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Ranking of Smart Building Design Factors with Efficient Energy Management Systems and Renewable Resources

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Abstract: This study aims to rank the design factors of smart buildings with efficient energy management systems and renewable resources. The research is applied in nature in terms of its objective, and descriptive-survey-based in terms of data collection. The study population comprised all academic faculty members in the field of architecture. Based on the collected information, approximately 112 architecture faculty members were included, and given the small sample size, a census approach was used, meaning the sample size was equal to the population. After distributing and collecting the questionnaires, 93 were completed and analyzed. A researcher-made questionnaire was employed, consisting of two sections: the first included personal details (age, gender, marital status, education, etc.), and the second was dedicated to ranking the design factors of smart buildings with efficient energy management systems and renewable resources. The questionnaire was structured on a 7-point Likert scale. To ensure the face and content validity of the questions, feedback was obtained from several architecture professors specializing in the field. Additionally, the construct validity of the questionnaire was confirmed through exploratory factor analysis. The results showed that six factors had eigenvalues greater than one and remained in the analysis. The study found that among the design factors examined, the lighting system, fire alarm system, and temperature and humidity sensors emerged as the most influential in enhancing smart building efficiency.

Keywords: Smart buildings, Smart systems, Efficient energy management, Renewable resources

1.Introduction

The concept of a smart building (Figure 1) is one of the most prominent contemporary trends, integrating the ideas of smart mobility, smart economy, smart people, smart governance, smart environment, and smart living (José, 2024) . The construction sector plays a crucial role in adapting to new challenges in all these areas. Buildings and infrastructures must be constructed and operated in accordance with the characteristics of a smart city (Kuzior, 2024). As a result, the term "smart building" has been widely discussed by researchers, industry professionals, society, and representatives at city and higher management levels (Kuzior, 2024). The European Union's policy focuses on developing ISO standards in specific areas of smart cities, funding smart city lighthouse projects, and providing financial incentives for smart buildings and smart city elements. Smart buildings are considered one of the main components of the built environment in a smart city (Wolniak, 2024).

The first definition of a smart building was published in 1989 by the U.S. Intelligent Building Institute, describing a smart building as providing an efficient environment through optimized structures, systems, services, management, and their interrelationships (Lim, 2024). Later, the emphasis was placed on its impact on operational efficiency, the effectiveness of its occupants, and the utilization of information and communication technologies. Smart cities, whose operational efficiency is heavily dependent on buildings (Stamopoulos, 2024), are the most prominent trend in creating a coherent environment for the future. However, there are no specific recommendations on how to utilize new materials and technologies in construction projects in smart cities (Zwick, 2024). Therefore, it is important to explore which features are more critical for adapting future buildings to the digital smart city platform. It is no surprise that there is a need to identify the integration requirements that construction projects must meet to be compatible with the overall context of a smart city (Nyathani, 2023).

The latest challenges in the advanced development of smart buildings and smart cities are related to digitization: aligning buildings with the new city's ecosystem, adapting to the environment, collecting and transmitting information, real-time communication of information, information management, and action control. Significant attention must be given to developing a new approach based on combining two separate fields that describe the core principles of integrating a smart building within a smart city (Adewnmi, 2024). After the Industrial Revolution, urbanization and extensive construction activities increased energy consumption and its detrimental environmental effects (Jebaraj, 2023). The need for sustainability for every community and individual in all sectors is undeniable and essential.

Traditional building technologies lead to high energy consumption and carbon emissions, exacerbating global warming and climate change (Cong, 2024). To mitigate these adverse effects, the construction industry has shifted towards innovative solutions by adopting the concept of green building, aiming to design sustainable and environmentally friendly structures that effectively utilize natural resources (Lacson, 2023). With the expansion of urbanization, the building sector has become the primary consumer of energy, thus increasing its share of total energy consumption. Constructing green buildings is one of the most effective ways to achieve energy savings (Ai, 2024). Green buildings significantly reduce energy consumption and greenhouse gas emissions, which in turn helps mitigate the harmful effects of climate change. Greenhouse gases have a wide-ranging impact on the climate, and their emissions in international trade are rapidly increasing (Adelekan, 2024).

