effective health system strengthening. Coletta et al. [37] use CLDs with Flood Risk Management in an Urban Regeneration Process. Pluchinotta et al. [28,38] studied both the complex urban system and the importance of stakeholders' elicitation by using CLDs to comprehend stakeholders' perceptions of system boundaries and problem definitions, and to analyze how these perceptions might influence decision-making by systematically comparing the causal maps of different stakeholder groups regarding a common concern. Tiller et al. [103] also use SD and CLDs to understand the stakeholder narratives into a quantitative environmental model.

In conclusion, results from the literature review suggest that urban lighting master planning is a multifaceted discipline shaped by a complex interplay of factors and diverse stakeholders with differing priorities. With the challenge in urban lighting complexity and the limitations of the participatory process in this interdisciplinary field, it results in a lack of awareness and holistic understanding of stakeholders' diverse perspectives. This is a barrier and challenge for the urban lighting master planning process.

To address these complexities, the initial step in developing an effective urban lighting master plan involves creating a clear visualization of the system's complexity. This requires understanding the intricate relationships and causal effects among the various multidimensional factors and stakeholders. CLDs are particularly well-suited for this purpose, providing a holistic approach to elucidate how different factors interact and influence each other. By employing CLDs, stakeholders can explore alternative scenarios and further the immediate and long-term needs of Chiang Mai Old City's urban lighting master plan.

3. Materials and Methods

This section outlines the entire research process, which employed a multi-stage qualitative method. It begins by describing the research design, data collection process through in-depth interviews and focus groups, followed by the data analysis used to address the in-depth interviews and focus groups outcome. Finally, it details the visualization process using CLDs as a key tool in Systems Dynamics methodology. CLDs visually represent the feedback relationships among different factors within a complex system [93], helping to capture the dynamics of urban lighting systems and facilitating the exploration of alternative proposed scenarios for Chiang Mai Old City. This approach also opens the discussion on its applicability and flexibility to other cities.

3.1. Site and Setting: Chiang Mai Old City

The focus area of this study is Chiang Mai Old City, located within the Chiang Mai municipality, covering an Old City area of 5.13 sq.km. according to Chiang Mai World Heritage Site. Chiang Mai is one of the country's major tourist destinations of northern Thailand, southeast Asia. With over 700 years of history, the city has a rich legacy of settlement and a distinct urban morphology [40]. Chiang Mai Old City reflects a unique blend of diversity and cultural dynamics, encompassing both the tangible and intangible urban heritage of the traditional Lanna Kingdom [42]. However, its long history of local traditions, combined with modern developments driven by tourism, has created a complex urban environment, both during the day and at night, shaped by the diverse activities and uses of various stakeholder groups.

Despite its cultural significance, the current nightscape of Chiang Mai Old City is insufficiently developed to maximize the potential of this cultural heritage area. For example, the lighting at Tha Phae Gate, a landmark of the Old City and an ancient city entrance, fails to adequately support many social activities. Moreover, the lack of a lighting design guideline has resulted in excessive illumination from surrounding buildings, contributing to light pollution that undermines the historic atmosphere and distracts from the landmark, as illustrated in Figure 3a,b.



Figure 3. Example of daytime and nighttime scenes of Chiang Mai's landmark, main street, and alleyway—(a,b) Tha Phae, landmark of Chiang Mai Old City, (c,d) Rachadamnoen Road, main axis of Chiang Mai Old City, (e,f) Phra Pok Klao 13 Alley, community pathway within the Old City. (Images were taken by authors during March–June 2024).

Similarly, Rachadamnoen Road, the main axis in Chiang Mai Old City featuring the Phra Singha Temple as a focal point, experiences challenges due to cluttered lighting

vignettes caused by unregulated façade, advertising controls, and street lighting. This disarray detracts from the significant value and majestic views of these historical sites, undermining the intended ambiance along the city's vista axis, as shown in Figure 3c,d.

Additionally, Phra Pok Klao 13 Alley, which serves as a community pathway within the Old City, is inadequately lit, resulting in a diminished sense of safety and a loss of direction and connectivity, particularly for tourists, as depicted in Figure 3e,f. This dynamic interplay of historical significance, modern challenges, and varying stakeholder needs presents unique opportunities and challenges for urban planning, especially regarding the development of nighttime lighting, which plays a critical role in addressing the city's evolving demands and future directions.

3.2. Research Design

The research design of this study was structured to three key objectives: identifying and prioritizing critical factors of urban lighting master plan for Chiang Mai Old City, understanding the complex interrelationships between those factors, and discussing the broader applicability of the approach to other cities. The research employed a multi-stage qualitative approach, as shown in Figure 4.

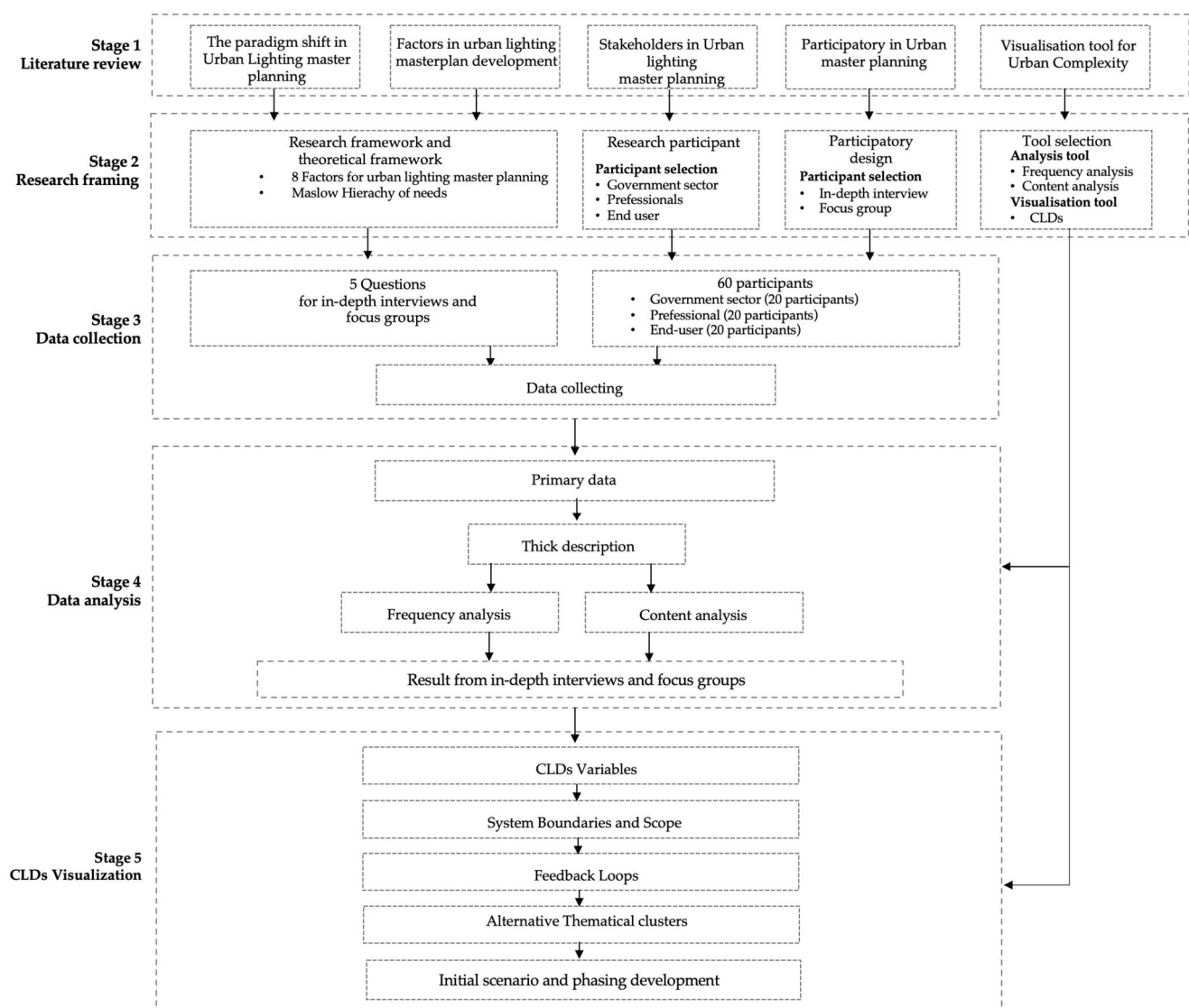


Figure 4. Multi-stage qualitative research process. Source: Authors.

3.2.1. Stage 1: Literature Review

This study began by reviewing five main pieces of the literature: examining the paradigm shift in urban lighting master planning, the factors in urban lighting master plan development, and the roles of stakeholders in the process. This stage also reviewed participatory urban master planning methods and visual tools like Causal Loop Diagrams (CLDs) for managing complex urban systems.

3.2.2. Stage 2: Research Framing

Based on the literature review, the research framework was structured from the eight factors of urban lighting master planning, as outlined by Zielińska-Dabkowska and Bobkowska [17]. In this research, Questions 1–3 asked participants to evaluate the satisfaction of existing urban lighting, the future perspective and vision, and the top three priorities factors which influenced Chiang Mai Old City. Questions 4–5, which asked for the unique conditions of Chiang Mai, refer to the strength of the city, and suggestions for developing Chiang Mai Old City' urban lighting. Lastly, Maslow's Hierarchy of Needs [61] was used as an assessment tool to evaluate the participants' perspective towards urban lighting, as part of an effort to adapt this framework for evaluating lighting at an urban scale.

For participant selection in this study, three key stakeholder groups adapted from stakeholders' literature reviews were used: the government sector, professionals, and end users. The participatory research design was structured around in-depth interviews and focus groups with 60 participants, equally divided among the three groups.

3.2.3. Stage 3: Data Collection—Semi-Structured In-Depth Interviews and Focus Groups

This stage involved gathering qualitative data from a selected group of 60 participants, representing three main stakeholder categories according to the stakeholders' literature review. Semi-structured in-depth interviews and focus groups, using five questions, were employed as the primary data collection methods. This stage was crucial for capturing the diverse insights and perspectives of various stakeholders on the challenges and opportunities surrounding urban lighting of Chiang Mai Old City.

3.2.4. Stage 4: Data Analysis—Identifying the Critical Factors and Key Stakeholders

Once the qualitative data were collected, the data analysis stage involved a frequency analysis and comprehensive content analysis. This process included coding and categorizing the participants' responses to identify the detailed perspectives on critical factors relevant to the development of the urban lighting master plan. This enabled a more holistic and systematic understanding of how diverse perspectives contribute to the urban lighting planning process. Furthermore, the content analysis uncovered underlying issues and potential opportunities, highlighting key aspects of urban lighting that were not immediately apparent during data collection.

3.2.5. Stage 5: CLDs Visualization Modeling

The stage of the research involved translating the qualitative insights gathered from the content analysis into visualization modeling using CLDs to visualize the complex interactions between the critical factors identified in the previous stage. The CLDs facilitated a deeper understanding of how various factors interact dynamically within the urban lighting system by representing these interactions visually. This stage allowed the exploration of a proposed alternative thematic cluster, providing a flexible possibility for considering different urban lighting development paths. Lastly, an initial scenario and phasing was proposed for Chiang Mai Old City's urban lighting master plan to tackle the city's urban lighting system.

3.3. Data Collection: Semi-Structured, In-Depth Interviews, and Focus Groups

In this stage, qualitative data collection was carefully structured to ensure balanced stakeholders' engagement, capturing a wide range of perspectives on urban lighting in

Chiang Mai Old City. A combination of theory-based and snowball sampling methods was employed to identify 60 participants representing three main stakeholder categories, as referenced in the stakeholder literature review [17,25–27,57]. This approach maximized diversity and relevance in the insights gathered, making sure the perspectives covered were well-aligned with the stakeholder groups outlined in previous studies.

Semi-structured in-depth interviews and focus groups are widely recognized qualitative research methods in urban planning, especially in the multi-stakeholder participatory approach [104]. These methods are often employed in the initial stages of identifying and defining problems and shared concerns, serving as a foundation for developing CLDs modeling processes, or other modeling approaches that contribute to urban solutions across various research topics [28,33,37].

