Beyond Illumination: Stakeholders Perspectives and Preferences on Eco-Friendly Lighting for Sustainable Cities

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Abstract: This study explores integrating eco-friendly lighting technologies as crucial components in advancing sustainable smart city infrastructure. As cities strive to reduce their carbon footprint and enhance energy efficiency, lighting systems like LEDs and OLEDs have emerged as critical components. This research aimed to assess industry stakeholders' awareness, adoption drivers, and challenges associated with these technologies. The survey, with a 73% response rate was conducted among key stakeholders in the construction, architecture, and real estate sectors, and the data was analyzed statistically (ANOVA and independent T-test) to capture differences in perceptions. Results indicate that over 70% of respondents are familiar with eco-friendly lighting, with key adoption drivers being energy savings, cost efficiency, and regulatory compliance. Similar perceptions between male and female respondents were observed, while more experienced professionals showed a greater preference for energy-saving innovations. However, significant barriers to widespread adoption include high upfront costs and installation complexity. The study concludes that financial incentives and targeted education are essential to overcoming the barriers and accelerating the adoption of sustainable lighting technologies. These findings align with Sustainable Development Goals (SDGs) 7, 11, and 13, supporting clean energy and resilient cities. These findings underscore the critical role that eco-friendly lighting technologies can play in advancing sustainable urban environments.

Keywords: Eco-friendly Lighting; Energy Savings; Cost Efficiency; Sustainable Development Goals (SDGs); Sustainable Urban Environments.

1. Introduction

Assessing the impact of urbanization on the environment is essential for sustainable development, especially in rapidly growing cities [1]. The greenhouse gas emissions, resource scarcity, climate change, and energy security pose concerns to sustainability and the level of living in urban areas worldwide [2, 3]. Many cities have been looking into ways to become "smarter" cities [4] to solve these issues. A method to achieve this would be to diminish their carbon footprint and energy use. The advancement of technology underscores the essential need for global environmental sustainability [5] in construction and architectural design, to promote eco-friendly practices globally [6, 7]. The fundamental aspect of a sustainable building environment is the reduction of energy consumption [8] and the promotion of a healthy working environment [9], accessible through eco-friendly lighting.

Lighting accounts for roughly 20% of global electricity consumption and 40% of energy used in buildings [10], while daylighting can decrease the reliance on artificial lighting by 50–80% each year [11]. Campisi et al. (2018) indicate that interventions utilizing multi-criteria analysis may result in a 73.44% decrease in household CO2 emissions per square meter [12].

Eco-friendly lighting, such as LEDs, consumes less energy and has a longer lifespan than conventional bulbs, hence decreasing electricity usage and waste [13]. They emit minimal heat, potentially decreasing cooling expenses. Moreover, they frequently comprise less quantity of dangerous substances, so improving the environment [14]. Eco-friendly lighting technology can improve efficiency in the construction sector while simultaneously providing environmental advantages. Olajiga et al. (2024) examine energy-efficient lighting systems, highlighting their advantages, applications, and new trends, while emphasizing their role in energy conservation and sustainability initiatives [15]. Juric and Lindenmeier (2019) analyze the elements impacting consumer resistance to smart lighting, emphasizing substantial barriers and the need for targeted measures to enhance adoption rates [16]. Agboola and Nnezi (2024) emphasize the role of smart technology in improving thermal comfort, in conjunction with the use of sustainable lighting for eco-friendly urban settings [17]. Alotaibi et al. (2024) integrate urbanization challenges with sustainable solutions, emphasizing the importance of eco-friendly lighting as an integral part of smart city infrastructure to enhance energy efficiency and urban resilience [18]. Prior research on sustainable building lighting has predominantly concentrated on energy efficiency, specifically the implementation of LED technology and the incorporation of natural light and their importance in sustainable urban environments. Studies demonstrate that energy-efficient lighting options, such as LEDs, can reduce energy use by up to 75%, resulting in substantial decreases in both expenses and carbon emissions [19]. Research highlights the significance of daylight harvesting, which utilizes sunlight to diminish reliance on artificial lighting during daytime [20]. These systems, integrated with sensors and intelligent lighting controls, have demonstrated efficacy in optimizing energy consumption while ensuring occupant comfort [21]. Buildings integrated with automated lighting controls that adapt to occupancy and daylight conditions have demonstrated a 20-60% decrease in energy consumption [22]. Prior research on sustainable building lighting has utilized diverse methodologies to assess energy efficiency [23, 24], user behavior [23], and environmental influence [25] from manufacture to disposal. This discussion is around the significance of environmental performance measures, which have become an essential part of comprehending the global sustainability scene [26] through building lighting. In addition to the environment, lighting has health benefits for people [27]. For example, using adjustable white lighting can help improve sleep patterns and regulate circadian cycles [9].

Eco-friendly building lighting encompasses recognizing the advantages of energy-efficient solutions, minimizing light pollution, and utilizing sustainable, non-toxic materials, all of which contribute to promoting environmental sustainability and conserving energy. These gaps frequently impede the adoption of sustainable lighting solutions. This study offers empirical insights into the decision-making processes of professionals such as engineers, developers, and architects, evaluating their awareness, significant influences, and perceptions of eco-friendly lighting. The results were subsequently utilized to assess Sustainable Development Goals (SDG) compliance.

1.1. Background

With Thomas Edison's creation of the incandescent light bulb in 1879, the path toward energy-efficient lighting was set in motion in the late 1800s. Although they were considered innovative at the time, incandescent light bulbs were quite inefficient, emitting heat instead of light with only around 10–15% of the power used being converted into light [28]. Researchers are looking at alternative lighting technologies even though they have been widely used for decades due to worries about energy consumption and environmental effects [29, 30].

1.1.1. Eco-friendly Lighting (EFL)

The need for more eco-friendly and energy-efficient lighting options is causing a big shift in the lighting sector. The move to solid-state lighting, the introduction of smart lighting, and other significant developments are influencing the future of energy-efficient lighting. Human-centric lighting design, as well as lighting systems [31]. Eco-friendly lighting refers to lighting systems that are designed to minimize their impact on the environment [32]. Light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs) are two examples of solid-state lighting (SSL) technologies that are quickly displacing conventional lighting technologies like fluorescent and incandescent lights. Because of their extended lifetime, excellent energy efficiency, and positive environmental effects, LEDs in particular have emerged as the go-to option for energy-efficient lighting. The development layout of lighting technologies [33] is shown in Figure 1.

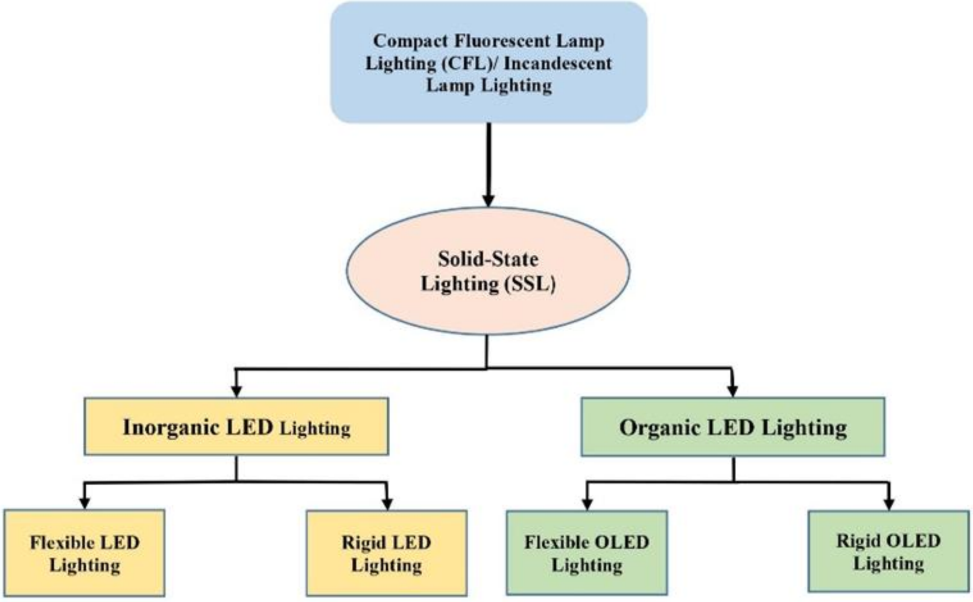


Figure 1. Development Layout of Lighting Technologies [33]

1.1.2. Types of Eco-friendly Lighting

Eco-friendly lighting options are designed to minimize environmental impact while providing energy-efficient illumination. Here are some common types:

1. Light Emitting Diodes (LED): These are energy-efficient, durable semiconductors that produce light with little thermal output and power usage, making them suitable for illumination and electronic applications.
2. Compact Fluorescent Lamps (CFL): These are energy-efficient bulbs that utilize mercury vapor for illumination, offering a longer lifespan than incandescent bulbs, but necessitating meticulous disposal. They are being supplanted by more efficient LEDs.

3. Solar-powered Lights: Solar-powered street lighting uses photovoltaic panels to transform sunlight into energy, providing a cost-efficient, low-maintenance alternative with LED lamps and battery storage.
4. Smart Lighting Systems: These systems encounter difficulties in controlling multiple fixtures, reconciling efficiency with life-cycle expenses, and validating that performance improvements justify elevated costs.
5. Daylighting: It is essential for energy efficiency in building environments, necessitating meticulous planning [34] to harmonize light quality, thermal gain, and accessibility [35]. Photosensors can maximize daylight utilization, improving energy efficiency; however, user acceptance is essential for achieving maximum energy savings.