In recent years, sustainable building practices have garnered significant attention in the construction industry, driven by growing concerns about the environmental impacts of traditional design and construction methods. Given that buildings account for nearly 40% of global energy consumption and 30% of annual greenhouse gas emissions (Kolhe, 2023), there is an urgent need to address these issues. Furthermore, as the world's urban population is expected to double by 2050, increasing the sustainability of buildings and infrastructures has never been more critical (Chen, 2024). Amid these challenges, there is deep optimism surrounding the potential of emerging technologies, particularly artificial intelligence, to revolutionize our approach to sustainable building practices. By employing AI at various stages of the building lifecycle, from design and construction to operation and maintenance, there is a unique opportunity to reduce systemic inefficiencies and enact meaningful changes.

One of the most significant issues facing the construction industry is the staggering amount of waste generated during construction (Stecyk, 2023). Globally, 11 to 15% of materials are wasted on construction sites, highlighting the need for more efficient processes and resource use. Additionally, operational inefficiencies significantly contribute to the carbon footprint. For example, lighting, heating, and cooling account for approximately 28% of the energy consumption of commercial buildings in the United States, while commercial and residential buildings in China make up 41.10% of total energy consumption. In Nigeria, residential buildings alone account for over 80% of all energy consumed (Adewumi A. O.-l., 2024). Ai (Ai, 2024) conducted a study titled " The impact of Smart city construction on labor spatial allocation: Evidence from China " using panel data from 2005 to 2020 and the Smart City Construction (SC) policy in China. The study utilized the Difference-in-Differences (DID) method to examine the impact of information construction on the spatial allocation of labor. The findings revealed that information construction significantly attracted labor and improved the spatial allocation of labor. After implementing the SC construction policy, the average increase in SC pilot labor was about 0.78 million people compared to non-SC areas. Furthermore, stimulating economic growth, improving the environment, and enhancing public services were mechanisms of the SC construction policy for labor's spatial allocation. Additionally, this policy effect has characteristics that vary by industry sector. The tertiary and secondary industry departments receive significant impacts.

Zaman (Zaman, 2024) discussed recent advances in the field of cyber cities for smart building management, highlighting recent updates to the pilot platform that enable further experiments in various smart city domains, aiming to improve energy conservation, transportation, building management, resilience, and sustainable infrastructure development. Lacson (Lacson, 2023) examined the assessment of smart buildings in developing economies, emphasizing the scope review due to a structured methodology, the ability to measure progress over time, and the potential for benchmarking against other cities. However, it's important to consider that every framework has its strengths and weaknesses, and cities might use multiple frameworks or adapt them to their specific needs. Our paper concludes by highlighting the importance of this research in providing comprehensive insights into smart city assessment in developing economies and the need for further studies to address identified gaps and enhance future evaluations.

As the integration of smart buildings in the construction sector increases, the need for proper management and energy dispatch at the building/area level becomes critical. Buildings must be able to balance their on-site energy production and consumption. Consequently, the traditional grid has been upgraded to a smart grid to cope with the increased penetration of solar and wind energy and manage its production. Following continuous global urbanization, the number of buildings (both residential and commercial) is increasing, whether in small cities or metropolises. In some global cities, nearly 50 residents arrive every hour for settlement (Adewumi A. O.-l., 2024).

Therefore, the aim of this study is to develop a new evaluation framework for " Ranking of Smart Building Design Factors with Efficient Energy Management Systems and Renewable Resources". It involves the intelligent use of sensors, actuators, information and communication technologies, and smart techniques and technologies to control and optimize the use of building resources (energy and infrastructure) and provide the best comfort for occupants. Buildings require sensors to obtain information about the building environment and available resources, which may include temperature, humidity, light intensity, airflow, and smart energy meters. Actuators are any item or device that can be controlled, such as light switches, windows, elevators, doors, air conditioning, ventilation systems, presence detectors, etc. Connecting all these elements is essential. This study also seeks to answer the question: How should the design factors of smart buildings with efficient energy management systems and renewable resources be ranked?