To ensure accessibility and meaningful engagement among participants from varied backgrounds, each interview and focus group began with a 5–10 min presentation that provided key context about the study, including its objectives and the specific site details of Chiang Mai Old City. This introductory presentation aimed to address potential communication barriers and ensure participants had a clear understanding of the research framework. Open-ended questions such as, “Do you have any questions before we proceed?” were used to confirm participants’ understanding, while technical jargon was avoided. Additionally, visual aids and simplified terminology were integrated to further support participants from non-technical backgrounds, enabling them to fully engage with and contribute to the discussions.

A total of 28 interviews and 8 focus group sessions were completed during June to August 2024. Each session lasted between 60 and 90 min and centered around five key questions designed to meet the research objective of developing an urban lighting master plan for the cultural heritage of Chiang Mai Old City, as shown in Table 3.

Table 3. Questions in semi-structured in-depth interviews and focus groups.

Order	Questions
Q1	How satisfied are you with the current nighttime lighting in Chiang Mai Old City?
Q2	What is your perspective and vision for the role of lighting in the nighttime development of Chiang Mai Old City?
Q3	What are the top three factors that should be prioritized in the design of nighttime lighting for Chiang Mai Old City? (Select 3 out of 8)
Q4	What do you consider to be the potential opportunities in developing nighttime lighting for Chiang Mai Old City?
Q5	Do you have any suggestions for urban lighting development for Chiang Mai Old City?

Urban lighting design is a technical topic that can be challenging for many people to discuss in depth. To make the interviews more accessible and engaging, a conversational semi-structured format was used. This approach allowed participants to share their thoughts naturally while giving the researcher the freedom to ask follow-up questions as needed, following guidance from Osborne and Grant-Smith [104].

The interview began with an easy question, asking participants to reflect on their experiences with Chiang Mai Old City’s current nighttime lighting (Question 1). This helped establish a connection with the topic and allowed participants to ease into the conversation. Next, they were encouraged to share their ideal vision for the city’s nighttime lighting (Question 2), moving gradually into more focused discussions. To make technical aspects more understandable, a simple diagram of the eight key lighting factors (as outlined by Zielińska-Dabkowska and Bobkowska [17]) was used to help participants choose which factors they felt were most important (Question 3).

As participants became more comfortable, they were asked to think about the city's strengths and potential in developing its lighting (Question 4). The final question invited open-ended suggestions for improving Chiang Mai's urban lighting (Question 5). The last 2 questions were positioned at the end to ensure participants felt relaxed and ready to share any sensitive ideas, such as ways to advance the project or involve other stakeholders.

This structured flow allowed for a smooth conversation, encouraging deeper insights while keeping the discussion accessible. It also enabled the researcher to ask clarifying and follow-up questions as necessary. During the interviews, close-ended or leading questions were avoided to ensure participants could freely express their thoughts.

Similarly, the focus groups followed a conversational flow, bringing together small to medium size groups of participants from 3 to 10 participants per session, fostering dynamic and meaningful discussions. This method is particularly useful for generating a range of ideas, identifying common themes, and understanding group dynamics, making it widely used in urban research [105–107]. In focus groups, the interactive nature compels participants to articulate the reasoning behind their views, enabling the researcher to observe not only how individuals develop their own perspectives but also how they relate and respond to differing viewpoints [108]. However, for focus groups, moderators followed a set of guidelines to prevent any single participant from dominating the discussion. Techniques such as “round-robin” questioning were employed, where each participant was given an equal opportunity to respond to each question.

3.4. Research Participants

3.4.1. Participant Selection

To create a comprehensive and representative sample of stakeholders involved in urban lighting master planning, participants were selected based on their relevance to the study's focus areas. The selection criteria, adapted from stakeholder literature [17,25–27,57], categorized participants into three distinct groups:

1. Government sector: Participants must hold positions within local or national government agencies or regulatory bodies involved in urban planning, public safety, or environmental regulations.
2. Professional sector: Participants should be professionals with expertise in urban lighting design, including architects, lighting designers, engineers, supplier, and consultants.
3. End user: Participants must represent private sector entities such as business owners, property developers, civil society, or community organizations that are directly impacted by urban lighting.

3.4.2. Participant Recruitment

To ensure balanced representation, a two-stage recruitment process, combining theory-based and snowball sampling methods, was utilized to create a well-rounded participant sample.

Initially, theory-based sampling was used to target key individuals and organizations directly relevant to the study's focus. This method involves selecting participants based on specific research needs to ensure the sample accurately represents the phenomenon under investigation [109]. Invitations were sent to stakeholders from diverse demographic backgrounds, including different ages, professional roles, and areas of expertise, to capture a broad spectrum of perspectives. Engaging individuals with varying levels of influence within organizations, from decision-makers to community representatives, helped avoid the overrepresentation of any single viewpoint.

The selection process began with identifying local individuals and organizations significantly involved in urban lighting, balancing representation equally among the three groups of stakeholders. Participants were approached through professional networks and recommendations, with initial contact made via email, phone, or formal invitations that outlined the study's objectives and emphasized the importance of their input. This method

ensured a comprehensive participant pool that reflected diverse insights, enhancing the overall quality of the research.

Next, snowball sampling was used to expand the participant pool. Initial participants were encouraged to refer colleagues or contacts with similar roles and responsibilities, systematically increasing the number of relevant participants. Efforts were made to achieve proportional representation across stakeholder groups, with quotas established to promote balanced participation. This approach helped capture data reflecting the interests and concerns of all relevant stakeholders.

3.5. Sample Size

The sample size of this research consists of 60 participants, categorized equally into three distinct groups based on the study's criteria, as shown in Table 4.

Table 4. Sample of stakeholders involved in urban lighting master planning.

Group	Stakeholders	No.	Total No.
Group 1: Government Sector	Local government	10	20
	Central/national government	10	
Group 2: Professional Sector	Local architect/urban architect/urban researcher	8	20
	Architect/urban architect/urban researcher	6	
	Lighting designer	5	
	Lighting manufacturer	1	
Group 3: End user	Private owners/business sectors	5	20
	Tourism industry	3	
	Civil society/community	7	
	Tourists	6	

3.6. Data Analysis Process

This section details the holistic and systematic approach used to analyze collected data. The initial step involved transcribing the recorded in-depth interviews and focus groups into detailed text descriptions, stored in Word document files. Content analysis was employed to identify and categorize key themes, patterns, and concepts within the data [110,111].

The initial coding process began with assigning preliminary codes to specific segments of text based on their content and context. This process involved generating codes from recurring themes and significant patterns observed in the data by using eight factors of urban lighting master planning [17] as a framework. These codes were compared with the original data to ensure accuracy and relevance. Similar codes were then consolidated into broader categories that reflected common themes and meanings. The categorized data were compiled into spreadsheet files, classifying large volumes of text into a manageable number of categories that represented similar meanings. Data from Question 1–5 were tabulated to show the total number of responses and the percentage of number of responses on each key factor and sub-factor. This organization facilitated coherent content analysis and interpretation.

The identified themes were linked to the broader objectives of developing a comprehensive urban lighting master plan referring to the theoretical framework from the literature reviews. The results were presented in a structured format using charts and tables to effectively communicate the findings. The analysis aimed to provide stakeholders with valuable insights into urban lighting master planning. Additionally, these insights were used as variables for creating further CLDs visualizations.

3.7. Visualization and Implication

Following the data analysis process, significant findings revealed complex relationships between existing problems, aspects and expectations, critical factors, methods and mechanisms, and key actors. These elements contribute to a complex, unstructured problem with various interrelations. To systematically represent this complexity and enhance understanding of the holistic and systematic approach, CLDs were utilized, as they provide a structured means of “Conceptualization” [112].

The process of building CLDs involved using Vensim PLE 10.2.1, a simulation software for developing dynamic feedback model. The first step in creating CLDs was to capture the intricacies of critical factors in urban lighting systems and their interactions visually. This approach highlights feedback loops and interdependencies among various factors influencing urban lighting, helping to identify the centrality of shared concerns, expectations, and aspects, and illustrating how these elements interact within the Urban Lighting Master plan. These visualizations aimed to clarify and depict the significant factors and their interrelationships, providing a comprehensive understanding of the urban lighting system and informing strategic planning. The main elements required creating CLDs which are outlined in Table 5.

Table 5. Key elements in CLDs.

Elements	Role	Symbol	Description
Nodes	Represent key factors or variables in the system	Variables	These are the critical elements or factors within the system that influence each other.
Connections (Arrows)	Indicate the relationships between variables	Positive (+)	A positive relationship: an increase in one variable leads to an increase in the other (or a decrease leads to a decrease).
		Negative (−)	A negative relationship: an increase in one variable leads to a decrease in the other (or vice versa).
Loops (Feedback Loops)	Show circular cause-and-effect relationships between variables	Reinforcing (R)	A reinforcing loop amplifies change, creating exponential growth or decline.
		Balancing (B)	A balancing loop counteracts change, promoting stability or equilibrium.

In applying CLDs to Chiang Mai Old City’s urban lighting system, the first step involved identifying key sub-factors, derived from in-depth interviews and focus groups. These sub-factors are defined as variables within the system. The next step was to map the relationships between them. Arrows were used to link the sub-factors, representing the direction of influence; a positive (+) relationship indicates that an increase in one variable causes an increase in another, while a negative (−) relationship means that an increase in one variable leads to a decrease in another.

As these relationships were mapped, feedback loops emerged. These loops were either reinforcing (R), where changes intensify over time, or balancing (B), where the system stabilizes or counteracts itself. After forming these loops, the next step was to group related loops into broader categories or factors, which refer back to the eight factors of urban lighting master planning [17]. The loops were then further gathered into thematic clusters to guide the direction of lighting development. This process allowed for a clear understanding of how the different thematic cluster influence each other and revealed the dynamic possibilities within Chiang Mai Old City’s urban lighting system. The final

step involved exploring alternative scenarios, using the insights from the CLDs to assess potential outcomes, as shown in Figure 5.

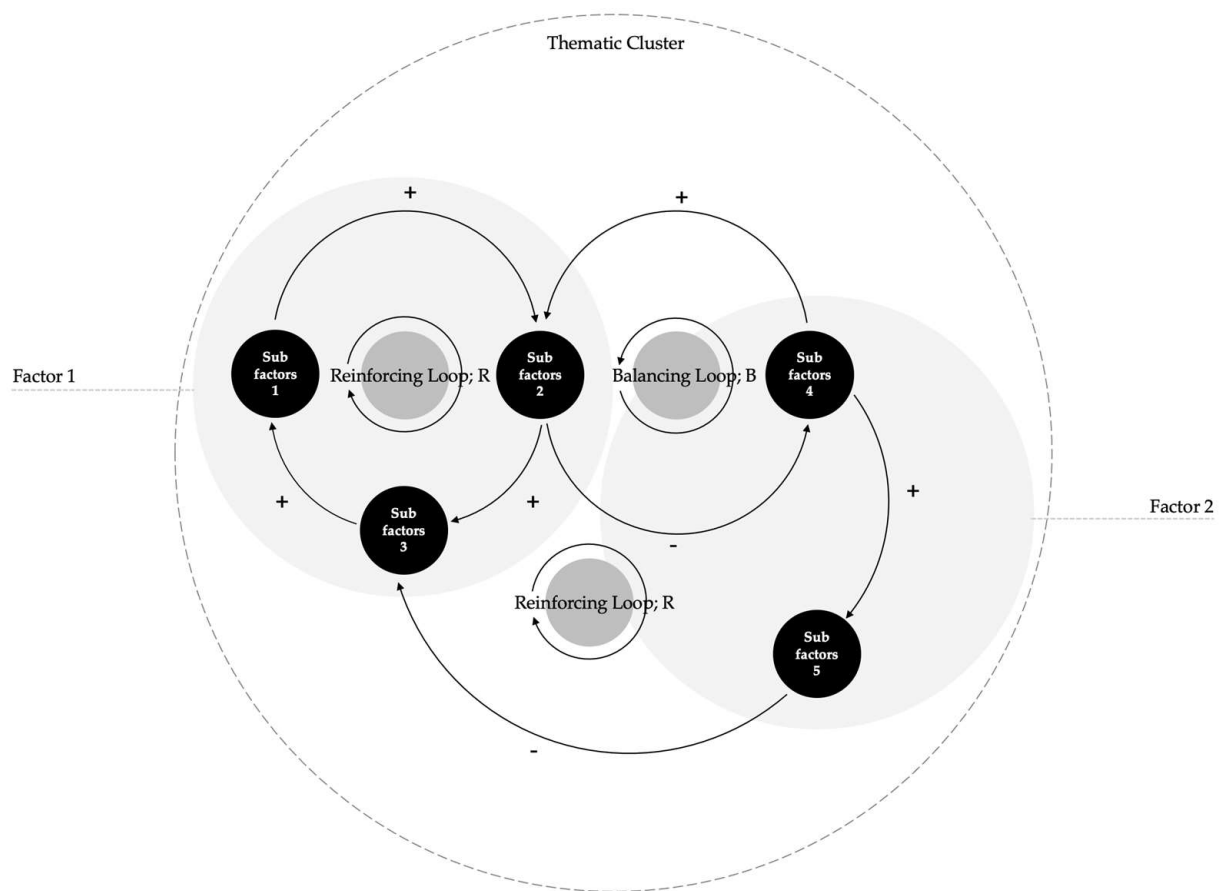


Figure 5. A schematic diagram of the CLDs system. Source: Authors.