1.1.3. Mechanisms of EFL

EFL lamps demonstrate performance characteristics similar to LEDs, particularly in light output (lm/W), color accuracy, lifespan, and the scotopic-to-photopic (S/P) ratio. This ratio signifies effectiveness under several lighting conditions, highlighting the improvement of visual systems in low-light settings, assisting the public as well as manufacturers in determining suitable lighting options [36]. Thus, comprehending the comparative characteristics of EFL and LED lamps is crucial for developing lighting technology and enhancing visual experiences. Artificial electric lighting significantly impacts circadian cycles, influencing several physiological, metabolic, and behavioral functions. Studies demonstrate that conventional household lighting utilized throughout the evening might delay the production of melatonin and reduce its peak levels, underscoring the possible health implications linked to artificial illumination [37]. Thus, these findings highlight the complex interplay between light exposure and physiological responses, prompting critical questions regarding the optimization of lighting to alleviate negative impacts on circadian health and general well-being. Electrodeless fluorescent lamps (EFLs), inspired by Nikola Tesla's pioneering work, rely on specialized ballasts to manage their distinctive negative impedance, ensuring both efficiency and safety in operation. This interaction exemplifies the complexities inherent in the design of lighting systems that meet the requirements of functionality, safety, and performance [38]. Electrodeless fluorescent lamps (EFLs) are a kind of discharge lamps that employ magnetic components instead of electrodes to ionize the internal gas. By employing an electromagnetic core and ballast, these lamps create a field that energizes the gas, improving both efficiency and lifespan, thereby establishing EFLs as advanced and energy-efficient lighting options compared to conventional lighting [39]. Electroluminescence is recognized for its exceptional efficiency and minimal heat generation, potentially lowering energy expenses by as much as 75% when compared to traditional incandescent bulbs [19].

1.1.4. Application of EFL

Research focuses on enhancing the efficiency of EFLs, while the scaling up of LED production is anticipated to lead to lower prices, making them more accessible. The widespread application of LEDs in areas such as displays, horticulture, and automotive lighting fosters innovation, prioritizing energy efficiency, minimizing light pollution, and utilizing sustainable materials to promote environmentally friendly options. [40]. Smart lighting systems are changing the way lighting is controlled across various settings, with a strong emphasis on energy efficiency, user-focused design, and sustainability. [41]. Future lighting solutions will be designed to be more user-friendly and environmentally sustainable, influenced by the move toward solid-state lighting, smart technologies, and human-centric design [42]. Energy-efficient lighting options such as CFLs and LEDs lower maintenance expenses, enhance the quality of illumination, and decrease energy consumption, making them well-suited for commercial, industrial, and residential applications [19]. Energy-efficient lighting options, especially LEDs, have a lifespan that is up to 25 times greater than that of incandescent bulbs and 10 times longer than CFLs, leading to lower maintenance costs and less frequent need for replacements [43]. Energy-efficient lighting, particularly LEDs, enhances safety by increasing visibility and minimizing glare. Additionally, smart systems that adapt to occupancy and natural light levels further improve security [44].

1.1.5. Driving Factors for EFL Adoption

The retail energy sector is experiencing substantial transformations, with multiple organizations offering diverse energy services designed to improve domestic efficiency. In most developed regions, consumers have presently benefitted from a wide variety of energy pricing alternatives, fostering competitiveness and enhancing choices. Additionally, advancements in data collection technology enable providers to deliver tailored, real-time insights that support energy efficiency and encourage shifts in consumption patterns. The interplay among consumer preferences, technology, and energy efficiency has the potential to transform the energy industry, promoting a more sustainable and adaptive marketplace [45]. The interplay between market dynamics and developments in demand-side technologies underscores the importance of fully recognizing energy behaviors in dwellings, essential for improving energy efficiency and sustainability in the residential sector [46].

More comprehensively, the various social factors affecting the adoption of sustainable technologies have become increasingly significant as policies and resources converge to create decarbonized and smart urban environments [47]. Customers and enterprises that may lack the knowledge or resources to properly integrate these technologies may find it difficult to overcome this complexity [48]. Compatibility challenges with existing systems can impede adoption; however, energy-efficient lighting continues to advance, aiming to lower energy consumption and minimize environmental effects [28]. The aforementioned field experiences serve to emphasize the importance of understanding energy behaviors to develop effective policies. The increasing research on the diffusion of sustainable technologies is crucial for promoting sustainability and addressing climate change [49].

Technologies for energy-efficient lighting, especially those that promote human-centric lighting design, may improve people's health and quality of life [50]. Reduced energy use, cheaper maintenance costs, better illumination quality, increased safety and security, and possible health and well-being benefits [51] are just a few advantages of energy-efficient lighting solutions [52]. These advantages contribute to a more sustainable and ecologically friendly lighting future by making energy-efficient lighting an appealing and affordable option for industrial, commercial, and residential applications [33]. Although there have been advancements in environmentally friendly lighting technologies, a gap persists in stakeholders' comprehension. Disjointed strategies have resulted in a wide array of factors affecting energy consumption and purchasing behaviors among different demographics, but they do not sufficiently consider the varied contexts that influence these behaviors [53]. The results of these studies cannot be broadly applied because of differences among product categories. A literature review identified few previous studies on the adoption of LED lamps [54, 55], thereby underscoring the scarcity of research in this particular domain. This gap within the building sector often hinders the adoption of sustainable lighting solutions.

In conclusion, energy-efficient lighting solutions have many advantages, but adoption is hampered by several issues, such as high upfront prices, technical difficulty, the need for regulatory assistance, market obstacles, and difficulties with disposal and recycling. This quantitative study provides insights into stakeholders' decision-making on eco-friendly lighting, assessing awareness, key influencers, and perspectives. Collaboration among policymakers, industry, and consumers is essential to promote these technologies and enhance sustainability and energy efficiency.

1.2. Novelty and Aim of Research

In summary, recent research on eco-friendly lighting (EFL) reveals three significant gaps: the limited reflections of multi-stakeholder perspectives in EFL studies, the under-examination of sector-specific barriers including high upfront cost and installation complexities, and a rare consideration of the effects of gender and professional experience. This paper aims to address these gaps through the following innovations:

- Conducted a comprehensive stakeholder analysis advancing research on EFL by capturing diverse perspectives.
- Provided a detailed study of specific adoption barriers of EFL, including high upfront costs and installation complexity. This thorough analysis offers targeted insights into the limitations of EFL implementation, making it a valuable resource for overcoming industry challenges.
- Evaluated multiple lighting technologies (LEDs, OLEDs, solar-powered lights, CFLs, smart lighting systems), to assess the viability and sectoral resistance patterns and preferences and offer valuable guidance for informed EFL technologies adoption across diverse sectors.
- Analyzed the impact of demographic factors, including gender and professional experience, on attitudes toward eco-friendly lighting, providing valuable insights for tailored adoption strategies and highlighting EFL's role in smart cities, focusing on its contributions to energy efficiency and sustainability.

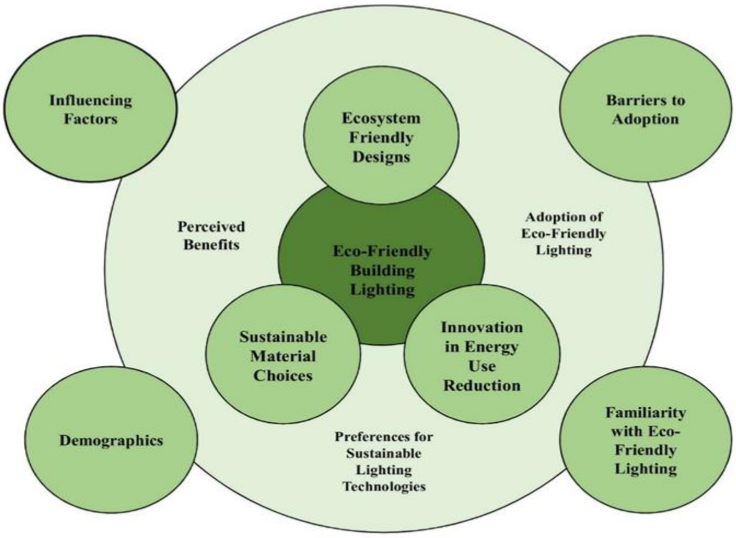


Figure 2. Schematic of Research Indicators

2. Material and Methods

A structured questionnaire is utilized, which was chosen as the primary research instrument due to its ability to gather quantifiable insights from industry professional's large sample [56], which is considered for evaluating the eco-friendly lighting adoption. The study surveyed participants from Asia and Europe, encompassing industry professionals from several geographical regions to capture differing regional perspectives on eco-friendly lighting systems. A targeted sampling method was employed to directly engage the experts in lighting design and execution. Survey participants were chosen via professional networks, industry associations, and targeted email invites to guarantee relevance and precision in gathering perceptions and insights. Hence, the sample consisted of 252 professionals in architecture, engineering, and facility management, selected for their direct involvement in lighting design and implementation, which aligns with previous findings that emphasize the pivotal role of these industry experts in sustainable building projects to provide accurate insights into practical challenges and adoption barriers [57].

The questionnaire contains two sections: first general information about demographics (gender, age, type of work, and work experience). The second part is classified as Familiarity with Eco-Friendly Lighting, Perceptions and Attitudes (perceptions and preferences related to sustainable lighting), Barriers to Adoption (challenges in adopting eco-friendly lighting technologies), and

Influencing Factors (factors influencing to adoption of eco-friendly lighting solutions), ensuring a logical flow and enhancing respondent engagement [58]. The survey on eco-friendly lighting was conducted over six months. This extended timeframe facilitated comprehensive data collection and allowed for a thorough analysis of participant responses. To maintain ethics in an eco-friendly building lighting questionnaire, ensure informed consent by explaining the study's purpose, guarantee anonymity and confidentiality of responses, and allow participants the right to withdraw at any time. Also, be transparent about how data will be used and shared, and ensure participation is voluntary without coercion.