2.Research Methodology

The study on ranking the design factors of smart buildings with efficient energy management systems and renewable resources is an applied research in terms of its objective and a descriptive-survey study in terms of data collection. The study population comprised all academic faculty members in the field of architecture, based on information gathered from 112 architecture faculty members. Due to the small sample size, a census approach was adopted, meaning the sample size equaled the entire population. Consequently, after distributing and collecting the questionnaires, 93 completed questionnaires were obtained and analyzed. By using a census approach with the entire population of available faculty members, the study aims to enhance the internal reliability of the findings and minimize sampling bias. While the relatively small size of the population may limit generalizability to other groups, the comprehensive nature of this approach ensures a robust representation of the architectural academic perspective on smart building design factors.

Given the small size of the study population, a census approach was adopted, including all faculty members in architecture as participants. To further strengthen the representativeness and reduce potential sampling biases, participants were selected across diverse architectural specializations, academic ranks, and institutions. This diversity was intended to encompass a broad spectrum of insights and expertise related to smart building design, thereby enhancing the depth and applicability of the findings.

A researcher-made questionnaire was utilized in this study. The first part of the questionnaire included personal details (age, gender, marital status, education, etc.), while the second part was dedicated to ranking the design factors of smart buildings with efficient energy management systems and renewable resources. The questionnaire was categorized into four subscales: occupational factors, purpose-driven factors, lighting system indicators, and commitment factors. It was designed using a 7-point Likert scale. To ensure the face and content validity of the questions, feedback was obtained from several architecture professors who specialized in the field. Additionally, the construct validity of the questionnaire was confirmed through exploratory factor analysis, and its reliability was calculated using Cronbach's alpha coefficient, as reported in Table 1. For inferential statistical analysis, exploratory factor analysis and path analysis were employed.

Table 1: *The mean values, standard deviation, and reliability of the dimensions of factors influencing the attraction of design elements in smart buildings with efficient energy management systems and renewable resources.*

Factors	Number of Items	Mean	Standard Deviation	Cronbach's Alpha Coefficient
Lighting System	2	1.63	0.63	0.80
Fire Alarm System	5	1.60	0.40	0.83
Temperature and Humidity Sensors	2	1.02	0.39	0.84
Air Conditioning	7	1.62	0.48	0.89
Safety and Security	2	1.52	0.41	0.83
Audio and Video Control System	5	1.51	0.37	0.81

Exploratory factor analysis (EFA) was chosen as the primary statistical technique due to its effectiveness in identifying latent variables within the dataset without assuming predefined factor structures. EFA allowed for the extraction of the most influential factors that could guide the design priorities of smart buildings. This approach is particularly suited to exploratory studies, as it enables a data-driven analysis that reveals natural groupings among variables, which in this study, provided valuable insights into design factor prioritization for energy-efficient and resource-optimized buildings.

As shown in the results of Table 2, the Kaiser-Meyer-Olkin (KMO) test index is 0.980. Since the closer this index is to one, the more it indicates a high level of sampling adequacy, it can be concluded that the data is suitable for factor analysis. To determine the correlation among the items under study, Bartlett's test was used. The results of this test are also presented in Table 2.

Table 2: *Kaiser-Meyer-Olkin (KMO) test*

Value	Description
0.980	KMO Index

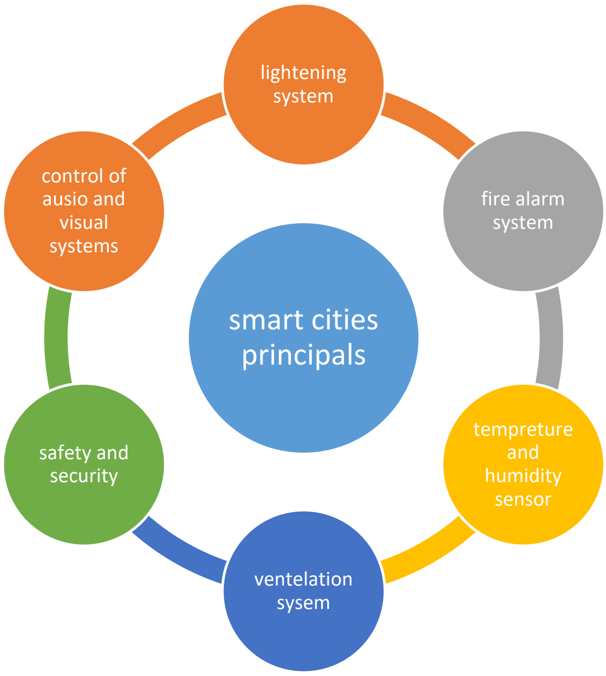

Figure 1: *Conceptual model of the research*

3.Research Findings

To examine the identified needs, the exploratory factor analysis method was used. To assess the adequacy of sampling for factor analysis, the Kaiser-Meyer-Olkin (KMO) test was employed. The results of this test are presented in Table 2.