4. Results

This section consists of three parts. First, it presents the results from the in-depth interviews and focus groups, highlighting key findings and insights from stakeholder discussions are presented. Second, it visualizes the CLDs that illustrate the complex relationships and feedback loops identified in the urban lighting systems for Chiang Mai Old City are visualized. Finally, it discusses the implications of these urban lighting recommendations by proposing thematical clusters, possible initial scenarios, and phases for developing urban lighting master planning for Chiang Mai Old City.

4.1. In-Depth Interviews and Focus Group Outcomes

4.1.1. Satisfaction with Existing Urban Lighting

The results from Question 1 asked participants to evaluate their satisfaction and dissatisfaction with the existing urban lighting in Chiang Mai Old City. The collected data were analyzed and categorized according to a framework of eight factors in urban lighting master planning, adapted from Zielińska-Dabkowska and Bobkowska [17]. The results provide a detailed account of participants' feedback, revealing their understanding and concerns regarding these eight factors as well as emergence and prioritization of sub-factors, representing different facets of urban lighting with varying degrees of importance based on the frequency of responses from participants, as shown in Table 6.

Table 6. Results from Question 1: Satisfaction and dissatisfaction with existing urban lighting in Chiang Mai Old City.

Factor	Sub-Factor	Response Rate (%)	No. of Responses
Safety and security	Adequate lighting, basic infrastructure	67.5	40 (66.7%)
	Connectivity and mobility	40.0	
	Safety	32.5	
	Feeling of security and reassurance	17.5	
	Orientation and navigation	10.0	
Cultural and heritage	Characteristic, place identity, and sense of place	48.6	35 (58.3%)
	Historical and architectural enhancement	37.1	
	Aesthetic and ambience	31.4	
	Hierarchical design	22.9	
	Storytelling	20.0	
	Vista and focal point	14.3	
	Intangible and cultural value	8.5	
	Emotional and feeling	2.9	
Regulation	Law and urban policy, lighting control, lighting standard	58.1	31 (51.7%)
	Master plan, zoning plan, strategic plan	54.8	
	Lighting design guideline	25.8	
	Incentive and mechanism	22.6	
Economy	Tourism and nightlife activity and entertainment	57.9	19 (31.7%)
	Activate economic value, long-term economy	42.1	
	City branding	10.5	
	Job and income	10.5	
	Festival	5.3	
Social	Serving social needs	70.6	17 (28.3%)
	Social activity and interaction	29.4	
Technology	Energy saving and alternative energy	50.0	10 (16.7%)
	Technology and innovation	40.0	
	Technology platform and data	10.0	
Well-being	Circadian lighting, impact on residents' health	75.0	8 (13.3%)
	Balancing needs and contexts	62.5	
Environment	Darkness and brightness control	80.0	5 (8.3%)
	Ecologically friendly	60.0	

Safety and security factors emerged as the most significant, noted by 66.7% of participants. The most frequently mentioned was the need of adequate lighting for safety, followed by connectivity and mobility, reflecting the need for well-lit streets and public spaces to ensure ease of movement. A feeling of security and reassurance was closely linked to the role of lighting in promoting a sense of personal safety, while orientation and navigation was highlighted as important for wayfinding within the city. This reinforces the importance of urban lighting in creating safer nighttime environments for residents and visitors alike.

Cultural and heritage considerations were another major concern, highlighted by 58.3% of participants, referencing high aspects related to enhancing the characteristic, place identity, and sense of place. Other key aspects included historical and architectural enhancement, emphasizing the importance of preserving and showcasing the city's heritage through lighting, aesthetic and ambience, hierarchical design, and storytelling through lighting, which indicates the importance of lighting in conveying the city's cultural narrative. Additional concerns like vista and focal points, and intangible cultural value further suggest that lighting plays a vital role in revitalizing the city's unique cultural identity.

The regulation framework surrounding urban lighting was another dominant theme, with 51.7% of participants referencing concerns as essential tools for balancing, preventing, and controlling light pollution to protect the well-being of residents and the city's environment. Participants emphasized the importance of law and urban policy, lighting control, and lighting standards, implemented through master plans, zoning plans, and strategic plans as mediators. They further highlighted the role of lighting design guidelines to create the unity of city's nighttime image. These responses indicate a strong demand for clearer regulations and policies to guide the development of lighting schemes that are both functional and aesthetically aligned with the city's needs. Incentives for businesses and stakeholders to adopt these guidelines were also mentioned, signaling the need for supportive policies to encourage compliance.

Economic considerations were highlighted by 31.7% of participants. The impact of lighting on tourism and nightlife activities was particularly important, with lighting seen as a way to activate public spaces for the nighttime economy and tourism. Additionally, concerns regarding city branding and job and income generation were notable, indicating the need for further development to maximize the nighttime economy. Participants also pointed to festivals as an economic driver, where urban lighting plays a crucial role in creating memorable experiences, drawing crowds, and stimulating the local economy.

Social aspects of urban lighting were acknowledged by 28.3% of respondents, who emphasized how lighting can foster social activity and interaction as well as serve social needs. These insights reflect the importance of lighting in enhancing the livability of public spaces, creating environments that encourage social gatherings and community engagement, particularly in the evening.

Technological aspects of urban lighting were addressed by 16.7% of participants, with discussions surrounding technology and innovation, energy-saving solutions, and the use of technology platforms and data to enhance the efficiency and effectiveness of urban lighting. These responses suggest an emerging interest in the integration of smart lighting technologies and sustainable practices within the city's lighting plan.

Well-being issues were cited by 13.3% of participants, focusing on circadian lighting, particularly regarding its impact on residents' health. The need for balancing lighting needs with the city's cultural and environmental contexts was another concern, indicating that lighting should be designed to promote both well-being and environmental harmony.

Although less frequently mentioned, environmental concerns such as light pollution and darkness control were raised by 8.3% of participants. These issues highlight the need for the lighting master plan to consider ecological impacts, particularly in terms of reducing unnecessary light spillage and maintaining natural darkness where appropriate.

4.1.2. Perspective and Vision

In Question 2, participants were asked to share their perspectives and vision for the future of urban lighting in Chiang Mai Old City based on the eight factors in urban lighting master planning, as shown in Table 7.

Table 7. Results from Question 2: Perspective and vision for urban lighting in Chiang Mai Old City.

Factor	Sub-Factor	Response Rate (%)	No of Responses
Cultural and heritage	Characteristic, place identity, and sense of place	49.0%	49 (81.7%)
	Historical and architectural enhancement	44.9%	
	Aesthetic and ambience	38.8%	
	Intangible and cultural value	24.5%	
	Storytelling	22.4%	
	Hierarchical design	20.4%	
	Emotional and feeling, experience	16.3%	
	Vista and focal point	16.3%	
Economy	City branding, destination, check-in	64.1%	39 (65.0%)
	Tourism and nightlife activity and entertainment	48.7%	
	Activate economic value	48.7%	
	Festival	20.5%	
	Job and income	5.1%	
Safety and security	Safety	76.5%	34 (56.7%)
	Connectivity and mobility	29.4%	
	Adequate lighting	17.6%	
	Feeling of security and reassurance	11.8%	
	Orientation and navigation	8.8%	
Social	Social activity and interaction	77.3%	22 (36.7%)
	Serving social needs	54.5%	
	Sense of belonging	4.5%	
Well-being	Balancing needs and contexts	50.0%	12 (20.0%)
	Circadian lighting, impact on residents' health	41.7%	
	Quality of life	25.0%	
Environment	Ecologically friendly	80.0%	5 (8.3%)
	Sustainability	40.0%	
Regulation	Law and urban policy, Lighting control, lighting standard	50.0%	2 (3.3%)
	Lighting design guideline	50.0%	
Technology	Energy saving and alternative energy	100.0%	1 (1.7%)

Cultural and heritage factor were the most frequently discussed for the future of urban lighting, with 81.7% of participants mentioning aspects related to culture. The highest response frequency was associated with the characteristic, place identity, and sense of place. This suggests that participants strongly value lighting that emphasizes Chiang Mai Old City's unique cultural identity and enhances its historical and architectural character. Other important cultural aspects including historical and architectural enhancement and aesthetic and ambience also play crucial roles in participants' visions for future lighting.

Participants also emphasized the intangible cultural value of lighting and its role in storytelling, in revitalization of the city's cultural assets. Hierarchical design, along with the use of vistas and focal points, were also mentioned as tools to shape the city's character at night. Additionally, participants raised the significance of the emotional and sensory

experiences elicited by lighting, showing a preference for lighting that fosters both visual and emotional connections with the city's heritage.

Economic factors were discussed by 65% of participants, indicating a strong desire for urban lighting to support city branding, with participants seeing lighting as a potential tool for creating a distinctive brand for Chiang Mai, especially by creating a sense of arrival and welcoming, creating a 'WOW' effect, and fostering a strong image for the city to promote tourism. Tourism, nightlife activities, and entertainment, were described in more detail, with lighting creating a strong magnet as a tourist destination, initiating night tours, and further check-in spots. This aligns with the need to leverage lighting as an economic tool to boost the city's nighttime economy and increase visitor engagement. Participants also expressed the need for lighting to activate economic value by enhancing commercial opportunities and supporting festivals as key drivers of local income and identity. Job and income creation were mentioned, though this was a less significant issue in the broader economic context.

The safety factor was highlighted by 56.7% of participants. Ensuring adequate lighting and addressing safety concerns was still a key issue, especially for the improvement of connectivity and mobility. However, fewer participants mentioned a feeling of security and reassurance nor orientation and navigation. These responses suggest that while participants recognize the importance of safety, other concerns like culture and economic opportunities took precedence in their vision for the future.

The social aspects of lighting were discussed by 36.7% of participants, with a focus on enhancing social activity and interaction and serving social needs. This reflects the recognition that urban lighting plays an important role in fostering social connections and creating spaces that accommodate community activities, both during the day and at night.

Well-being was mentioned by 20% of respondents. Participants emphasized the need for balancing lighting with contextual needs and addressing the impact of lighting on circadian rhythms and residents' health. Environmental concerns were relatively under-represented, with only 8.3% of participants discussing this factor. Of those who did, most emphasized the need for ecologically friendly lighting and another subtopic of sustainable practices was mentioned. No responses were recorded for darkness and brightness control. Meanwhile, regulation and technology were mentioned by a small number of participants, 3.3% and 1.7%, respectively. This could indicate a lack of awareness or overlooking the importance of these two factors towards urban lighting for Chiang Mai Old City.

4.1.3. Top Three Critical Factors

To have double confirmation of participant's prioritizing of critical factors, in Question 3, participants were asked to select their top three from eight key factors. The responses were analyzed at two levels: first, by examining the overall prioritization of all participants, and second, by breaking down the results into three distinct stakeholder groups: government sector, professional sector, and end users, to understand the diverse perspectives each group brings to urban lighting in Chiang Mai Old City.

For the first level of result analysis, overall results illustrate that the most highly prioritized factor was safety and security, chosen by 70% of participants. This highlights the importance of creating a safe nighttime environment. The economic factor came in second, prioritized by 45% of participants, reflecting the recognition that lighting can boost the local economy, enhance tourism, and create a vibrant nighttime atmosphere that encourages business activity. Cultural and heritage factors ranked third, with 40% of participants emphasizing the value of lighting that enhances the historical and cultural identity of Chiang Mai Old City.