We used a 5-point Likert scale in the eco-friendly building lighting questionnaire to capture a range of responses. The numbers assigned for the Likert scale are assumed to be 1, and 2,3,4,5, respectively. The Likert scale is one of the most widely used ranking tools in lighting research, helping to assess participants' attitudes and preferences systematically [59] [60]. Data from an eco-friendly building lighting questionnaire is parametric because it involves Likert scale responses, which are treated as interval data for statistical analysis, assuming underlying continuous distribution and equal intervals between scale points [61]. This allows for the use of parametric tests to analyze and interpret the data. An online survey was chosen for its cost-effectiveness and ability to reach a broad, diverse group of stakeholders quickly [62]. This method has been successfully used in lighting studies to capture consumer attitudes towards energy-efficient technologies [48, 62]. The survey was sent out using targeted email invites, industry groups, and professional networks. The 73% response rate was attained by focused interaction with essential stakeholders and the survey's pertinence to their professional interests. The collected data was analyzed using descriptive and inferential statistics through SPSS to identify relationships between variables and inform decision-making regarding eco-friendly lighting solutions. An ANOVA test was conducted to evaluate the perceptions of stakeholders across innovation in energy use reduction, sustainable material choices, and ecosystem-friendly designs [63]. The independent samples t-test was used to compare perceptions of sustainability [64] between male and female respondents. The Descriptive analysis was utilized to gain insights into the demographic characteristics and professional backgrounds of the respondents. For this step, it is appropriate to use descriptive analysis for the mean value and standard deviation of stakeholders [65]. Quantitative studies provide references to acknowledge prior research, ensuring credibility and supporting the validity of findings by building on established knowledge [48]. This helps situate new research within the broader academic context. The overall methodology flow diagram is mentioned in Figure 3.

The questionnaire contributes to the theoretical framework of sustainable architecture by elucidating building stakeholder’s attitudes and preferences towards eco-friendly lighting, enhancing knowledge in the field of sustainable design. It offers valuable data for architects, designers, and policymakers to develop and implement more effective strategies for incorporating energy-efficient lighting solutions in building projects, promoting broader adoption of sustainable practices. In eco-friendly building lighting, the materials and methods are often analyzed based on energy efficiency, light distribution, and environmental impact [66]. Here is a generalized mathematical framework involving some key principles and equations: (1)

$$\eta=\text{Power Input/Luminous Flux} \qquad (1)$$

Measures how efficiently a light source converts electrical energy into visible light. It's typically measured in lumens per watt (lm/W) [67].

$$LPD=\text{Area } (m^2)/\text{Power } (W) \qquad (2)$$

to be used to assess the contribution of daylighting to indoor lighting levels [68].

$$DF=Eo/Ei\times 100 \qquad (3)$$

Where, E_iE_iE_i = Illuminance level inside the building (lux) and E_oE_oE_o = Illuminance level outside the building (lux).

To estimate the total energy consumed for lighting based on the area, usage patterns, and efficiency of lighting fixtures [69].

$TEC=LPD\times \text{Occupancy hours} \times area$ (4)

To quantify the amount of heat generated by lighting, which affects the building's cooling requirements [70].

$Q=U\times A\times \Delta T$ (5)

Where, U = Thermal transmittance (W/m^2K), A = Area (m^2), ΔT = Temperature difference between inside and outside

Simple cost analysis of lighting based on energy consumption and local energy rates [71].

$C=\text{Energy Consumption}\times\text{Energy Price}$ (6)

To ensure that lighting is distributed evenly across a space. E_{min} is the minimum illuminance, and E_{avg} is the average illuminance in the space.

$U=E_{avg}/E_{min}$ (7)

For an eco-friendly building lighting questionnaire using a Likert scale, the relevant index is calculated using a specific formula (8). This formula translates qualitative responses (such as levels of agreement or satisfaction) into quantitative values, allowing for statistical analysis.

$\text{Overall Satisfaction Index}=\sum^{n}_{i=1}\text{Satisfaction Score}_i/n$ (8)

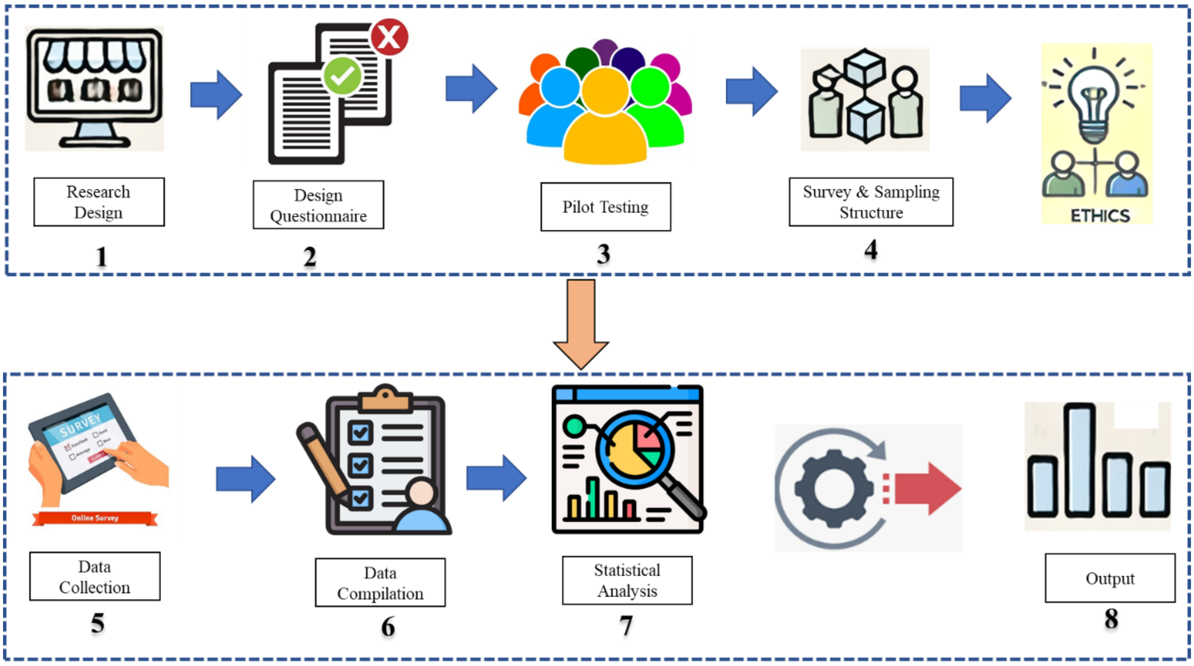


Figure 3. Schematic presentation of methodology

3. Results & Discussions

3.1. Demographics

The study utilizes a robust sample of 252 respondents to provide a detailed analysis of key research variables, including industrial sector, years of professional experience, geographic origin, and gender. Descriptive statistics reveal insights into the respondent demographics and professional backgrounds. The industry sector is divided into three primary categories—architecture, construction, and real estate—to enable the comparison of stakeholder perspectives among these groups. The mean number of years of professional experience is 2.48, indicating a diverse range among respondents. The geographic origin primarily stems from two regions, Asia and Europe, with an average value of 1.51, suggesting a probable representation of several locations. Demographic factors significantly impact perceptions and adoption rates of eco-friendly lighting technologies. Results show that age, gender, and education level all play a role in shaping attitudes towards sustainable lighting solutions. For instance, younger individuals and those with higher educational attainment tend to exhibit greater familiarity and positive attitudes towards eco-friendly lighting, likely due to increased exposure to environmental issues and technological innovations [72]. Gender differences also emerge, with studies indicating that women are generally more supportive of sustainability initiatives, including eco-friendly lighting, compared to men [73]. The gender variable exhibits a mean of 1.46, signifying a marginally greater proportion of male respondents (54.4%) relative to female respondents (45.6%), as shown in Table 1. These findings indicate fewer extreme values and less concentration around the mean, suggesting greater variability within the sample, especially for gender and geographic location.

Additionally, geographic location can influence perceptions, as individuals in urban areas may have more exposure to and access to sustainable lighting options compared to those in rural settings [74]. Understanding these demographic variations is essential for developing targeted strategies that address diverse needs and enhance the effectiveness of eco-friendly lighting adoption.

Table 1. Descriptive Analysis of Demographic Variables

Industry sector	Frequency	Percent	Average value	S.D
Construction	84	33.3	2.00	.818
Architecture	84	33.3		
Real estate	84	33.3		
Total	252	100.0		
Years of experience	Frequency	Percent	Mean	S.D
1-10	64	25.4	2.48	1.113
11-20	64	25.4		
21-30	64	25.4		
31 above	60	23.8		
Total	252	100.0		
Geographic Location	Frequency	Percent	Mean	S.D
Asia	124	49.2	1.51	.501
Europe	128	50.8		
Total	252	100.0		
Gender	Frequency	Percent	Mean	S.D
Male	137	54.4	1.46	.499
Female	115	45.6		
Total	252	100.0		

3.2. Perceptions

The perceptions of consumers and stakeholders about eco-friendly lighting are becoming increasingly important as sustainability gains prominence in both residential and commercial domains [75]. Studies demonstrate that consumers are increasingly predisposed to select energy-efficient lighting alternatives, such as LEDs, owing to their long-term financial benefits and diminished ecological footprint [76]. Stakeholders, such as manufacturers and legislators, see this change in consumer behavior and are responding by creating innovative products that correspond with these environmentally conscious preferences [77]. Thus, it is essential for various stakeholders, including government entities, innovative entrepreneurs, and the dynamic private sector, to collaborate on public initiatives that facilitate LED adoption to diminish expenses and environmental effects. An innovative green marketing strategy is essential to inform consumers about the advantages of energy efficiency, thereby fostering and maintaining informed choices.

The findings from this study highlight numerous implications that could be crucial in developing efficient strategies or sound policy plans to promote eco-friendly products. Ultimately, utilizing this useful information could result in a more sustainable marketplace where customers are better informed and encouraged to make decisions that benefit both themselves and promote a healthy world for future generations. Realizing that attitudes affect consumer behavior, policymakers and marketers must develop innovative strategies—such as dynamic marketing and appealing infomercials—to increase enthusiasm for energy-efficient options and foster environmental awareness. This dual approach attempts to transform consumer attitudes and foster an enduring link between consumers and energy-efficient technologies, thus facilitating a healthier and environmentally friendly future.

3.2.1. Familiarity

Familiarity with eco-friendly lighting denotes the degree of knowledge and awareness individuals or professionals have concerning sustainable lighting systems. This encompasses knowledge of energy-efficient lighting technologies, including LED, CFL, and solar-powered fixtures, along with innovations such as smart lighting systems. Familiarity also includes awareness of the environmental advantages associated with these systems, such as decreased energy use and reduced carbon footprints [78]. Additionally, it involves awareness of the materials utilized in EFL, including recyclable or sustainable components. Professionals may also be aware of LEED and other industry certifications and standards that encourage the use of sustainable lighting [79]. The degree of familiarity may vary based on exposure to these technologies through education, industry trends, or practical application in construction, architecture, and real estate fields.