Table 3 *:Bartlett's test*

Value	Description
1102.011	Approximate Chi-Square Statistic
0.001*	Significance Level

**Significance level less than 0.05*

***Table 4**: Results of explained variances*

Factors	Eigenvalue	Percentage of Variance	Cumulative Percentage
Economic Factors	7.675	30.700	30.700
Social Factors	6.203	24.811	55.511
Environmental Factors	3.250	13.000	68.511
Physical Factors	1.798	7.191	75.701
Cultural Factors	1.425	3.152	78.853
Managerial Factors	1.325	2.170	81.023

As the results of Bartlett's test indicate in Table 3, given that the significance level is less than 0.05, the assumption that the correlation matrix is an identity matrix is rejected. Therefore, this confirms that conducting factor analysis is entirely appropriate for the data in this study. In the next section, the factors are extracted from the questionnaire items. Table 4 shows the results of the explained variances.

According to the results in Table 4, after performing Varimax rotation to better clarify the factor loadings, it was determined that six factors have eigenvalues greater than one and remain in the analysis. Based on the cumulative percentage column, it is shown that these six factors can explain 81.023% of the variability (variance) of the variables. The screen Plot in Figure 2 illustrates this point.

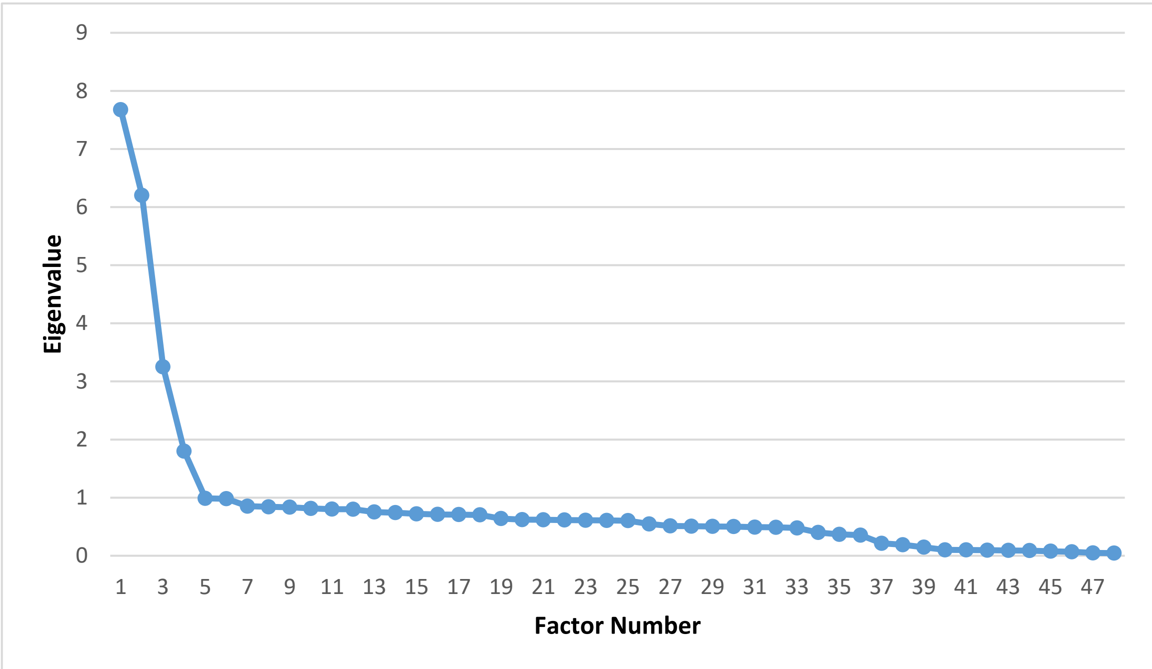

***Figure 2**: Screen Plot*

Table 5*: The factor loadings of each item in the remaining factors after rotation*