Regulation came in fourth, as lighting control, standards, and policies were chosen by 28.3% of participants. This reflects an awareness of the need for strong governance and regulations to ensure that urban lighting adheres to safety standards and zoning guidelines. Social and environment were chosen by 25% of participants, while well-being was chosen

by 20% of participants. Lastly, technology received the lowest priority, selected by 18.3% of participants. This indicates less awareness of technological benefits.

For the second level analysis, the data breakdown by stakeholder groups (government sector, professional sector, and end users) reveals different priorities and perspectives across these groups as shown in Figure 6.

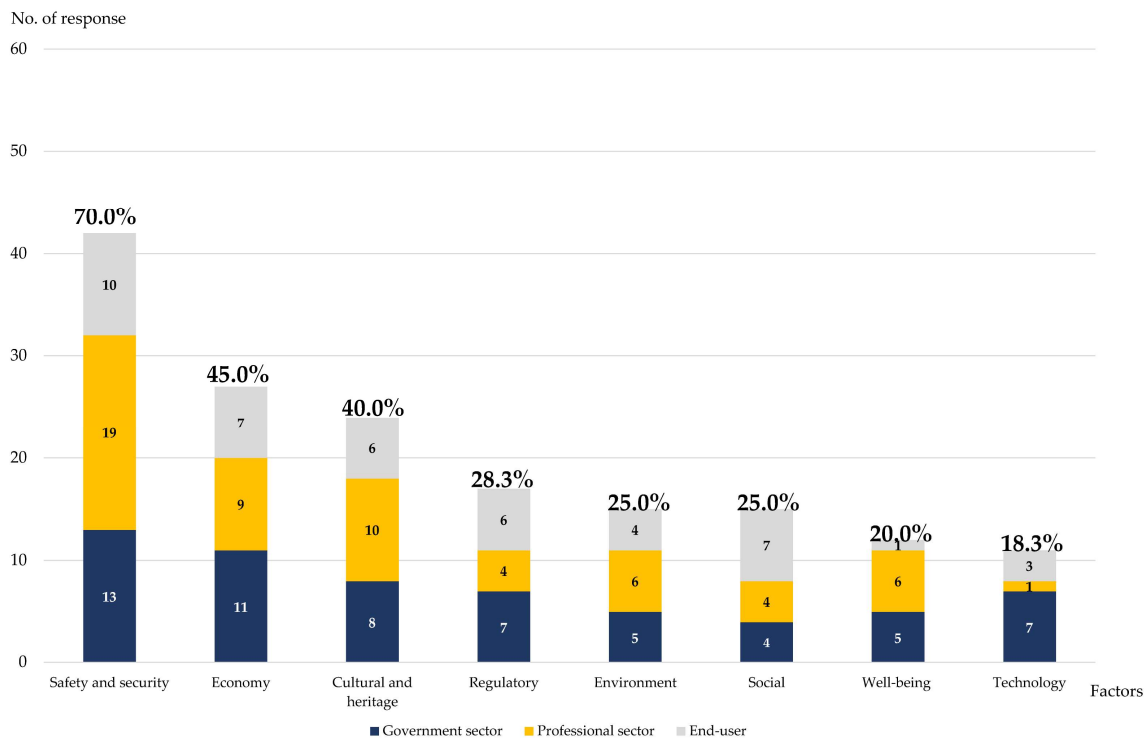


Figure 6. Results from Question 3: Critical factors that should be prioritized in designing nighttime lighting for Chiang Mai Old City. Source: Authors.

The results indicate that the government sector focuses primarily on safety and security, followed by economic development and cultural and heritage, while for the professional sector and end users, the top priority is safety and security, followed by cultural heritage and economic. The overall prioritization results demonstrate a strong consensus across all stakeholder groups regarding the importance of safety and security in urban lighting design. This emphasis on safety and security reflects a shared recognition of the need to create a safe and secure nighttime environment, which is particularly critical in urban lighting design. Each group overwhelmingly prioritized this factor, signaling that it is viewed as a foundational aspect of any urban lighting strategy.

The economic and cultural heritage factors are closely intertwined in the context of urban lighting, as both contribute significantly to the vibrancy and identity of Chiang Mai Old City. Lighting plays a dual role; economically, it has the potential to boost tourism, extend business hours, and foster a vibrant nighttime economy by activating public spaces and encouraging social activities. At the same time, lighting is essential for emphasizing the city's unique cultural and historical identity, enhancing its architectural features, and preserving the intangible cultural elements that define the city's character.

In summary, data analysis shows an imbalanced factor prioritization. This presents a potential risk in urban lighting design. Overemphasizing certain factors, such as safety, may come at the expense of other critical dimensions, such as environmental sustainability or social inclusion, which are essential for creating a more holistic and well-rounded urban environment. Ignoring these areas could lead to challenges in long-term governance, community well-being, and environmental stewardship.

4.1.4. Strengths and Potential of Chiang Mai Old City

The results from Question 4, which addressed the strengths and potential opportunities for developing nighttime lighting in Chiang Mai Old City, are shown in Table 8.

Table 8. Strengths and potential opportunities for developing nighttime lighting in Chiang Mai Old City.

Factor	Sub-Factor	Response Rate (%)	No. of Responses
Cultural and heritage	Cultural capital (Intangible)	84.1	44 (73.3%)
	Old town morphology (Tangible)	36.4	
	Lifestyle	13.6	
	Art and culture	6.8	
Economic	One-stop destination	64.5	31 (51.7%)
	Tourism industry	48.4	
	Festival	12.9	
	Nightlife	9.7	
	Economic value	6.5	
People	Professional sector	63.2	19 (31.7%)
	Community and citizen	52.6	
	Government sector	36.8	
Safety and security	Connectivity and mobility	66.7	3 (5.0%)
	Safety	33.3	

The findings reveal that the most significant strength is cultural and heritage at 73.3%, with the most frequent aspect highlighted being “Cultural capital”. Participants emphasized the value of Chiang Mai’s rich intangible cultural heritage, followed by the unique tangible morphology and physical elements of Old Town. Additionally, lifestyle characteristics such as a passive and relaxed atmosphere were mentioned, along with the city’s creativity in arts and culture.

Economic opportunities were the second most frequently mentioned strength, cited by 51.7% of participants. The key themes included Chiang Mai Old City as a “one-stop destination” for tourism and the tourism industry’s importance, its well-developed attractions, services, and facilities. Other economic factors include the broader city economy and the significance of festivals. These responses suggest that stakeholders see nighttime lighting as a tool to bolster the tourism industry and attract more visitors, extending business hours and creating an economically vibrant nighttime environment.

However, another strength mentioned by 31.7% of respondents was the strong and active community, including professionals and the government, reflecting the potential of engaging the local community to support nighttime lighting initiatives. Safety at 5% was not considered a strength of the city, although it was a significant concern in responses to Questions 1, 2, and 3.

4.1.5. Suggestions for Urban Lighting Development for Chiang Mai Old City

The last part is an open-ended question allowing participants to share further suggestions towards the success of developing urban lighting development for Chiang Mai Old City. The findings were categorized into three key factors: mechanism, technical, and administrative factors, as detailed in Table 9.

Table 9. Results from Question 5: Suggestions for urban lighting development for Chiang Mai Old City.

Factor	Sub-Factor	Response Rate (%)	No. of Responses
Mechanism factor	Social engagement	59.5	37 (61.7%)
	Key performance indicator	35.1	
	Awareness and public relation	27.0	
	Festival/tourism-led	16.2	
	Pilot project	13.5	
	Knowledge and expertise	10.8	
	Technology and innovation	10.8	
	Incentive	5.4	
Technical factor	Master plan, zoning plan, strategic plan	67.9	28 (46.7%)
	Lighting design guideline	50.0	
	Law and urban policy, lighting control	35.7	
	Lighting procedure, standard	10.7	
	Proposal	10.7	
Administration factor	Collaboration	52.4	21 (35.0%)
	Ownership	28.6	
	Decision-maker and politician power	28.6	
	Sponsorship	14.3	
	Management and maintenance	9.5	

The mechanism factors focus on the strategies required to implement and sustain lighting projects. Social engagement was identified as the most significant factor, with 59.5% of participants acknowledging the importance of involving multi stakeholders in the planning and execution of urban lighting initiatives. This highlights the critical role of a participatory approach in achieving success. In addition, key performance indicators (KPIs) were noted by 35.1% of respondents, suggesting a demand for measurable outcomes to assess the effectiveness of lighting projects. Awareness and public relations (27.0%) also play a key role in garnering public support and educating stakeholders about the benefits of improved urban lighting. Other important mechanisms include festival/tourism-led initiatives and pilot projects which suggest that lighting projects tied to cultural events and tourism can serve as effective starting points for broader development. Finally, factors such as knowledge and expertise, technology and innovation, and incentives highlight the need to incorporate modern, innovative approaches and motivate stakeholders to actively participate in lighting initiatives.

Technical considerations form the foundation of urban lighting strategies, with 67.9% of participants emphasizing the need for a comprehensive master plan, zoning plan, and strategic plan. This reflects the importance of aligning lighting efforts with broader urban planning initiatives. Additionally, 50.0% of respondents highlighted the need for a clear lighting design guideline, highlighting the city's unified atmosphere and collaboration with the private sector. Regulatory aspects, such as law and urban policy and lighting control, were mentioned by 35.7% of respondents, suggesting gaps in regulatory enforcement or the need for more robust policies. Less frequently mentioned were lighting standards and procedures and proposals.

On the administrative side, the findings highlight the significance of governance and collaboration in executing urban lighting plans. Collaboration emerged as a crucial factor, with 52.4% of participants emphasizing the need for mostly coordinated efforts between government sector. Additionally, ownership and the role of politicians and decision-makers

were each mentioned by 28.6% of respondents, reflecting the need for clear leadership and accountability in driving projects forward. Sponsorship and management and maintenance were cited as important for the long-term sustainability and funding of lighting projects.

In conclusion, the findings highlight the multifaceted nature of urban lighting development, requiring a balance of technical planning, administrative collaboration, and mechanisms. Together, these factors can support the creation of a sustainable, inclusive, and culturally sensitive urban lighting strategy for Chiang Mai Old City.

4.2. CM and CLD Visualizaiaon

Based on the outcomes of in-depth interviews and focus groups, key variables related to urban lighting emerged from participants within a complex and unstructured context. To visualize these significant variables and their interrelationships holistically, three visualization steps were employed.

First, Cognitive Mapping (CM) was used to identify the system boundaries and scope, providing a comprehensive view of the urban lighting issues. Following this, Causal Loop Diagrams (CLDs) were applied to establish causal relationships between variables, revealing feedback loops and leverage points. This approach illuminated shared interests and the interconnected cause-and-effect dynamics. Finally, the feedback loops were grouped into thematic cluster analysis, proposing possible initial scenarios and phasing for the development of an urban lighting master plan for Chiang Mai Old City.

4.2.1. Identifying the System Boundaries and Scopes

To identify the system boundaries and scope of urban lighting master planning for Chiang Mai Old City, the in-depth interviews and focus groups results revealed a 'core system engine' [113] which was derived from thematic analysis of responses to Question 1, 2, and 3.

Key variables from the 60 participants' responses were organized into a systematic and holistic framework, highlighting the scope and system boundaries of the project. The variables were grouped into eight factors as adapted from Zielińska-Dabkowska and Bobkowska [17]. The resulting diagram, as shown in Figure 7, provides a CM of a comprehensive understanding of all the variables in the master planning process.

This CM is a useful starting point for understanding the broad themes and key variables in the urban lighting master planning process from a stakeholder perspective. However, it has limitations as it does not capture the detailed cause-and-effect relationships or dynamic interactions between the variables. To address this, CLDs are needed to visualize how changes in one part of the system might reinforce or balance other parts. The real complexity of the system lies in these interactions.



Figure 7. Cognitive mapping (CM) of system boundaries and scope of urban lighting master planning for Chiang Mai Old City. The dashed lines represent the conceptual hierarchy of the system with the main factors placed at the center of the diagram. The branches with solid lines indicate the sub-factors of each main factor. Source: Authors.

4.2.2. Identifying Feedback Loops and Thematical Clusters

In constructing the CLDs, the initial step involves identifying key variables (represented as nodes) that reflect significant issues related to urban lighting. Each node represents a critical aspect of the system under study. The next step is to establish cause-and-effect relationships between these nodes (represented as loops). This mapping process illustrates how changes in one variable can positively or negatively impact another, facilitating a clear understanding of interactions within the system, regardless of whether they occur within the same category or across different groups.