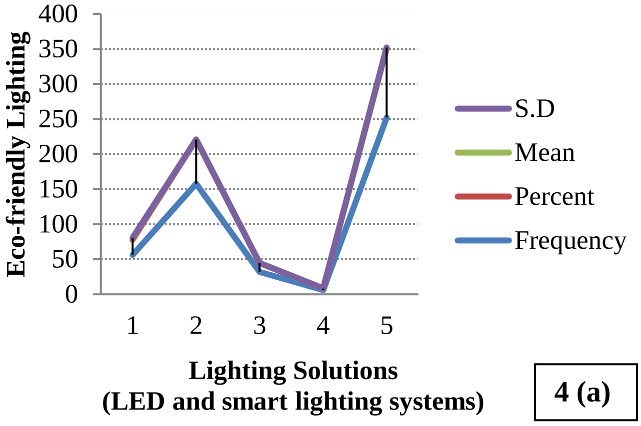
3.2.2. Influential Factors

The adoption and perception of eco-friendly lighting technologies are influenced by several key factors. Energy efficiency is a primary consideration, as systems like LEDs and solar-powered lights reduce energy consumption and operational costs over time. Cost-effectiveness, particularly the balance between initial investment and long-term savings, is also critical. The graphs depict the eco-friendly lighting survey results across various response categories. The x-axis of each subplot represents the frequency of responses (ranging from 1 to 7, depending on the chart), while the y-axis represents the values for Standard Deviation (S.D.), Mean, Percent, and Frequency of responses. Each colored line provides different statistical insights: purple for S.D., green for Mean, red for Percent, and blue for Frequency. Across many graphs, the frequency (blue line) reaches its highest point at frequencies 4 or 5. In some subplots, the frequency value at 4 reaches as high as 350, particularly in the bottom row's graphs. This suggests a concentration of respondents favoring mid-level engagement with eco-friendly lighting. In some graphs (e.g., top right), frequencies 3 and 5 are high, with values reaching 200 and 250, respectively. The purple line, representing the variability in responses, tends to peak at higher frequencies. For example, in the graph at the bottom left, S.D. reaches nearly 400 at frequency 4, indicating significant variability in opinions at this frequency. In Figure 4, S.D. remains closely aligned with frequency, indicating that the spread of responses is directly related to how frequently eco-friendly lighting is used. The green line, representing the mean, follows a similar trend to the frequency line. For example, in the middle left graph, the mean peaks around frequency 4 with a value close to 250. This consistent alignment between the frequency and mean values implies that the majority of respondents reported mid-range frequencies in terms of eco-friendly lighting practices shown in Table 2. The percentage line (red) is consistently lower than the frequency and S.D. lines in most subplots, reflecting a relatively lower overall proportion of respondents at each frequency level. For example, in the top middle graph, the percentage value at frequency 5 is around 50, whereas the frequency value is close to 200. This suggests that while certain groups engage with eco-friendly lighting, they represent a smaller proportion of the total responses. The frequency and S.D. tend to peak at similar points in most graphs, typically around frequency 4 or 5. In contrast, the mean and percentage values show smaller peaks and more modest variations. The pattern of these peaks, particularly at mid-level frequencies, suggests that respondents are inclined toward moderate use of eco-friendly lighting, with significant variability among responses.

Table 2. Descriptive Analysis of Eco-Friendly Lighting with Influencing Factors (N=252)

How familiar are you with eco-friendly building lighting technologies (e.g., LED, smart lighting systems	Frequency	Percent	Mean	S.D
Very familiar	56	22.2	1.95	.666
Familiar	158	62.7		
Somewhat familiar	32	12.7		
Not familiar	6	2.4		
Total	252	100.0		
What factors influence your decision to adopt eco-friendly lighting solutions in building projects?	Frequency	Percent	Mean	S.D
Energy efficiency	47	18.7	2.81	1.323
Cost savings	73	29.0		
Environmental impact reduction	49	19.4		
Regulatory compliance	48	19.0		
Occupant health and well-being	35	13.9		
Total	252	100.0		
To what extent do you believe eco-friendly building lighting solutions contribute to energy savings, improved indoor environment quality, and reduced carbon footprint	Frequency	Percent	Mean	S.D
Strongly agree	48	19.0	2.27	.927
Agree	121	48.0		
Neutral	52	20.6		
Disagree	29	11.5		
Strongly disagree	2	.8		
Total	252	100.0		
What are the main barriers preventing the wider adoption of eco-friendly building lighting?	Frequency	Percent	Mean	S.D
Initial costs	48	19.0	2.27	.927
Lack of awareness or information	121	48.0		
Perceived complexity of installation or maintenance	52	20.6		
Resistance to change from traditional lighting systems	29	11.5		
Other	2	.8		
Total	252	100.0		
Which eco-friendly lighting technology do you prefer for building projects?	Frequency	Percent	Mean	S.D
LED	84	33.3	2.00	818
CFL	84	33.3		
OLED	84	33.3		
Total	252	100.0		
Have you implemented or worked with smart lighting systems in building projects?	Frequency	Percent	Mean	S.D
Yes, extensively	119	47.2	1.57	.571
Yes, to some extent	123	48.8		
No, not yet	10	4.0		
Total	252	100.0		
How important is lighting quality (e.g., color rendering, uniformity) in your decision-making for building lighting systems?	Frequency	Percent	Mean	S.D
Very important	48	19.0	2.27	.927
Important	121	48.0		
Neutral	52	20.6		
Less important	29	11.5		
Not important at all	2	.8		
Total	252	100.0		

How important are green building certifications (e.g., LEED, BREEAM) in influencing your choice of lighting solutions for building projects?	Frequency	Percent	Mean	S.D
Very important	48	19.0	2.27	.927
Important	121	48.0		
Neutral	52	20.6		
Less important	29	11.5		
Not important at all	2	.8		
Total	252	100.0		
To what extent do government policies and incentives influence your decision to adopt eco-friendly lighting solutions?	Frequency	Percent	Mean	S.D
Strongly influence	124	49.2	1.88	1.053
Influence	66	26.2		
Neutral	30	11.9		
Do not influence	32	12.7		
Total	252	100.0		
How often do you consider life cycle costs (including maintenance and disposal) when selecting lighting systems for building projects?	Frequency	Percent	Mean	S.D
Always	78	31.0	1.88	.698
Often	126	50.0		
Sometimes	48	19.0		
Total	252	100.0		
Do you believe there is a need for more training and education on eco-friendly lighting technologies and practices within your industry?	Frequency	Percent	Mean	S.D
Yes, strongly agree	47	18.7	1.99	.665
Yes, agree	169	67.1		
Neutral	30	11.9		
No, disagree	4	1.6		
No, strongly disagree	2	.8		
Total	252	100.0		
How often do client preferences or demands influence your decision to incorporate eco-friendly lighting solutions in building projects?	Frequency	Percent	Mean	S.D
Always	116	46.0	1.85	.984
Often	87	34.5		
Sometimes	21	8.3		
Rarely	28	11.1		
Total	252	100.0		
What future trends do you foresee in eco-friendly building lighting over the next 5-10 years?	Frequency	Percent	Mean	S.D
Increased adoption of smart lighting systems	64	25.4	2.02	.806
Integration of renewable energy sources with lighting systems	134	53.2		
Advancements in OLED technology	39	15.5		
Greater emphasis on circadian lighting	15	6.0		
Total	252	100.0		
How important are collaborations and partnerships with lighting manufacturers and suppliers in achieving sustainable lighting solutions?	Frequency	Percent	Mean	S.D
Very important	75	29.8	1.85	.659
Important	143	56.7		
Neutral	32	12.7		
Less important	2	.8		
Total	252	100.0		



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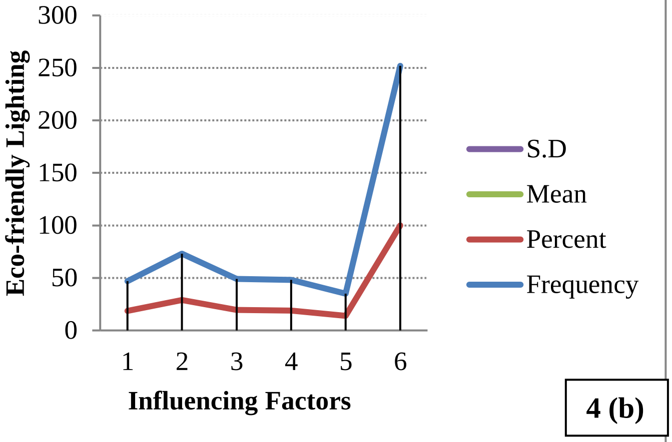

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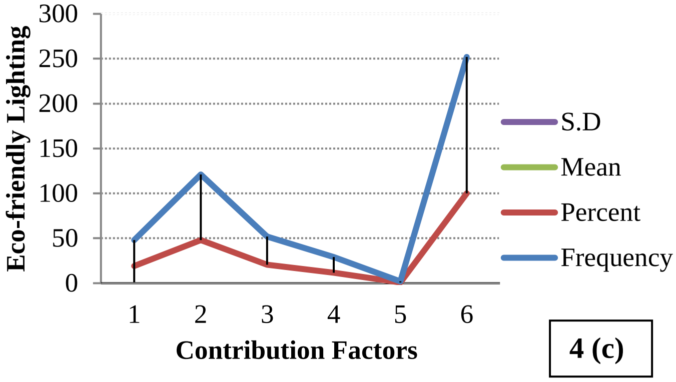