No.	Statement	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	Does the use of smart lighting systems help manage renewable resources?	0.87					
2	Will the use of smart lighting systems save energy?	0.74					
3	Does the use of fire alarm systems in buildings help manage renewable resources?		0.65				
4	Will the use of smart fire alarm systems reduce human and financial losses?		0.52				
5	Does the ability to connect to other security equipment make the building smart?		0.84				
6	Will 24/7 building monitoring help make buildings smart?		0.63				
7	Will the use of fire alarm systems to detect fires help make buildings smart?		0.61				
8	Does the use of temperature and humidity sensors help make the building smart?			0.78			
9	Does using this system in smart buildings result in energy waste?			0.81			
10	Is the design and use of this sensor in enclosed spaces effective for making buildings smart?			0.83			
11	Is the use of this system effective in saving energy?			0.89			
12	Is the use of this system effective in air circulation in building spaces?			0.85			
13	Does the use of this system impact building temperature reduction?			0.65			
14	Will using this system in air circulation reduce bacteria in spaces?			0.70			
15	Are security systems effective in making the building smart?				0.62		
16	Do safety systems improve the quality level of buildings?				0.62		
17	Does the use of audio-visual systems help make the building smart?					0.67	
18	Does the use of audio-visual systems reduce energy waste?					0.74	
19	Does this sensor help save energy in smart buildings?						0.63
20	Does the use of these sensors help regulate temperature in buildings?						0.54
21	Does the use of this system help make the building smart?						0.59

Identifying the items related to each factor in the unrotated method is not straightforward. To enhance interpretability, the Varimax rotation method is used to rotate the factors. Table 5 presents the factors and items of the study along with their factor loadings after rotation.

As shown in the results in Table 6, the lighting system has the highest impact on smart buildings with efficient energy management systems and renewable resources, with an impact coefficient of 0.602.

As seen in Table 7, the overall research model demonstrates a good fit according to the goodness-of-fit indices. Figure 1 shows the impacts of the variables on smart buildings with efficient energy management systems and renewable resources. A one-sample t-test was used to examine this issue.

***Table 6**: Effects of variables on smart buildings with efficient energy management systems and renewable resources*

Variables	T-Statistic Value	Significance Level	Direct Effect	Indirect Effect	Total Effect
Lighting System	15.531	0.001	0.602	None	0.602
Fire Alarm System	13.265	0.001	0.570	None	0.570
Temperature and Humidity Sensor	10.876	0.001	0.551	None	0.551
Air Conditioning	5.745	0.001	0.542	None	0.542
Safety and Security	4.701	0.001	0.523	None	0.523
Audio and Video Control System	3.324	0.003	0.501	None	0.501

***Table** 7: Model fitting*

	Chi-square (X^2)	df	X^2/df	RMSEA	CFI	GFI	AGFI	NFI
Value	132.343	64	2.067	0.004	0.923	0.920	0.925	0.924
Criterion	...	Not less than 0	Less than 3	Less than 0.05	Greater than 0.90	Greater than 0.90	Greater than 0.90	Greater than 0.90
Interpretation	Good fit	Good fit	Good fit	Good fit	Good fit	Good fit	Good fit	Good fit

***Table 8**: Result of one-sample t-test*

Variables	Mean	Standard Deviation	T-Test Value	Significance Level	Mean Difference
Lighting System	3.17	0.47	3.46	0.001	0.17
Fire Alarm System	3.72	0.50	3.35	0.001	0.28
Temperature and Humidity Sensor	3.40	0.52	7.47	0.001	0.40
Air Conditioning	3.46	0.52	8.49	0.001	0.46
Safety and Security	3.19	0.44	4.13	0.001	0.19
Audio and Video Control System	3.60	0.60	3.20	0.001	0.23

Based on the results in Table 8 and the significance level of the one-sample t-test (0.001), which is less than 0.05, it can be concluded that the null hypothesis is rejected. This suggests that, according to the research indices, the implementation of smart buildings with efficient energy management systems and renewable resources should be adhered to.