The overall structure of the Causal Loop Diagrams (CLDs) is presented in Figure 8, revealing a set of thirteen feedback loops: eleven reinforcing loops (R) and two balancing loops (B). These loops are vital for understanding the dynamics influencing urban lighting in Chiang Mai Old City.

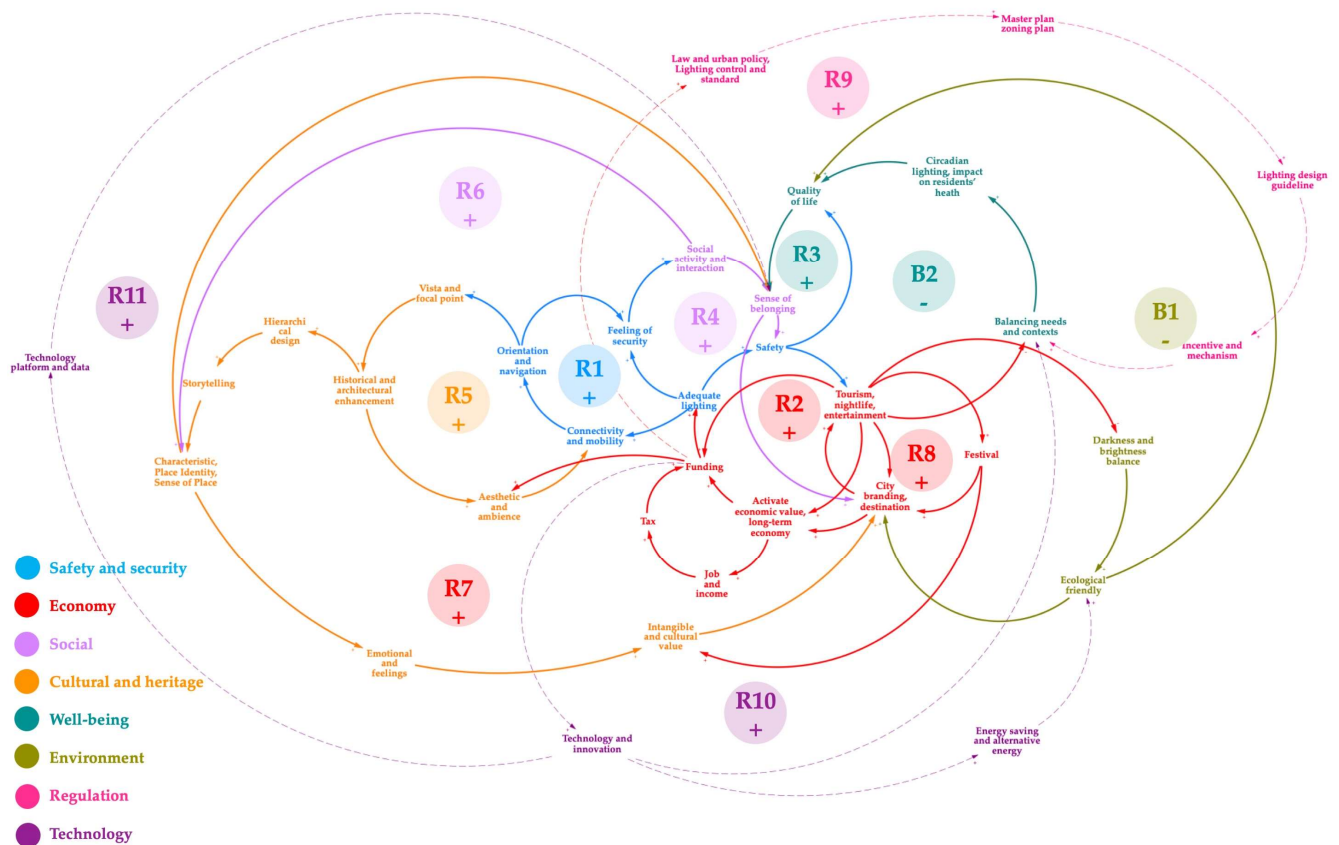


Figure 8. CLDs of a set of thirteen feedback loops, with eleven reinforcing loops (R) and two balancing loops (B) for Chiang Mai Old City urban lighting master planning. The solid arrow lines represent the initial set of feedback loops. The dashed arrow lines indicate the proposed feedback loops for conflict resolution. Source: Authors.

CLDs reveal an initial set of 10 feedback loops, highlighting key dynamics influencing urban lighting in Chiang Mai Old City. The reinforcing loops (R1–R8) demonstrate the positive feedback effects of well-designed lighting on safety, economy, social well-being, and cultural identity, creating a continuous cycle of benefits. Meanwhile, the balancing loops (B1–B2) introduce a necessary check on excessive lighting, which can significantly impact the ecological balance and residents' well-being. This could hinder overall development and create obstacles to achieving long-term sustainable growth.

To further mitigate potential conflicts and enhance control, an additional three reinforcing loops (R9–R11) have been proposed. These loops emphasize the role of regulation and technology in supporting long-term sustainable urban development goals, ensuring that lighting systems not only enhance city dynamics but also align with broader sustainability objectives. A summary of all feedback loops is presented in Table 10.

Table 10. Feedback loops for urban lighting development for Chiang Mai Old City.

Loops	Category	Type	Description
R1	Safety and Security, Economy, and Social	Reinforcing	Adequate lighting enhances connectivity and mobility, improving orientation, navigation, and the feeling of security. This increases nighttime activity, activates economy, and in turn, provides funding for urban lighting infrastructure.

Table 10. Cont.

Loops	Category	Type	Description
R2	Economy	Reinforcing	Lighting transforms the city into a nighttime entertainment destination, boosting tourism, generating income, and increasing long-term economic value. This leads to higher tax revenue and more funding for urban lighting infrastructure.
R3	Well-being and Social	Reinforcing	Improved lighting enhances quality of life, raises awareness of its benefits, promotes social activity and interaction, and fosters a sense of belonging. This, in turn, strengthens feelings of safety, which encourages more nighttime activity and further strengthens community well-being.
R4	Safety and Security, and Social	Reinforcing	Urban lighting increases safety by encouraging social activity in public spaces, promoting a vibrant nighttime social environment. In turn, this enhances feelings of security, which motivates more people to engage in nighttime activities.
R5	Cultural and Heritage	Reinforcing	Lighting highlights historical architecture, creates a visual hierarchy, enhances specific vistas and focal points, aids orientation, and contributes to the city's nighttime aesthetic appeal. In turn, this strengthens cultural and heritage values, attracting more visitors.
R6	Social, Cultural and Heritage	Reinforcing	Lighting encourages social activities and strengthens social identity, which, in turn, reinforces a sense of place and belonging. This further enhances the cultural and heritage appeal of the area, creating a positive feedback loop that strengthens community identity.
R7	Cultural and Heritage	Reinforcing	Lighting evokes emotions and tells stories, revitalizing the intangible and cultural values of the city. This, in turn, enhances the city's cultural identity, attracting visitors and creating more opportunities to showcase these values.
R8	Economy	Reinforcing	Well-designed lighting enhances city branding for festivals and nightlife, attracting more tourists. In turn, this generates long-term economic benefits, which provide further funding for urban lighting infrastructure, allowing for continued improvements in lighting design.
B1	Environment	Balancing	Excessive lighting driven by tourism can disrupt the natural balance of brightness and darkness, leading to ecological impacts such as light pollution. In turn, this can create a negative impression for tourists, diminishing their overall experience of the environment.
B2	Social and Well-Being	Balancing	Overexposure to artificial lighting from nightlife activity can disrupt circadian rhythms and negatively impact health. In turn, this leads to negative perceptions of lighting, reduces the social sense of belonging, and, in turn, discourages community engagement in nighttime activities, weakening social cohesion.
R9	Regulation	Reinforcing	Technological advancements provide innovative solutions for lighting control and maintenance, promoting healthier environments. In turn, this contributes to environmental sustainability and well-being, encouraging further technological improvements and investment in lighting systems.
R10	Technology, Well-Being, and Environment	Reinforcing	Technological advancements provide innovative solutions for lighting control and maintenance, promoting healthier environments. In turn, this contributes to environmental sustainability and well-being, encouraging further technological improvements and investment in lighting systems.
R11	Technology and Social	Reinforcing	Technology platforms enhance social engagement, fostering a sense of belonging within the community. In turn, this increased social interaction helps strengthen ties to the urban space, reinforcing the community's connection to place and the positive outcomes of better lighting design.

4.2.3. Proposing Thematic Clusters, Possible Initial Scenarios

In this section, five thematic clusters were proposed based on a set of 13 feedback loops. These clusters were developed into possible initial scenarios, with their prioritization and phasing informed by Maslow's hierarchy of needs [61] as the guiding framework.

Scenario 1: Basic Needs Loop (R1–R4): In the initial stages, these loops illustrate how improved urban lighting enhances safety as a foundation, stimulates the economy, fosters nighttime activities, and furthers quality of life. As residents feel safer and more connected to their environment, social activities and a sense of belonging grow, creating a reinforcing cycle that further strengthens urban safety.

Scenario 2: City Enhancement Loop (R5–R6): These loops focus on how lighting enhances historical architecture, create a visual hierarchy, enhancing specific vista and focal points, guiding orientation, and contributing to the city's nighttime aesthetic appeal as city beautification.

Scenario 3: Extending City Value Loop (R7–R8): These loops focus on how lighting evokes emotional and feelings, storytelling, revitalize intangible and cultural value of the city and maximize the potential to create city branding for festivals and nightlife, attracting tourists and generating long-term economic benefits.

Scenario 4: Conflict Loop (B1–B2): These loops illustrate the unintended scenario of how increased tourism and economic activity can lead to conflicts such as light pollution, harm to the environment and residents' well-being. As nightlife grows, light pollution worsens, negatively affecting the environment and residents. This decline in environmental and social well-being reduces tourism and hospitality, weakening the sense of belonging.

Scenario 5: Problem-Solving Loop (R9–R11): These loops focus on how regulation and technological solutions technological advancements in urban lighting and the implementation of smart systems can improve lighting efficiency and management. This growth in technology reinforces sustainability efforts by optimizing energy usage and minimizing waste.

4.2.4. Developing Phasing Plan

The proposed phasing plan for the urban lighting masterplan in Chiang Mai Old City is structured around the scenarios derived from CLDs, prioritized based on stakeholder feedback through a participatory process and using Maslow's hierarchy of needs [61] as an evaluative framework to guide implementation, as shown in Figure 9.

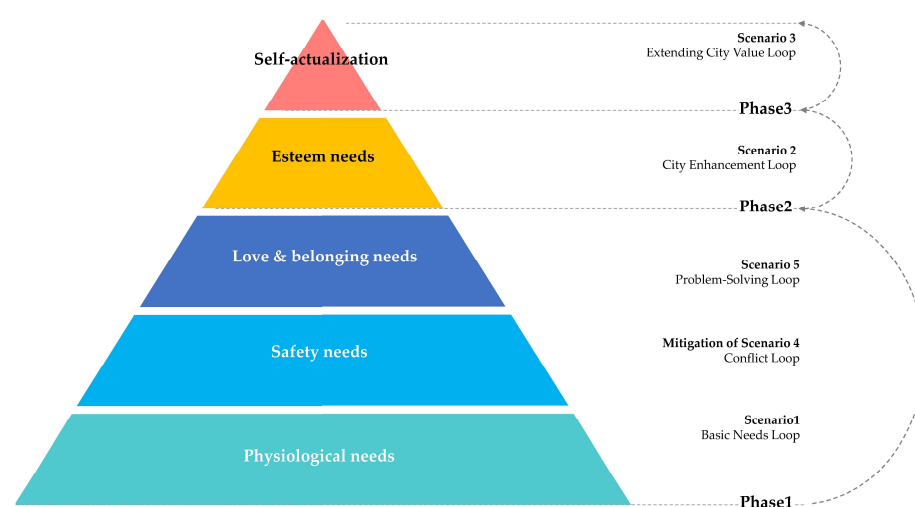


Figure 9. Scenario prioritization based on Maslow's hierarchy of needs framework [61]. Source: Authors.