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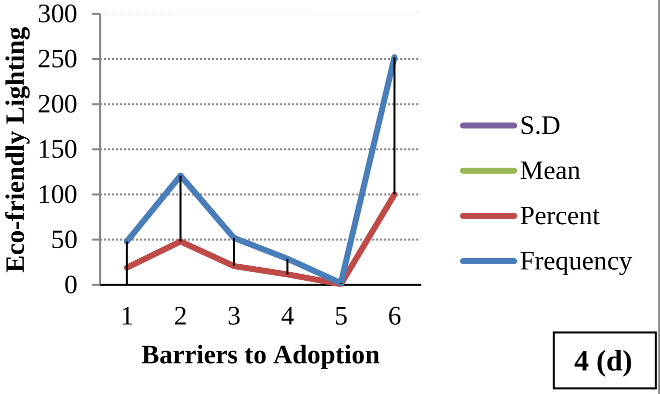

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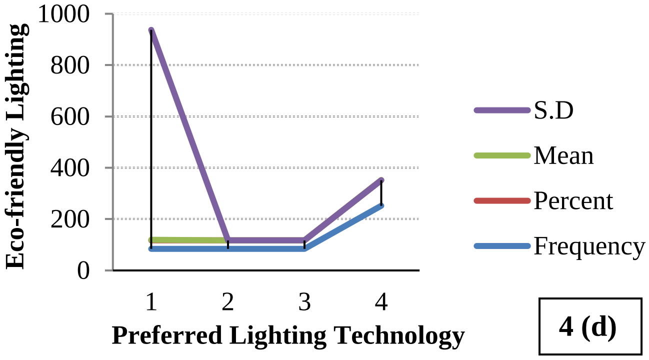

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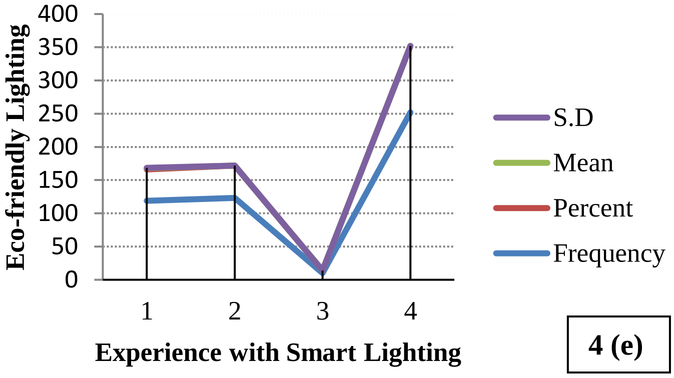

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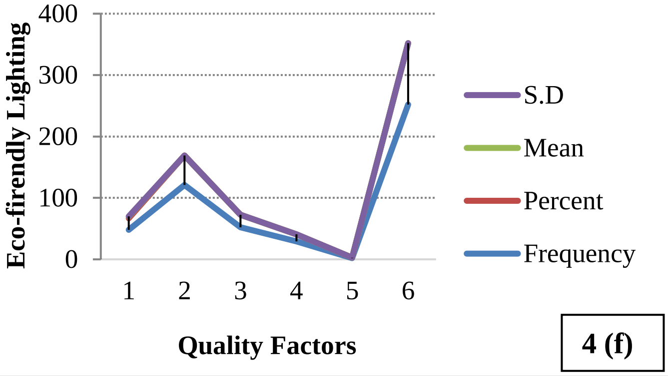

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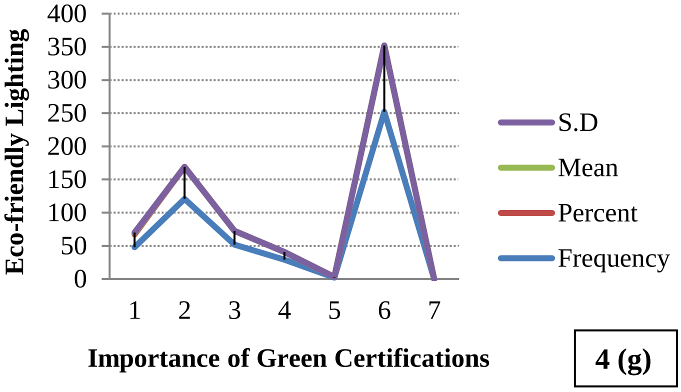

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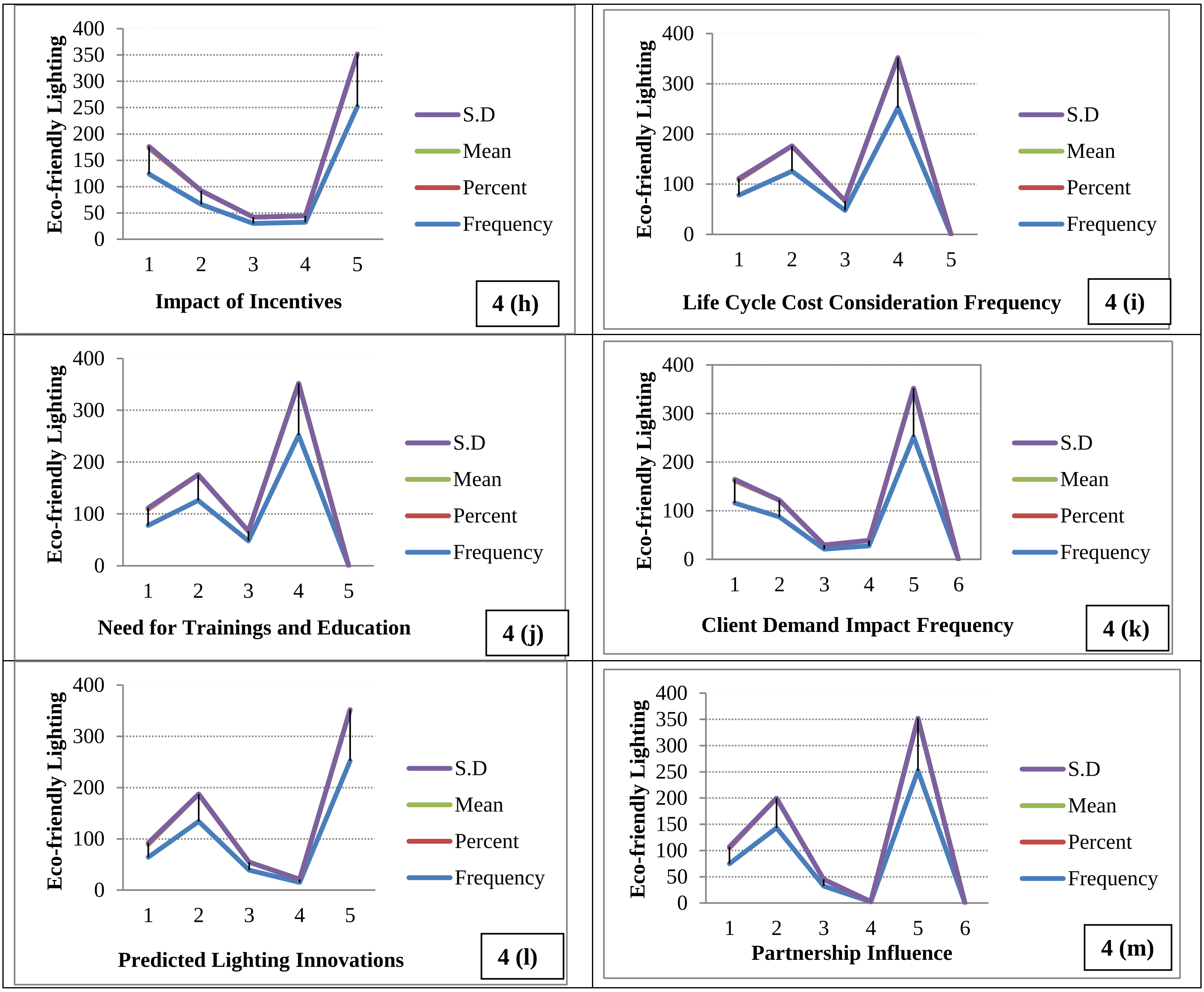

Figure 4. Factors Influencing Eco-Friendly Lighting Adoption

The survey of 252 participants on environmentally friendly lighting solutions for construction projects, detailed in Table 2 and Figure 4, reveals that respondents generally have a moderate to high level of familiarity with LEDs, CFLs, and OLEDs, with a strong preference for these technologies. Key drivers for adopting eco-friendly lighting include the reduction of environmental impact, financial effectiveness, and regulatory compliance. While benefits such as lower energy costs and improved indoor environment quality are recognized, adoption is hindered by initial costs, lack of knowledge, and installation complexity. Government regulations significantly influence decision-making, though factors like green certifications and lighting quality are also important. Future trends indicate a shift towards smart lighting systems, integration of renewable energy sources, and advancements in OLED technology, underscoring the need for industry partnerships with manufacturers to deliver sustainable lighting solutions.

3.3. Perceptual Differences

Perceptual differences regarding eco-friendly lighting can be influenced by various factors, including demographic variables, professional background, and exposure to sustainability practices. Studies indicate that perceptions of eco-friendly lighting technologies, such as LEDs and solar-powered systems, vary across different professional sectors and experience levels

[80]. Gender and age have also been found to affect attitudes towards these technologies, with some research suggesting that women and older individuals may express more positive perceptions of environmental benefits [81]. Furthermore, familiarity with regulatory standards and technological advancements influences how individuals perceive the efficacy and adoption of sustainable lighting solutions [82]. These perceptual differences highlight the importance of targeted education and awareness campaigns to address varied perceptions and promote broader acceptance of eco-friendly lighting technologies.

3.3.1. Gender-based

Gender-based differences in perceptions of eco-friendly lighting reflect varying attitudes towards sustainability and technological adoption. The graph illustrates gender differences in perception, where males show a slightly higher peak value (160) compared to females (140). The alternating trend between genders, with a narrow difference of 10-20 units, suggests relatively minor variations in perception shown in Table 3. Similar findings have been observed in prior studies [83], such as, where gender differences in environmental perception were reported to be minimal, often within a 10-15% range. These results support the notion that while gender may influence perception, the overall impact remains statistically limited. Further comparison with studies [84] shows similar small variances between male and female environmental attitudes. Research indicates that women often exhibit a higher degree of environmental concern and support for sustainable practices compared to men, which extends to eco-friendly lighting technologies [85, 86]. Studies also suggest that women are more likely to prioritize environmental benefits and energy efficiency in their lighting choices [87]. Conversely, men may focus more on technical aspects such as cost-effectiveness and performance [88]. These differences highlight the need for tailored marketing and educational strategies to address gender-specific preferences and enhance the adoption of sustainable lighting solutions. Addressing these gender-based perceptual variations can lead to more effective promotion of eco-friendly technologies across diverse demographic groups.