4.Discussion and Conclusion

The results of this study align with the findings of Sharifi (Sharifi, 2024) and Zwick (Zwick, 2024) . These researchers found that renewable energies could lead to economic development and increased per capita income, which is consistent with the findings of this research. It has been found that with an average daily waste production of 1.3 kilograms per person, a sensor-based mechanism significantly outperforms the periodic survey approach by covering shorter distances with fewer trucks, while simultaneously achieving key objectives of cost efficiency, environmental preservation, public satisfaction, and reducing employee workload. This research contributes to the evolving field of smart building technology by providing vital insights for urban planners, policymakers, and technologists working to build more sustainable, efficient, and livable cities.

Sharifi (Sharifi, 2024) conducted a study that identifies and analyzes various business models employed in urban contexts through a systematic literature review and comparative analysis. The findings reveal a diverse range of models, including public-private partnerships, build-operate-transfer arrangements, performance-based contracts, community-based models, innovation hubs, revenue-sharing models, outcome-based financing, and asset monetization strategies. Each city uses a unique combination of these models to address its specific building challenges and priorities.

Lim (Lim, 2024), in a study aims to find empirical evidence of the positive and negative outcomes of smart city development. The Smart City Impact Index was developed with indicators across four pillars of sustainability (economic, environmental, social, and governance) and a technological dimension, as technology is the main driver of smart cities.

Zwick (Zwick, 2024) conducted a study focusing on the challenges of smart infrastructure. This research indicates that practitioners primarily perceive smart city buildings as a government-driven and data-driven effort, rather than vendor transactions , resident participation, or community partnership creation (Smart City 4.0), where specific technology takes a secondary role to the project's goals. We conclude that rather than moving through distinct generations, the smart city movement should be understood as a gradual process of modernizing municipal public management, as local governments become increasingly knowledgeable and experienced in contracting with technology companies to address urban problems.

José (José, 2024), in a study titled "A Review of Key Innovation Challenges for Smart Building Initiatives," found that qualitative results indicate there are 44 research articles reporting on the practices and outcomes of smart city innovation. The findings identify five main categories of challenges for smart city innovation: strategic vision, organizational capabilities and agility, technology internalization, ecosystem development, and cross-border innovation. This study also explores the relationship between these challenges and digital innovation practices in smart building projects. The main conclusion is that current innovation practices in smart cities are not well aligned with what the research literature typically describes as the core features of digital innovation, which may be one of the main reasons for limited progress in smart city projects.

Proper design and implementation of energy technologies and the built environment are critical for enhancing the energy efficiency and cost-effective performance of buildings and their connected systems to address global energy and environmental issues. Therefore, to achieve objectives while facilitating existing technologies and simultaneously meeting the needs and comfort of occupants within buildings, appropriate techniques and designs must be selected. In this context, a comprehensive review of the design and implementation of smart building energy and environmental systems was conducted and presented in this article.

To enable smart and sustainable homes/buildings in an energy-efficient manner, understanding the overall details of energy flow between a building and its connected systems (e.g., distributed renewable energy, energy storage, and electric vehicle systems) can be a critical aspect of future buildings at the community level. Furthermore, future smart buildings will fundamentally require advanced energy management and control systems that can provide efficient and cost-effective operations of the respective energy subsystems in parallel and be capable of integrating them into a communication network for real-time information exchange with others in the community and regional levels under various constraints, such as net metering, demand response, or carbon tax or credit, etc. Based on the current review study, it is recommended that future work focus on the implementation and case study of smart energy technologies in building, city, and community-level applications together in a practical application, considering the benefits of economic and environmental life-cycle analysis.

From the detailed literature review, the main conclusions and perspectives for future work can be highlighted as follows: from the review articles related to smart homes/buildings, this study identified that technologies in smart home/building applications are maturing, and the current research trend in smart homes/buildings is moving towards precise system integration or guidelines to enhance people's daily activities. The sustainability of the built environment, using recent advances in digital solutions (such as the Internet of Things), practical designs, and concepts in a cost-effective manner, addresses changes in people's lives and technologies while building connected systems.

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