First Phase: The initial phase emphasizes fulfilling basic physiological and safety needs, which form the foundation of Maslow's hierarchy. Stakeholder insights from

interviews and focus groups (results from Question 1) identified safety and security as top priorities. This aligns with the Basic Needs Loop scenario, emphasizing improvements in core infrastructure, mobility, and the balance between essential services and quality of life. Establishing a secure environment is crucial as it forms the foundation for subsequent urban lighting developments. To mitigate risks associated with excessive artificial lighting as highlighted in the Conflict Loop scenario, the Problem-Solving Loop scenario is further considered to prevent unintended negative consequences from the Conflict Loop. This scenario incorporates smart technologies, innovations in urban design, and potential regulatory measures, such as curfews or controls on lighting intensity, to address issues like light pollution and environmental degradation. This loop can positively impact people's perception by fostering a sense of belonging.

Second phase: Given Chiang Mai Old City's strong cultural and economic potential (results from Question 5), stakeholders' expectations extend beyond basic needs to focus on cultural heritage and economic development, particularly in tourism (results from Questions 2 and 3). This phase addresses the higher levels of Maslow's hierarchy, focusing on love, belonging, and esteem needs. The City Enhancement Loop drives this phase, combining practical and aesthetic improvements with economic objectives, particularly in the tourism sector. Key elements include enhancing the city's ambiance, highlighting its cultural heritage, boosting tourist attractions, and supporting festivals and iconic spaces. These improvements offer immediate and visible benefits.

Third phase: This phase addresses the highest level of Maslow's hierarchy, the Extending City Value Loop. This complex, long-term phase builds on the successes of earlier phases by enhancing the city's unique characteristics, revitalizing intangible cultural assets, and creating emotional connections. The ultimate goal is to shape the city's image and uniqueness through storytelling and deep cultural engagement.

In conclusion, each scenario represents a different pathway in the urban lighting master planning process for Chiang Mai. However, to ensure a holistic and inclusive approach that balances economic, social, cultural, and other key priorities, stakeholder analysis must be continuously conducted to make the scenarios and phasing more realistic and practical. The iterative design process should continue evolving, developing, and testing solutions until a fully functional and effective lighting strategy is achieved and ready for implementation [92].

5. Discussion and Conclusions

Based on the study's results and research framework, the discussion first highlights key insights into Chiang Mai Old City's unique characteristics, derived from a co-creative and holistic process called "side-to-side", which reflects multidisciplinary and interdisciplinary collaboration to enhance communication among stakeholders [17]. These insights align with the theoretical framework of an interactive process where knowledge is co-created through stakeholder engagement, rather than simply transferred from experts to the public as linear approach [17,85,86]. This participatory approach emphasizes shared interests and interconnections, with the potential to reveal broader urban lighting systems [87–89]. Finally, the discussion concludes by emphasizing how this systematic and holistic approach offers a comprehensive roadmap for urban lighting design that is adaptable to various urban contexts, particularly in other cultural heritage cities.

5.1. Evaluating Critical Factors

The framework of eight factors, derived from the literature review, provides a general interpretation of each factor. However, these interpretations may vary based on the diverse perspectives of researchers from different fields, helping to define the scope of the urban lighting system. This diversity of understanding, however, may lead to differences in interpretation between researchers and stakeholders.

Through the participatory process involving both in-depth interviews and focus groups, the shared interests of stakeholders were not only prioritized [87–89], but the pro-

cess also revealed a deeper, more accurate understanding of how each factor is interpreted by stakeholders. This collaborative approach helps reduce miscommunication and aligns the perspectives of both researchers and stakeholders. Additionally, sub-factors identified by stakeholders are crucial for enhancing the uniqueness of the city's lighting attributes. The following section discusses the role of each factor in the development of the urban lighting master plan for Chiang Mai Old City, aligning with the level of Maslow's hierarchy of needs [61].

5.1.1. Primary Concern Factor: Safety and Security

Safety and security emerged as the top priority across all stakeholder sectors (from Question 3), and were further highlighted as the first and second greatest concerns for Chiang Mai Old City (from Questions 1 and 2). Additionally, the interpretation of "safety and security" from their perspective specifically emphasizes the role of adequate lighting, which not only serve community needs equitably but also enhances the opportunities presented by Chiang Mai's walkable and pedestrian-friendly urban morphology (from Question 4).

Stakeholders agreed that sufficient lighting improves connectivity and mobility at night, fostering a sense of safety and security. This supports the notion that adequate lighting enhances individuals' confidence to venture outdoors after dark [13,16,19,76]. Therefore, this factor should be considered foundational, aligning with Maslow's "Physiological and Safety needs" [61], as it provides the necessary infrastructure to maximize the city's potential and create a secure nighttime environment.

5.1.2. Uniqueness Factor: Cultural and Heritage

Stakeholders emphasized that cultural and heritage is vital factor for shaping an ideal future perspective for urban lighting in Chiang Mai (from Question 2). This is supported by the results from Question 4, which identify culture and heritage as the greatest strengths of Chiang Mai Old City, though their potential is not fully maximized, raising concerns about the potential loss of cultural capital (as noted in Question 1). Moreover, stakeholders expect cultural and heritage aspects to extend beyond showcasing the tangible historical and architectural elements. They seek to enrich the spatial experience and emotional perception for residents and visitors by revitalizing the city's intangible assets through lighting.

This approach can enhance the city's identity and sense of place, creating a distinctive nighttime atmosphere that aligns with the phenomenology of light and cultural heritage issues [15,64–67]. These findings highlight the importance of leveraging cultural and heritage elements to maximize Chiang Mai's assets, aligning with the "esteem and self-actualization" level of Maslow's hierarchy of needs [61], and further supporting Chiang Mai as a culturally led development city [23].

5.1.3. Driver Factor: Economy

The economy, particularly the tourism sector, is considered one of the most important factors (from Question 2). This is further supported by Question 3, which shows that the economy ranks among the top three prioritized factors with high interest from all stakeholder sectors. Additionally, in Question 4, the tourism sector is identified as a strength of Chiang Mai, with its reputation as one-stop destination offering diverse tourist attractions, services, and hospitality, and backed by a well-developed and robust tourism industry.

As a result, this factor receives substantial support from various stakeholder groups, serving as a significant driver that attracts investment and fuels other aspects of urban development. This aligns with the notion that effective lighting not only enables businesses to operate after dark but also encourages people to gatherings and activities, creating vibrant and dynamic environments [13,24] and promoting nighttime tourism [23]. Furthermore, lighting can enhance features like public art, tourist attractions, and light festivals, which serve not only as cultural events but also as economic tools to attract tourists [15,63].

5.1.4. Sensitive Factor: Well-Being and Environment

Although the urban lighting design paradigm is increasingly focusing on holistic approach that goes beyond vision to include human well-being and environment [24,68], there are growing concerns about the impact of artificial lighting on circadian rhythms and overall health [17,20,67,69,72], including nocturnal landscapes, environmental considerations, and ecological impacts [17,57,58].

The results from stakeholders indicated that these two sensitive factors do not receive adequate attention (as shown in the results from Questions 1–3). In a city like Chiang Mai which has a mix of urban and natural landscapes, there is some discussion about balancing needs and contexts, particularly regarding the impact of lighting on residents' health and local wildlife. Improperly directed artificial light can disrupt wildlife patterns and interfere with essential behaviors, such as feeding, mating, and navigation.

This neglect poses a risk of long-term problems, as stakeholders may overlook important concerns, and effective lighting solution from literature related to controlling light pollution are receiving less attention [70]. This oversight could lead to the unchecked creation of light pollution with excessive illumination of streets, buildings, landscape, advertising, and skyglow [67,71,72].

5.1.5. Problem-Solving Factor: Technology and Regulation

The results from Questions 1, 2, and 3 revealed a surprising lack of awareness about technology and regulation. Technology is widely seen as a smarter, sustainable solution for addressing long-term environmental and social challenges [73,75]. Most stakeholders agreed with technology with energy-saving innovations and alternative energy to reduce costs and maintenance [74], and they mentioned its potential to drive long-term projects or raise public awareness through platform like big-data (question 5), supporting human-centered lighting design [15,20,71]. Interestingly, technology was also mentioned for its role in festival lighting, such as 3D mapping and lasers, which reflect short-term design priorities.

Regarding regulation, stakeholders saw it as essential for implementing urban policies, enforcing lighting standards, and guiding nightscape design as a balancing tool of environmental, health, and social concerns [25,69,71]. They emphasized both soft and hard laws [17] as well as design guidelines, as collaborative solutions, with public engagement and campaigns acting as incentives. Master plans, zoning, and strategic plans were highlighted as tools to ensure understanding across sectors.

5.1.6. Tricker Factors: Social

The social factor is considered as an ambiguous but critical element. Although the results from Questions 1–3 do not emphasize its significance as a technical major priority in terms of lighting design as a role to serve social needs or foster social interactions physically [15,21], there is a deep understanding of its broader social dimension. This extends beyond technical and aesthetic design to include mechanisms of administration [20] such as social engagement, collaboration, awareness, and public relations, which was reflected in the results from Question 4 and 5, where the involvement of diverse groups was highlighted as a key factor in creating opportunities for success. Social engagement emerges as a critical and complex factor that significantly influences long-term sustainable development.

5.1.7. Unexpected Factor: Mechanisms, Technical, Administration, and People Factors in Urban Lighting Master Plan Success

While the study framework initially focused on eight key factors from the literature for the urban lighting master plan [17], the participatory process revealed deeper concerns among stakeholders. Success in creating an urban lighting master plan extends beyond technical solutions which it requires a robust mechanism and effective administration (Question 5). Specifically, integrating strong social mechanisms is vital for fostering shared understanding and unity among all stakeholders, leading to long-term sustainability.

The results from Question 4 further highlight the strength of Chiang Mai's people, emphasizing that collaboration between government sectors, professionals, and end users is essential for driving engagement and cooperation. This aligns with the importance of stakeholders and participatory processes [28,32,33]. The paradigm in Chiang Mai Old City is shifting from a purely technical and aesthetic focus to a more holistic approach, aiming for sustainable development [8,17,25].

5.1.8. Shared-Interest Factor Between Local and Non-Local Participants: Cultural and Heritage

The findings reveal a strong shared-interest among both local residents and non-local tourists which is the significance of cultural heritage and the unique characteristics of Chiang Mai, particularly its Lanna culture. Many research participants mentioned the use of the "Phang Preteep", a traditional candlelit lantern, which not only represents local aesthetics but also embodies the community's deep-rooted spiritual practices. The collective acknowledgment of this lighting attributes reflects the predominant national and local Buddhist faith and represents the city's unique cultural identity.

The use of the Phang Prateep as a means of prayer illustrates the emotional and spiritual connection residents have with their faith and city, portraying lighting as a medium for expressing devotion to both the Buddha and the protective deities of the region. Additionally, warm colored-light is often highlighted as representative of the authenticity of brick materials, evoking feelings of calmness and tranquility within the city's natural context.

While it is common for different stakeholders to hold varying perspectives and concerns, the shared-interest in cultural heritage serves as a powerful unifying force. This alignment among diverse stakeholders presents a significant opportunity for developing an urban lighting master plan that resonates with the community's values and aspirations, ensuring the project reflects the city's rich cultural fabric while addressing the needs of its community members.

5.2. Relationship Among Urban Lighting Design Factors

Previous research has identified eight key factors contributing to a successful urban lighting master plan [17], but the dynamic relationships among these factors remain largely unexplored. This study addresses this gap by using CLDs to visualize how these factors interact, influencing each other through reinforcing or balancing feedback loops. The CLDs reveal the complex web of influences that shapes the effectiveness of a lighting master plan. The findings highlight two significant, opposing approaches to urban lighting development in Chiang Mai Old City, one driven by economic and cultural priorities and the other by well-being and environmental concerns.

The economy and culture-led approach prioritizes tourism, extended business hours, and the city's cultural identity, reinforcing Chiang Mai's attractiveness as a tourist destination. However, this approach poses risks such as exacerbating light pollution and negatively impacting residents' well-being and the environment. On the other hand, the well-being and environment-led approach aims to protect public health and preserve natural ecosystems. While beneficial in terms of reducing environmental impact, this approach may miss opportunities to capitalize on the city's cultural and economic assets, leading to potential losses in economic growth and cultural enhancement.

This tension between the two approaches presents a critical challenge for urban lighting designers and policymakers. Balancing the economic benefits of tourism with the need to protect the environment and improve residents' quality of life requires careful management. Without this balance, these competing priorities could undermine each other, resulting in less effective outcomes overall. To mitigate these conflicts and achieve a sustainable urban lighting master plan, preventive factors such as technology and regulation must be considered. Additionally, three key factors beyond the original eight are mechanisms, technical, and administrative factors which also influence the successful implementation of

a foundational structure that supports the carrying out, coordination, and monitoring of the lighting plan over time as part of sustainable development.