Table 3. Difference between Male and Female Perceptions

	Gender	N	Mean	Std. Deviation
Innovation in Energy Use Reduction	Male	137	7.6715	1.64991
	Female	115	7.8174	1.72486
Sustainable Material Choices	Male	137	7.9927	1.58345
	Female	115	8.0000	1.36369
Ecosystem Friendly Designs	Male	137	13.1314	3.15953
	Female	115	13.1304	2.64085

Table 4 and Figure 5, present the comparison of opinions on sustainable practices between male and female respondents across three areas. Males rated "Innovation in energy use reduction" slightly lower (mean = 7.67, SD = 1.65) compared to females (mean = 7.82, SD = 1.72). Ratings for "Sustainable material choices" were similar, with men averaging 7.99 (SD = 1.58) and women 8.00 (SD = 1.36). For "Ecosystem-friendly designs," both genders rated it identically (mean = 13.13) with women having a slightly higher standard deviation (SD = 3.16) than men (SD = 2.64). Overall, gender differences in perceptions are minimal, indicating a generally uniform attitude toward these sustainability practices.

Table 4. Independent T-Test Analysis Between Genders

		T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Innovation in energy use reduction	Equal variances assumed	-.685	250	.494	-.14586	.21304	-.5654	.27372
	Equal variances not assumed	-.682	238.45	.496	-.14586	.21387	-.5671	.27546
Sustainable material choices	Equal variances assumed	-.039	250	.969	-.00730	.18810	-.3777	.36316
	Equal variances not assumed	-.039	249.82	.969	-.00730	.18567	-.3729	.35837
Ecosystem friendly designs	Equal variances assumed	.003	250	.998	.00095	.37112	-.7299	.73187
	Equal variances not assumed	.003	249.99	.998	.00095	.36539	-.7186	.72059

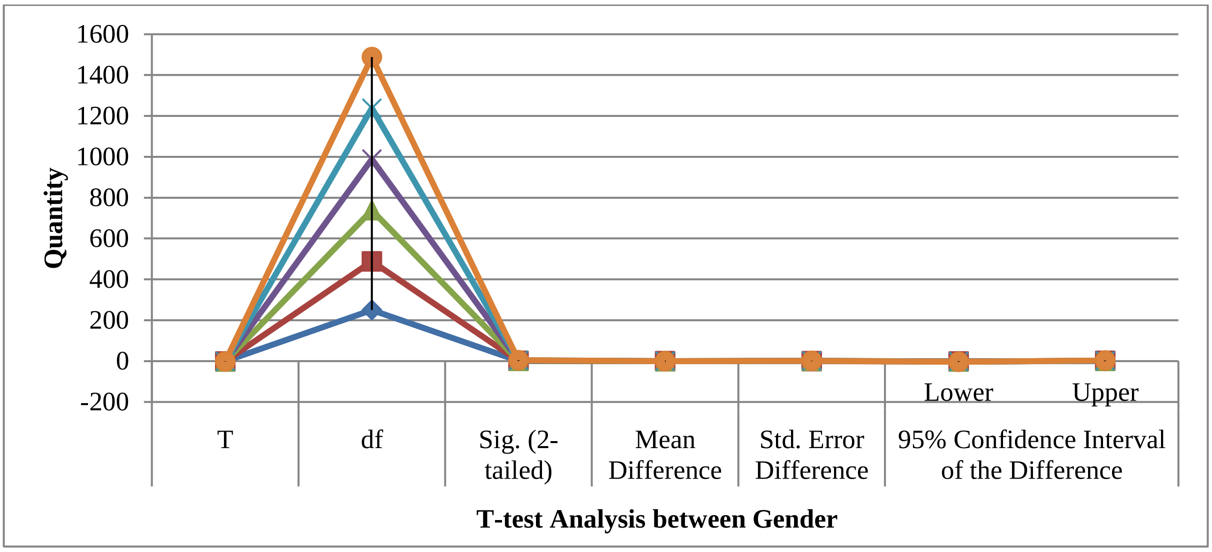

Figure 5. T-Test Analysis between Genders

The independent samples t-tests presented in Table 4 and Figure 6, reveal no significant gender disparities in views on sustainability across three areas: energy-saving design, sustainable material selection, and ecologically friendly architecture. For "Innovation in energy use reduction," the mean difference of -0.146 and overlapping confidence intervals (-0.565 to 0.274) indicate no significant variation between males and females (p =.494). Similarly, "Sustainable material choices" show a negligible mean difference of -0.007 and non-significant p-values (p =.969), with narrow confidence intervals (-0.378 to 0.363). For "Ecosystem-friendly designs," the mean difference of 0.001 and confidence intervals (-0.730 to 0.732) also demonstrate no significant gender difference (p =.998). These findings suggest gender does not substantially influence perceptions of sustainability across the examined categories.

3.3.2. Stakeholder Based

Stakeholder perceptions of eco-friendly lighting are influenced by varying interests and priorities across different groups, including policymakers, industry professionals, and consumers [89]. Table 5 and Figure 6 present the mean variations in views on sustainable methods across three sectors within the construction industry: construction, architecture, and real estate. For "Innovation in energy use reduction," the mean ratings are 7.76 for construction, 7.80 for architecture, and 7.65 for real estate, with an overall mean of 7.74. These results suggest that opinions on energy use reduction innovation are generally consistent across the sectors. In contrast, there are notable differences in opinions on "Sustainable material choices," with means of 7.13 for construction, 7.96 for architecture, and 8.89 for real estate, yielding an overall mean of 7.99. Real estate professionals rate sustainable material choices significantly higher than their counterparts in construction. Regarding "Ecosystem-friendly designs," the mean ratings are 13.70 for construction, 12.62 for architecture, and 13.07 for real estate, with an overall mean of 13.13. This indicates a consistent appreciation for ecosystem-friendly designs, with construction professionals rating them slightly higher than architects. Overall, while there are minor sector-specific variations, there is a shared understanding and importance placed on these sustainability aspects across all surveyed sectors. Research indicates that policymakers are often focused on the regulatory compliance and environmental impact of sustainable lighting solutions, promoting adoption through incentives and standards [75]. Industry professionals, including architects and builders, may prioritize technological performance and cost-effectiveness, integrating eco-friendly lighting into designs to meet both client expectations and sustainability goals [90]. Consumers, on the other hand, tend to be driven by the immediate benefits of energy savings and improved lighting quality, though their adoption rates can be affected by perceived complexity and cost [91]. Understanding these stakeholder-specific perspectives is crucial for developing targeted strategies that address diverse needs and foster broader acceptance of eco-friendly lighting technologies.

Table 5. Mean Difference between Construction Sectors

Categories		N	Mean	Std. Deviation
Innovation in energy use reduction	Construction	84	7.7619	1.80106
	Architecture	84	7.7976	1.67029
	Real Estate	84	7.6548	1.58680
	Total	252	7.7381	1.68272
Sustainable material choices	Construction	84	7.1310	1.26852
	Architecture	84	7.9643	1.42648
	Real Estate	84	8.8929	1.20259
	Total	252	7.9960	1.48431
Ecosystem friendly designs	Construction	84	13.7024	2.93619
	Architecture	84	12.6190	2.96528
	Real Estate	84	13.0714	2.81470
	Total	252	13.1310	2.92855

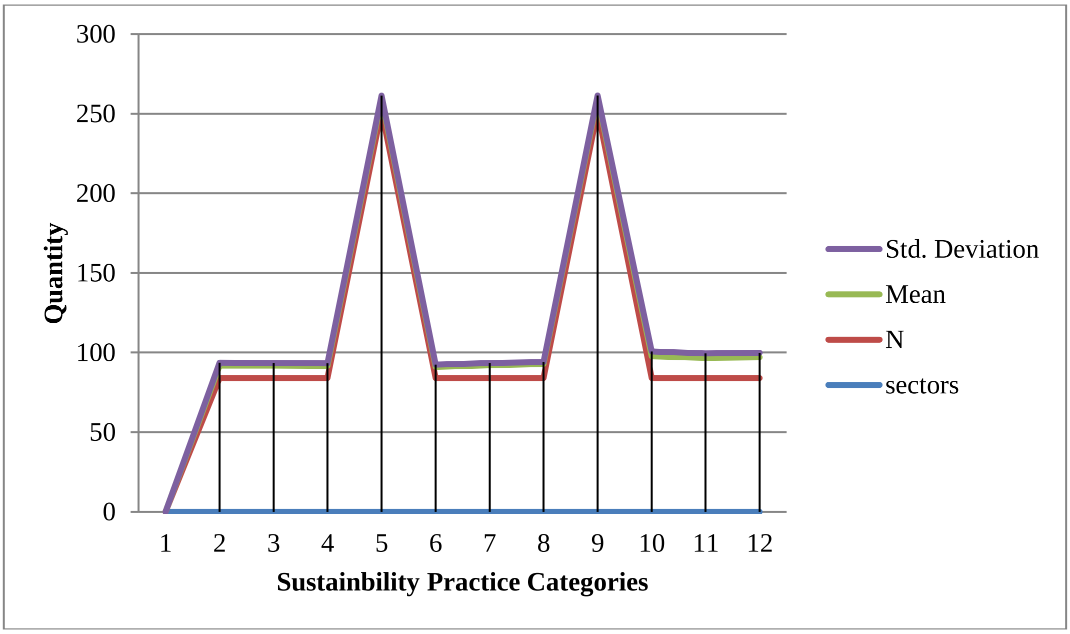

Figure 6. Influence of Varying Interests and Priorities on Eco-Friendly Lighting Across Different Categories

The findings of ANOVA analyses of three sustainability practice categories—innovation in energy consumption reduction, sustainable material selection, and ecosystem-friendly design—conducted within the construction industry are shown in Table 6 and Figure 7. About "Innovation in energy use reduction," the F-ratio (F = 0.163, p = 0.850) reveals a non-significant difference between the within-groups variance (SS = 709.786) and the between-groups variance (SS = 0.929). This suggests that there are no statistically significant differences in perceptions among the various subgroups within the construction sector. The within-groups variance (SS = 422.488) is substantially lower than the between-groups variance (SS = 130.508) for "Sustainable material choices," resulting in a very significant F-ratio (F = 38.458, $p < 0.001$). This implies that various factions within the building industry have rather differing perspectives about sustainable material selections. However, for "Ecosystem friendly designs," the resultant F-ratio (F = 2.945, p = 0.054) only misses traditional significant standards ($p < 0.05$), despite a considerable between-groups variance (SS = 49.738) compared to within-groups variation (SS = 2102.940). This suggests that opinions on ecosystem-friendly designs vary somewhat within subgroups in the building industry. Overall, the ANOVA findings demonstrate that there are disparities in views and differing degrees of agreement across all areas of sustainability practices in the construction industry, with the most notable differences across subgroups being shown in sustainable material selections.