The overall relationship from this research reveals the need for a balanced lighting strategy that harmonizes these opposing forces. The eight factors, as shown in Figure 10, emphasize the importance of a holistic approach to urban lighting design [17], especially for a culturally significant tourist destination like Chiang Mai Old City with sensitive and diverse stakeholders. Understanding these intricate interactions is essential to addressing not only the technical aspects but also the social, cultural, well-being, and environmental dimensions of lighting design [8,17,25,26].

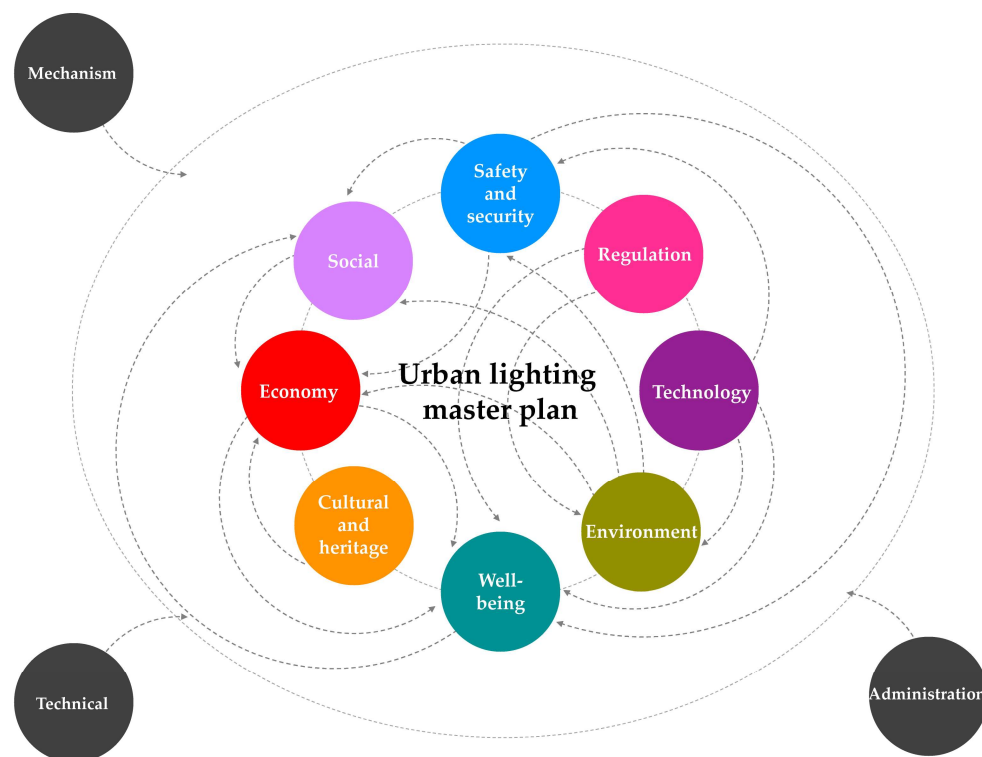


Figure 10. Interrelation of eight factors of urban lighting master planning, adapted from Zielińska-Dabkowska and Bobkowska’s framework [17], and three new influencing factors proposed in this research. The dashed arrow lines indicate influencing relationships between factors. Source: Authors.

5.3. Implementation

The framework presented in this study offers a systematic, holistic approach to developing urban lighting strategies. Its critical factors and their interrelationships can serve as a model for other cultural heritage cities. Additionally, this systematic approach offers a scalable roadmap for urban lighting design applicable to diverse urban contexts.

5.3.1. Urban Lighting Design Considerations for Cultural Heritage Cities

Results indicate that cultural and heritage factors play a crucial role in defining a city’s unique character, enhancing its identity, and fostering a distinct nighttime ambiance. To fully realize the potential of cultural heritage cities, urban lighting must evolve beyond basic technical requirements focused solely on safety and security. Instead, it should aim to create an environment that highlights the city’s unique character and sense of place, cultivating a distinctive nighttime atmosphere that aligns with the phenomenology of light and cultural heritage concerns [15,64–67].

A tailored urban lighting design guideline for cultural heritage cities can prioritize cultural and heritage element, serving as a strategic tool to enhance the overall aesthetic experience of urban environments [64,65]. This, in turn, contributes to effective city branding,

stimulating economic activity by attracting tourists, creating jobs, and driving consumption in vibrant nighttime destinations [5–7,13,15,17,22–24,67].

To effectively adapt these insights, four critical considerations should guide the development of urban lighting design guidelines for cultural heritage cities. First, the interpretation of cultural and heritage elements must extend beyond tangible historical and architectural features [17] to include intangible cultural assets to enrich the spatial experience for both residents and tourists, enhancing their emotional connection to the city [67].

However, interpreting these intangible cultural assets requires a sensitive approach, as lighting can impart meaning and emotional resonance to a place. The authenticity of the place should be preserved without misrepresentation, since diverse stakeholder perceptions may differ regarding the city's identity and character. Substantial social engagement and participatory processes are therefore essential to accurately capture these perspectives and reflect them in lighting strategies. Additionally, exploring and understanding the unique place identity of each city is essential for ensuring that lighting supports the city's cultural and historical essence.

In addition, specific attributes of lighting such as color temperature, type of light source, and direction, must be carefully controlled across both public and private properties to maintain a cohesive nightscape that authentically reflects the cultural heritage [15,64–67]. Ensuring a balance between public and private lighting elements fosters an integrated visual experience that respects the historic atmosphere of the heritage environment. Harmonizing lighting standards across public and private domains is essential to avoid conflicting light sources or color imbalances, which may detract from the nightscape's visual unity and cultural authenticity.

Second, this study reveals two contrasting approaches to urban lighting in heritage cities, one centered on economic and cultural tourism, and the other focused on community well-being and environmental concerns as responsible practices that minimize harm to local ecosystems, including insects and nocturnal animals. Artificial light, especially when improperly directed, can disrupt wildlife patterns and interfere with essential behaviors, such as feeding, mating, and navigation. Research indicates that artificial light can have detrimental effects on nocturnal species, disrupting their circadian rhythms and altering their interactions with the environment [67,70].

A key approach to mitigating these effects involves using fully shielded fixtures that direct light downward, reducing both skyglow and light pollution in sensitive areas. This strategy is crucial for species that rely on natural light cues to maintain their circadian rhythms, as shielded lighting can help preserve the nighttime environment [67,70]. Additionally, the guidelines should promote an environmental-friendly lighting with proper color temperatures, to reduce the attraction of insects, who play vital roles in ecosystems as pollinators and food sources for other animals. Lighting selection should also be less disruptive to the many animals that depend on natural darkness, such as bats, amphibians, and certain bird species [15,64–67].

Third, adaptive lighting technologies, which can dim or turn off lights during late-night hours or in response to occupancy, offer another layer of protection. This practice reduces unnecessary illumination, helping to limit the disruption of insects and nocturnal animals, and preserves dark sanctuaries within urban spaces. Such “dark refuges” create safe zones for wildlife, aligning lighting strategies with environmental and biodiversity goals [5–7,13,15,17,22–24,67]. Through these environmentally considerate lighting guidelines, cultural heritage cities can enhance their nighttime ambiance while actively supporting ecological health and sustainability.

Lastly, to support the long-term vitality of cultural heritage cities through extended nighttime activities and increased urban vibrancy, it is crucial to address the financial and environmental impacts of urban lighting. As cities invest in enhancing nighttime environments, costs associated with energy use, maintenance, and environmental management may increase. To mitigate these responsibilities and reduce associated costs, the

lighting guidelines should prioritize sustainable practices. This includes adopting energy-efficient lighting technologies, such as LED fixtures and smart control systems, which can significantly decrease energy consumption and maintenance requirements.

Sustainable lighting solutions not only reduce operating costs but also lessen the environmental footprint, benefiting both humans and local wildlife. By minimizing light pollution and carefully selecting lighting attributes like color temperature and brightness, cities can create a nighttime environment that is welcoming and attractive without disrupting local ecosystems. These practices ultimately enhance the aesthetic appeal and cultural integrity of heritage areas while supporting the ecological and economic sustainability of urban lighting initiatives.

5.3.2. The Application of Maslow's Hierarchy of Needs in Urban Lighting at City Scale

The framework of Maslow's hierarchy of needs, traditionally used to analyze individual psychological development [11–13,56,61], offers a unique approach for understanding and prioritizing diverse lighting requirements across a city's scale when adapted to urban lighting design. This framework aligns with a city's varying demands and enables a more holistic understanding of urban lighting, shifting the focus from purely technical considerations to human-centered outcomes [60].

Each city has its own set of challenges, making standardized solutions inadequate. Integrating Maslow's hierarchy of needs allows for a better understanding of stakeholders' expectations regarding urban lighting complexity in each city. Furthermore, the use of this hierarchy provides a clear method for prioritizing resource allocation and project phasing. This phased approach, in turn, helps manage stakeholder expectations and fosters a collaborative environment where stakeholders can see immediate benefits from lighting improvements while understanding the broader, long-term vision. Lastly, the flexibility of Maslow's hierarchy of needs ensures that the framework is adaptable to different cities and contexts, serving as a practical and scalable tool for urban lighting strategies.

5.3.3. Application of the System Dynamic Approach

While frequency and content analysis from in-depth interviews and focus groups helped identify and prioritize critical factors individually, CLDs provided a more comprehensive understanding of how these factors interact. CLDs are valuable for visualizing dynamic interrelationships [39,113], mapping feedback structures [101], and emphasizing non-hierarchical relationships [102]. This non-linear approach allows all variables to be considered equally, illustrating how feedback loops, whether reinforcing or balancing, impact the system and influence critical decision-making processes [28].

The key benefit of CLDs is their ability to capture complexity to understand the entire system [93]. Unlike traditional linear models that often oversimplify urban systems [85,86], CLDs highlight how factors interact over time, helping stakeholders understand potential compromises and unintended consequences. Urban lighting master plans rely on understanding these dynamics to create more informed and resilient strategies.

Previous research shows CLDs' effectiveness in exploring complex urban systems and integrating stakeholder perspectives [28,36–38,103]. This research builds on these findings, showing that CLDs are equally effective when applied to the specific field of urban lighting master planning. By making stakeholders' diverse perspectives more visible, CLDs reduce barriers to collaboration and help navigate challenges that typically arise in the planning process. Moreover, CLDs offer a way to reassess assumptions and identify potential risks not evident in the initial analysis, and guide decision-makers towards more adaptive, resilient strategies. This enhances the sustainability of urban lighting designs by addressing both current needs and future uncertainties.

5.3.4. Application of Multi-Stage Approach in Urban Lighting Master Planning

This study highlights the advantages of a multi-stage analysis approach in urban lighting master planning. Traditionally, single-step analysis methods, such as factor validation,

are applied to urban planning; however, these methods often overlook the interconnected relationships between factors. This lack of holistic analysis can result in unintended consequences due to insufficient consideration of interdependencies within the system.

To address these limitations, this research presents a systematic, multi-stage framework designed to enhance urban lighting master planning. The framework provides a structured, three-stage approach to account for complex interrelations, enabling a deeper understanding of urban dynamics. This process not only supports a more robust planning and development strategy, but also can be applied to cities of varying sizes and complexities, as illustrated in Figure 11.