Table 6. ANOVA Analysis of the Construction Sector

Categories		Sum of Squares	df	Mean Square	F	Sig.
Innovation in energy use reduction	Between Groups	.929	2	.464	.163	.850
	Within Groups	709.786	249	2.851		
	Total	710.714	251			
Sustainable material choices	Between Groups	130.508	2	65.254	38.458	.000
	Within Groups	422.488	249	1.697		
	Total	552.996	251			
Ecosystem friendly designs	Between Groups	49.738	2	24.869	2.945	.054
	Within Groups	2102.940	249	8.446		
	Total	2152.679	251			

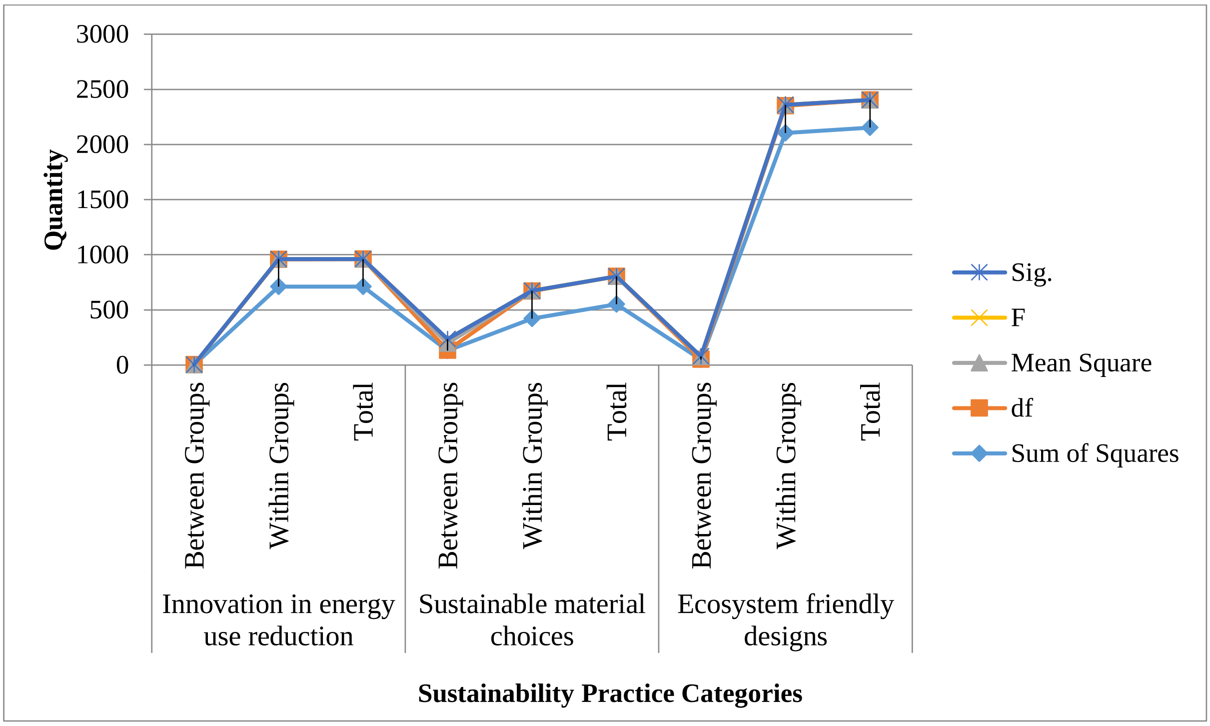

Figure 7. ANOVA Analyses between Sustainability Practice Categories

3.3.3. Experienced based

Experience-based perceptions of eco-friendly lighting reveal significant insights into how professional background and exposure influence attitudes toward sustainable technologies. The analysis of mean variations in opinions on sustainable practices across different experience levels reveals consistent perspectives, with some differences based on years of experience shown in Table 7 and Figure 8. Respondents with over 31 years of experience recorded the highest mean score (7.95) for "Innovation in energy use reduction," closely followed by those with 11–20 years of experience (7.77). Minimal variations were observed across other experience categories, with scores ranging from 7.69 for those with 1–10 years of experience to 7.56 for those with 21–30 years of experience. The overall mean score of 7.74 suggests a generally uniform view across all experience levels. In terms of "Sustainable material choices," respondents with 11–20 years of experience had the highest mean score (8.13), followed by those with over 31 years (7.97). The differences among respondents with 1–10 years (8.05) and 21–30 years (7.84) of experience were less pronounced, with an overall mean of 8.00, indicating broad support for sustainable material choices across all experience groups. For "Ecosystem-friendly designs," the highest mean score (13.52) was again recorded by respondents with over 31 years of experience, followed by those with 11–20 years (13.09). Other groups showed very small differences, with mean scores of 13.05 for 1–10 years and 12.89 for 21–30 years. The overall mean of 13.13 demonstrates a strong positive perception of ecosystem-friendly designs across all experience levels. These findings suggest that while minor variations exist, more experienced professionals tend to have slightly higher opinions of sustainable practices, with broad support across all categories.

Studies indicate that individuals with extensive experience in fields related to construction and design tend to have a more nuanced understanding of the benefits and challenges associated with eco-friendly lighting [92]. These experienced professionals often recognize the long-term cost savings and environmental benefits of technologies such as LEDs and solar-powered systems [93]. Conversely, those with limited experience may have less familiarity with the technical aspects and may rely more on general perceptions or marketing information [94]. This disparity highlights the importance of targeted education and training to bridge knowledge gaps and enhance the adoption of sustainable lighting solutions across all experience levels.

Table 7. Mean Difference between Years of Experience

Categories	Years	N	Mean	Std. Deviation
Innovation in energy use reduction	1-10	64	7.6875	1.54175
	11-20	64	7.7656	1.74340
	21-30	64	7.5625	1.76271
	31 above	60	7.9500	1.69170
	Total	252	7.7381	1.68272
Sustainable material choices	1-10	64	8.0469	1.57792
	11-20	64	8.1250	1.56854
	21-30	64	7.8438	1.29980
	31 above	60	7.9667	1.49538
	Total	252	7.9960	1.48431
Ecosystem friendly designs	1-10	64	13.0469	3.07798
	11-20	64	13.0938	2.99056
	21-30	64	12.8906	3.03481
	31 above	60	13.5167	2.60047
	Total	252	13.1310	2.92855

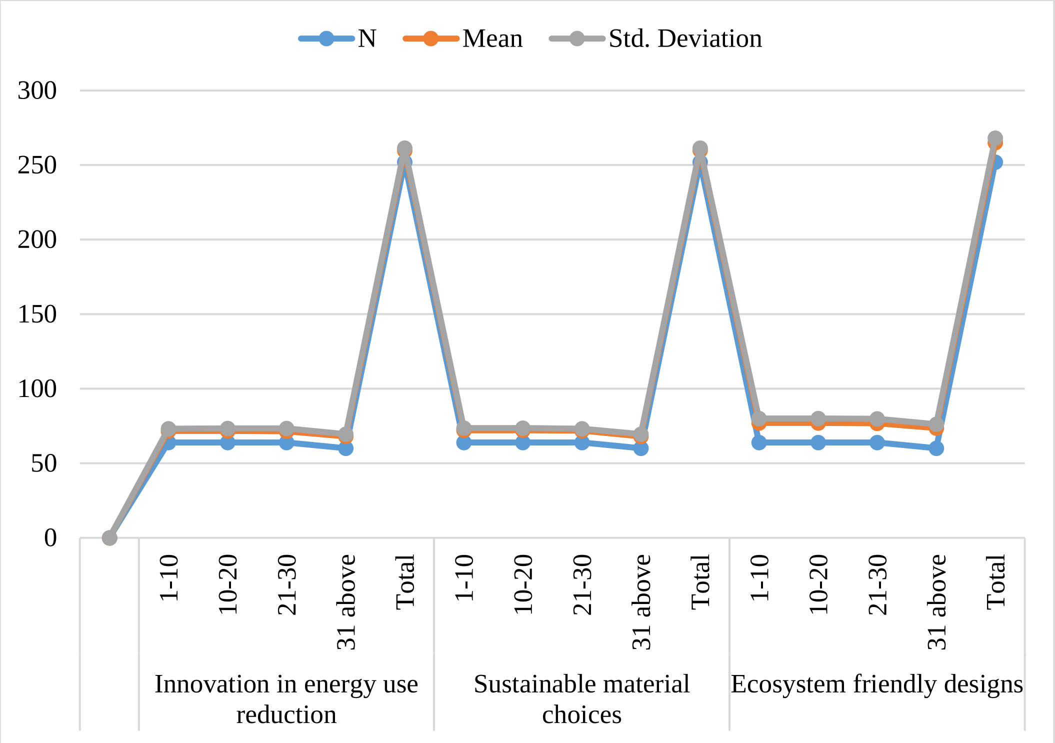

Figure 8. Experience-based perceptions of eco-friendly lighting

The analysis of variance (ANOVA) results concerning perceptions of sustainable practices across varying levels of professional experience reveal no significant differences in any assessed category. For "Innovation in energy use reduction," the non-significant F-ratio (F = 0.572, p = 0.634) suggests that perceptions do not vary significantly among the experience groups. This is supported by a low between-groups variance (SS = 4.880) compared to the within-groups variance (SS = 705.834). Similarly, in the "Sustainable material choices" category, the F-ratio (F = 0.416, p = 0.742) also indicates no significant differences in perceptions, with comparable variances between groups (SS = 2.766) and within groups (SS = 550.230). For "Ecosystem-friendly designs," despite a slightly higher between-groups variance (SS = 13.164), the F-ratio (F = 0.509, p = 0.677) remains non-significant, indicating that opinions do not differ meaningfully based on experience levels shown in Table 8 and Figure 9. These findings suggest that attitudes toward sustainable practices remain relatively consistent across varying degrees of professional experience. This uniformity indicates that professional experience may not be a key determinant in shaping perceptions of sustainability-related practices in the construction industry.

Table 8. ANOVA Analysis of Working Experience

Sustainability Practice Categories		Sum of Squares	df	Mean Square	F	Sig.
Innovation in energy use reduction	Between Groups	4.880	3	1.627	.572	.634
	Within Groups	705.834	248	2.846		
	Total	710.714	251			
Sustainable material choices	Between Groups	2.766	3	.922	.416	.742
	Within Groups	550.230	248	2.219		
	Total	552.996	251			
Ecosystem friendly designs	Between Groups	13.164	3	4.388	.509	.677
	Within Groups	2139.515	248	8.627		
	Total	2152.679	251			

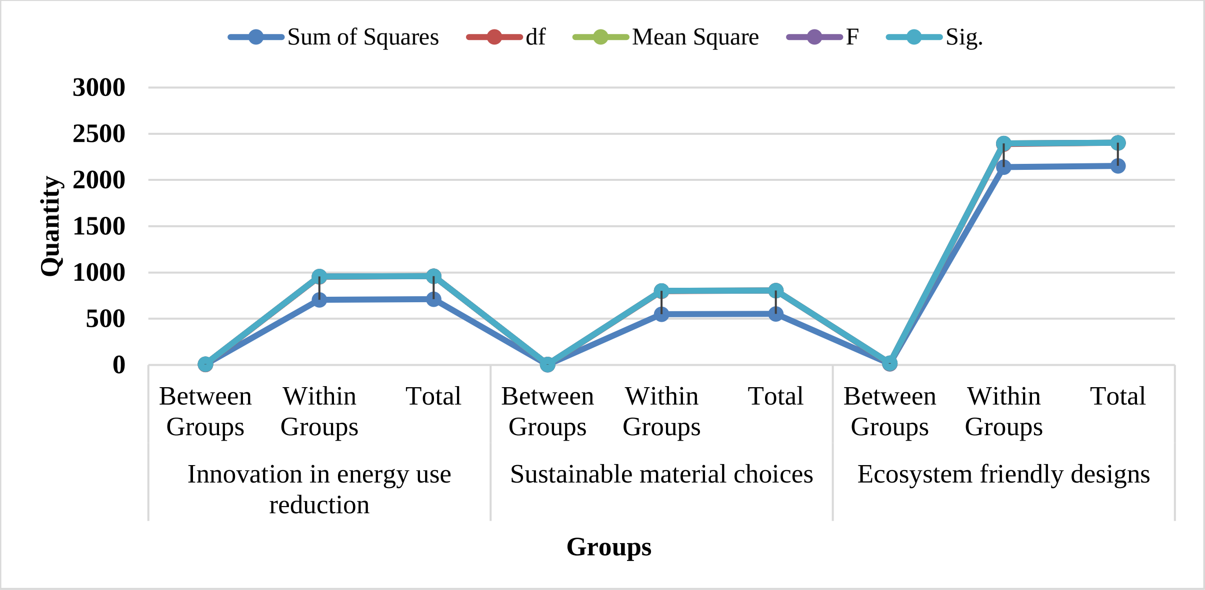

Figure 9. ANOVA Analysis: Perceptions of Sustainable Practices across Different Levels of Professional Experience

The implications for eco-friendly lighting highlight the need for enhanced energy efficiency and occupant well-being while minimizing environmental impacts. Raising awareness of sustainable practices among stakeholders in the construction, design, and real estate sectors is crucial, as familiarity with eco-friendly technologies correlates with their integration into projects. Furthermore, cost-effectiveness and compliance with regulations, such as Leadership in Energy and Environmental Design (LEED) certifications, emerge as critical factors influencing the adoption of sustainable innovations, driving decision-making processes, and facilitating the broader implementation of environmentally sound practices [95].

The integration of modern technology has produced a cost-effective, environmentally sustainable LED lighting system that accommodates diverse configurations, incorporating ambient light sensors, automated battery management, and low battery cut-off mechanisms. Characterized by energy efficiency, extended operational hours, and versatile lighting, it accommodates various requirements; yet, restricted sunlight and increased complexity for high-powered LEDs present impediments. Nonetheless, the overall design enhances sustainability and offers versatile lighting solutions [96]. The cost implications of energy-efficient lighting in the building industry highlight its essential role in achieving both economic viability and environmental sustainability. Through a review of existing literature and theoretical models, this research uncovers key trends affecting the adoption and financial impact of such technologies. Simplifying the energy efficiency process is deemed crucial by industry professionals. Understanding consumer behavior, market dynamics, and regulatory frameworks is vital for enhancing market penetration and widespread adoption of energy-efficient lighting systems [97]. The coordination of environmental, social, and financial components into design, using standard parts to chip away at flourishing, enhancing lighting capability and quality, and valuing how new headways are taken on by affiliations and social orders are maintained by these contemplations [98, 99]. Inspecting eco-obliging design lighting appears to be alright because of the crushing need to diminish building energy use and work on indoor regular quality, especially taking into account the need to meet overall energy efficiency targets and advance sensible improvement goals [100]. Advancements in materials and intelligent lighting can reduce energy consumption and enhance quality; however, comprehending stakeholder challenges is essential for increasing the utilization of sustainable lighting in construction, and this study aids in closing these gaps.

3.4. EFL for Global Sustainability Goals (SDGs)

By 2050, smart energy systems combined with eco-friendly lighting could reduce lighting energy consumption worldwide by about 40% [101] substantially supporting the sustainable development goals. Due to longer lifespan and efficiency, LEDs can replace conventional lighting with automated controls, reducing urban greenhouse gas emissions and electricity costs [102]. To make cities more resilient to resource and environmental issues [7], this study focuses on integrating Eco-friendly lighting methods with urban infrastructure.

Through its detailed and systematic data analysis, this study supports SDG 7 (Affordable and Clean Energy) in particular by providing useful insights into the adoption of eco-friendly lighting inside building infrastructures. A strong response rate and target reveals that industry stakeholders are highly aware of clean energy technologies like LEDs and OLEDs. These technologies are known for their benefits in lowering both greenhouse gas emissions and electricity use, which also helps achieve SDG 13 (Climate Action).

The study also highlights important demographic and experience-based disparities, pointing out that energy-saving technologies are valued by seasoned industry workers than by the green hand counterparts. This provides focused educational initiatives and policies that support SDG 11 (Sustainable Cities and Communities), encouraging eco-friendly lighting and sustainable construction methods to create resilient and resource-efficient urban environments. In addition, the research highlights barriers such as perceived technological complexity and high upfront costs, which are pertinent to SDG 9 (Industry, Innovation, and Infrastructure). It also promotes funding for research and development to improve the scalability and accessibility of sustainable technologies in the construction industry.

Last but not least, this research supports SDG-3 (Good Health and Well-Being) by demonstrating the positive impacts of eco-friendly lighting on indoor environmental quality and indicating better occupant comfort and productivity. Conclusively, the study suggests financial incentives, educational initiatives, and legal frameworks to encourage industry stakeholders and decision makers a data-driven approach for sustainable urban expansion and promote the role of SDGs in construction techniques.

4. Conclusion

The study reveals crucial insights into stakeholder perceptions and decision-making processes regarding eco-friendly lighting solutions in buildings. This study also enhances the ability of eco-friendly lighting in building design by integrating concepts of energy efficiency, and ecological impact and diminishing the carbon footprint of construction projects. A quantitative analysis of questionnaire responses from industry professionals was performed to identify the key variables affecting the adoption of eco-friendly lighting technology. The findings indicate that there is a moderate to high level of familiarity with eco-friendly lighting technologies, with a marked preference for LEDs, CFLs, and OLEDs. The primary drivers for adopting sustainable lighting include energy efficiency, cost savings, and compliance with regulatory standards. However, significant barriers remain, including high initial costs, limited awareness, and the perceived complexity of installation and maintenance. Minimal differences in perception were observed across gender and industry sectors, though experience level slightly influenced views on sustainable practices. The study underscores the importance of ongoing education, supportive government policies, and industry collaboration to address existing barriers and leverage emerging trends, ultimately promoting sustainable lighting practices and contributing to energy savings and reduced environmental impact. By advocating for such incentives and focused training for industry professionals, the paper establishes the foundation for a more cohesive policy approach for sustainable lighting and the broader development of sustainable urban initiatives.

The findings also promote global sustainability initiatives, including the UN's Sustainable Development Goals (SDGs), particularly those related to affordable and clean energy, sustainable urban development, and responsible consumption and production, by integrating eco-friendly lighting into the paradigm of smart city development.

The study is constrained by its reliance on a single survey among professionals, potentially failing to encompass all industry perspectives and preferences across various areas. Additionally, it fails to fully examine how barriers such as cost and complexity fluctuate among various stakeholder roles, hence constraining the comprehension of tailored adoption approaches. Future studies ought to investigate sector-specific impediments, the long-term impact of incentives on eco-friendly lighting adoption, and stakeholder-specific barriers and perspectives to promote sustainable implementation of sustainable lighting approaches.

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