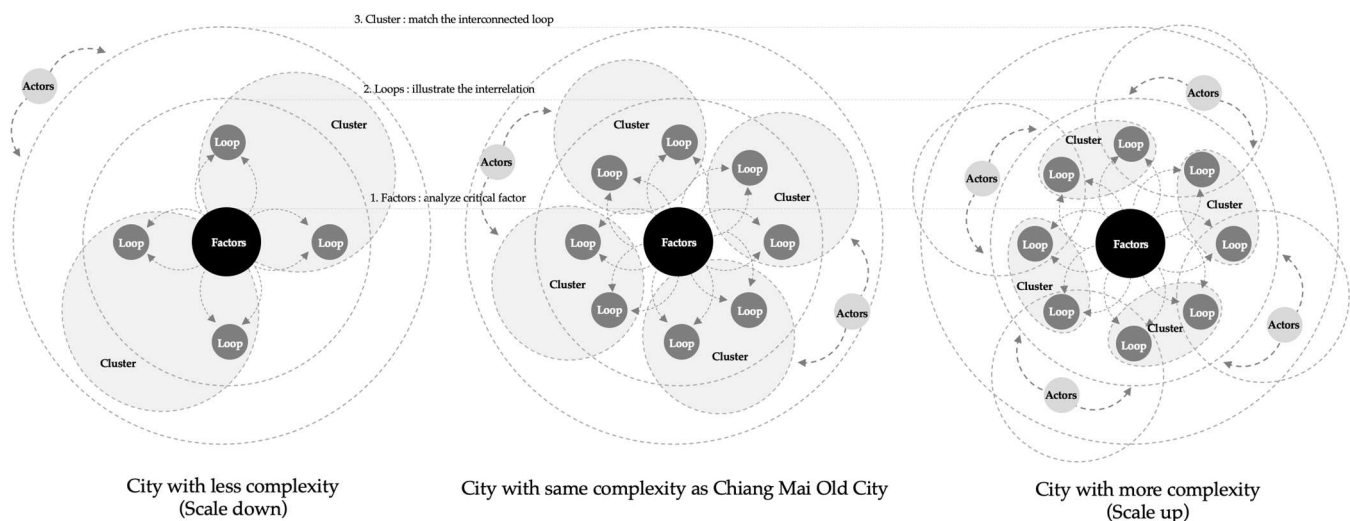


Figure 11. Schematic diagrams displaying application of a proposed multi-stage approach in urban lighting master planning for cities of varying complexities. The dashed arrow lines represent conceptual influencing relationships between factors. Source: Authors.

The Factors (Core Layer) serve as the initial analysis step in identifying critical factors and sub-factors that influence city development from the stakeholders' perspectives. In this stage, engaging with key stakeholders is crucial to uncovering the unique critical factors that vary by city. Identifying shared interest factors is essential, as these act as catalysts for stakeholder engagement, directly impacting the city's goal and challenges.

The complexity of the stakeholder landscape varies significantly between cities. In smaller and less complex cities, identifying shared interest factors is often straightforward due to a limited pool of stakeholders, which provides a well-rounded perspective. In contrast, in larger urban areas with diverse stakeholders, a broader pool of participants and a more structured stakeholder analysis are essential to assess each actor's power, influence, and interests.

This analysis illustrates the hierarchical relationships among stakeholders, highlighting key actors who can positively or negatively impact project development. Additionally, it helps minimize political sensitivities that could delay project implementation. Therefore, the depth of stakeholder engagement and analysis must align with the specific complexities of each urban context. For high-complexity cities, incorporating quantitative data collection methods, such as questionnaires, may be beneficial in engaging a larger pool of participants.

The Loops (Middle Layer) represent the interrelations between critical factors, capturing causal relationships and feedback loops. This layer illustrates how changes in one factor can either reinforce or balance the effects on others, emphasizing the dynamic nature of urban systems. CLDs serve as an effective tool for clarifying these interrelations.

In simpler urban contexts, CLD visualization can be completed by the researcher and later validated by stakeholders. However, in more complex cities, a more intensive participatory process, such as workshops involving stakeholders, is recommended to

collaboratively construct the CLD visualization. This approach helps address potential gaps that may arise from a researcher-led analysis.

For larger cities, CLDs can be divided into distinct zones or areas of shared interest to minimize errors that may occur when attempting to overlay complex relationships in a single diagram. Given the intricacies of these urban systems, this stage may necessitate multiple revision workshops to thoroughly address and complete the visualization of interrelations, ensuring that all complexities are carefully considered and integrated.

The Clusters (Outer Layer) illustrate potential scenarios for the city's development, arising from the interplay of factors and loops. These scenarios provide various pathways for future growth. In simpler, small-scale cities, thematic clusters can be directly translated into actionable implementation scenarios. In contrast, for more complex urban areas like Chiang Mai Old City, the development process may involve phasing to prioritize implementation areas one at a time. Mock-up installations can be used to test the impact of specific projects prior to full-scale implementation. In cities with even higher complexity, extended mock-up testing may be required, with pilot projects designed to assess impacts repeatedly until all gaps are identified and addressed. This iterative design process [17,92] highlights the necessity of refining solutions to minimize negative effects on both human and animal populations, thereby ensuring sustainable urban development.

5.3.5. Participatory Process: Challenges and Further Exploration

This study emphasizes the valuable insights gained from the participatory process, which are essential for decision-makers to ensure that the urban lighting master plan aligns with the community's needs and aspirations. These insights support the crucial role of participatory processes in fostering collaboration and developing sustainable solutions through a comprehensive and long-term approach [29–31].

The deep insight findings derived from in-depth interviews and focus groups also validate the benefit of shifting from conventional traditional linear, hierarchical methods, which may prove inadequate for addressing the complexities inherent in urban development projects like urban lighting master planning [17,85,86], to more co-creative and holistic approaches in urban lighting master planning.

This paradigm shift increasingly embraces participatory processes that involve a broader range of stakeholders, resulting in a more inclusive and effective strategy [8,17,25,26,57]. By employing a side-to-side approach, this research illustrates how collaborative engagement not only improves the efficacy of the design process but also reduces the potential negative impacts associated with implementation towards sustainable urban lighting strategies that align with the stakeholder and city's vision and values.

Nevertheless, several challenges and barriers emerged during the participatory process of this study. First, potential bias in snowball sampling was a concern due to the non-local status of the researcher, which may have limited the establishment of trust and familiarity. This complicates the achievement of fully random sampling, particularly in qualitative methods like in-depth interviews and focus groups. Consequently, reliance on personal recommendations from stakeholders becomes essential. To mitigate this bias, participants recommended by multiple primary stakeholders were prioritized, ensuring that key individuals were consistently identified throughout the sampling process. Additionally, efforts were made to expand the participant pool to balance the diverse perspectives obtained through snowball sampling. This involved reassessing the representation of various stakeholder types to identify and fill any gaps.

Second, the prioritization of stakeholder groups can provide varying scopes and perceptions of deep insights depending on participant selection. In this study, three groups were categorized based on the literature review [17,25–27,57], prioritizing stakeholders according to their roles, which were government sector, professional sector, and end users. While the results offer strong perspectives from various actors, there is less emphasis on a deeper analysis of the perceptions of local versus non-local stakeholders, such as tourists

versus residents. To address this limitation, future research should prioritize these two groups to gain a more comprehensive understanding of their sensitive differing viewpoints.

Third, a logistical challenge of this study was the non-local basis of the researcher, which introduced time constraints and travel limitations. While most interviews and focus groups were held in Chiang Mai, some were conducted online, which posed potential limitations in interactivity and understanding. To address this, Zoom Meeting Version: 5.17.7 (31859), a video conferencing platform, was used to facilitate face-to-face online engagement, allowing observations of participant reactions and the use of shared presentations to enhance clarity.

Finally, a semi-structured interview format was used to encourage open responses, following recommendations from the literature [104]. However, discussing urban lighting, a technical subject, proved challenging for some participants. Communication barriers, such as pauses or unclear answers, were mitigated by providing reference images in the presentation, allowing participants to select images that reflected their preferences. Additionally, a simple scoring system (e.g., 1–5) helped them express their evaluations more easily. Additionally, focus groups sometimes faced barriers when stakeholders from different organizations or levels of hierarchy were grouped together, as political sensitivities occasionally hindered open discussion. To address this in future studies, careful stakeholder grouping and offering individual questionnaires should be considered to capture more detailed, sensitive insights.

6. Conclusions and Suggestions

This research emphasizes the significance of a holistic approach informed by stakeholder perspectives, utilizing a comprehensive multi-stage analysis method through in-depth interviews, focus groups, and CLDs. This method enhances understanding of the complex factors influencing urban lighting while aligning strategies with stakeholder expectations through Maslow's hierarchy of needs [61].

The participatory process addresses diverse needs and facilitates a deeper understanding of each city's unique critical factors. CLDs provide insights into the interactions among various factors, minimizing unintended risks during implementation. However, the qualitative nature of this study limits the generalizability of findings, as they are based on in-depth interviews with only 60 participants. The selection of stakeholders may also introduce bias, with potential overrepresentation or underrepresentation of certain groups. Expanding stakeholder engagement and incorporating quantitative methods, such as surveys, would enhance the robustness and scalability of future research.

Additionally, reliance on the researcher's interpretation in CLD visualizations may introduce bias. Engaging stakeholders in an iterative feedback process to validate and refine these diagrams will improve the accuracy of insights and ensure a more inclusive urban lighting strategy.

To address these limitations, future research should explore the following factors:

- **Conducting Comprehensive Stakeholder Analysis:** Conduct a thorough stakeholder analysis to ensure more realistic and applicable urban lighting scenarios. Different stakeholder groups, each responsible for specific roles and stages in the planning process [28,32,33] have distinct short-term and long-term expectations, with different beneficiaries receiving value at each stage [31]
- **Validation and Refinement of CLDs with Stakeholders:** Engage in additional focus group discussions with diverse stakeholders to validate and refine the CLDs. This will ensure that the identified loops accurately reflect stakeholders' realities, concerns, and priorities, bridging the gap between theoretical models and practical application. This process will also help reduce researcher bias, making the urban lighting strategy more grounded and inclusive.
- **Development of CLDs into System Dynamics Models:** Expand the CLDs into comprehensive SD models to provide a dynamic, quantitative analysis of urban system. SD modeling can simulate interactions and changes over time, offering insights into long-

term impacts of urban lighting decisions. These insights should inform hypotheses that guide the testing of various urban lighting scenarios, leading to a more holistic and adaptive urban lighting master plan.

- **Conducting Comparative Studies Across Cultural Contexts:** Conduct comparative studies across diverse cultural, geographical, and demographic contexts to assess the applicability and scalability of this framework in other heritage cities.
- **Sensitive Demographic Groups Investigation:** Explore the contrasting needs of tourists and residents to identify leverage points that balance their interests.
- **Well-Being and Environmental Impact Examination:** Investigate the effects of urban lighting development on animal and wildlife well-being to ensure that lighting proposals promote sustainability.
- **Innovative Lighting Solutions Exploration towards sustainable development:** Utilize participatory insights to investigate lighting dynamics and technological innovations in urban lighting standards and design guidelines. Solutions like smart lighting systems should balance human, environmental, cultural, and aesthetic needs that contribute to sustainable urban lighting systems.

These suggestions provide a roadmap for developing a strategic urban lighting master plan that can serve as a framework for other cities, effectively balancing stakeholder interests with long-term sustainable urban lighting goals. By prioritizing inclusivity and integrating the perspectives of diverse stakeholders, including vulnerable communities and ecological considerations, this plan aligns urban lighting strategies with sustainable development objectives. Ultimately, it ensures that cities meet current needs while preserving their cultural and environmental assets for future generations.

Author Contributions: Conceptualization, P.N. and V.I.; methodology, P.N. and V.I.; formal analysis, P.N. and V.I.; investigation, P.N. and V.I.; data curation, P.N.; writing—original draft preparation, P.N.; writing—review and editing, P.N. and V.I.; visualization, P.N.; supervision, V.I.; project administration, V.I.; funding acquisition, V.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by Thailand Science Research and Innovation Fund Chulalongkorn University (SOCF67250004).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Office of the Research Ethics Review Committee for Research Involving Human Subjects: The Second Allied Academic Group in Social Sciences, Humanities, and Fine and Applied Arts of CHULALONGKORN UNIVERSITY (COA No. 262/67, 10 June 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Acknowledgments: The Thainess Study Scholarship for Graduate Students is deeply appreciated. The authors acknowledge the use of ChatGPT (<https://chat.openai.com/>, accessed during August–September 2024) to brainstorm information on related topics at the initial stage of manuscript preparation. ChatGPT was also used for suggestions on English grammar corrections and paraphrase. The following prompts were used: “stakeholder engagement for urban lighting”, “urban lighting design factor”, “participatory process in urban design”, “urban planning analysis method”, “visualization for urban complexity”, “correct grammar” and “paraphrase”. The output was used as a starting point to give a better understanding on related topics. The output was critically reviewed for idea generations. Selected sentences were checked for grammatical errors. The authors reviewed the generated feedback and revised the writing using their own words and expressions.

Conflicts of Interest: The authors declare no conflicts of interest.

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