

Application of Green Architecture Principles in the Design of Public Buildings in Tropical Urban Areas

Mulyana* & Ar.Marson Maizi

Universitas Tomakaka

Abstract

Rapid urbanization in tropical cities increases energy use and environmental degradation, highlighting the need for green architecture to promote sustainable and resilient public buildings. This study investigates the application of green architecture principles in the design of public buildings in tropical urban areas, emphasizing their impact on environmental sustainability. Using a quantitative explanatory approach and multiple regression analysis with EViews 12, the research examines the influence of three primary variables green design principles, tropical climate adaptation, and building energy efficiency on environmental sustainability (Y). Data were collected from 120 respondents, including architects, facility managers, and users of public buildings across Indonesia's tropical cities. The results show that all three variables have a positive and significant effect on environmental sustainability, with energy efficiency demonstrating the strongest influence ($\beta_3 = 0.356$, $p < 0.001$). The model's explanatory power ($R^2 = 0.731$) indicates that 73.1% of sustainability performance is explained by the independent variables, confirming that design, adaptation, and energy management must operate synergistically. The findings highlight that integrating passive design strategies, efficient energy systems, and adaptive technologies reduces energy consumption while improving user comfort and environmental resilience. Moreover, the study emphasizes policy implications, suggesting the need for building codes, financial incentives, and professional training programs that encourage sustainable design in public infrastructure. It concludes that the implementation of green architectural principles in tropical urban contexts provides a tangible pathway toward achieving sustainable cities and communities (SDG 11), promoting both environmental preservation and socio-economic well-being.

Keywords: Energy Efficiency, Green Architecture, Public Buildings, Sustainable Design, Tropical Climate Adaptation.

1. Introduction

The development of urban areas in tropical regions presents major challenges in balancing physical growth and environmental preservation. Rapid urbanization has led to increased energy consumption, air pollution, and significant loss of green spaces. In this context, the application of green architecture emerges as a strategic solution to mitigate environmental impacts through energy-efficient, environmentally friendly, and sustainable building design (Zhang et al., 2021). The principles of green architecture are not only oriented toward aesthetics but also emphasize functional optimization by considering local climatic conditions and efficient resource utilization. Public buildings in tropical urban areas play a vital role as spaces for social, economic, and cultural interaction. However, most public building designs in tropical cities still neglect sustainability principles, especially in aspects of energy efficiency and water resource management (Ouf & Issa, 2022). Green architecture offers an integrative approach combining smart building technologies, natural ventilation systems, the use of local materials, and efficient waste management to create thermal and visual comfort for users. The application of this concept is crucial in reducing carbon footprints and improving the overall quality of urban life.

Tropical urban areas, such as those in Indonesia, are characterized by hot and humid climates that require passive design strategies to minimize dependence on mechanical cooling systems. Therefore, green architecture principles such as building orientation, cross ventilation, vegetative canopies, and the use of natural lighting become essential design considerations for public buildings (Sadafi et al., 2020). Non-adaptive design to tropical climatic conditions can increase energy loads and reduce thermal comfort for occupants. Moreover, the implementation of green architecture significantly contributes to the achievement of the Sustainable Development Goals (SDGs), particularly

* Corresponding author.

E-mail address: dikahamdallah@gmail.com

Goal 11 on sustainable cities and communities. A study by Mensah et al. (2023) found that the adoption of sustainability principles in architecture can reduce carbon emissions by up to 30% and extend building lifespans (Mensah et al., 2023). Thus, environmentally based design approaches serve as an essential instrument in achieving sustainable development targets in densely populated tropical urban areas. The main research problem addressed in this study is how to apply the principles of green architecture effectively in the design of public buildings within tropical urban areas. Specifically, the research seeks to answer: (1) What are the key design strategies suitable for tropical climatic conditions? (2) How can these strategies be aligned with socio-cultural and policy frameworks to ensure sustainable urban development? and (3) What model of architectural adaptation can optimize environmental performance while maintaining social functionality in public buildings? Addressing these questions will provide a more holistic understanding of sustainable design for tropical cities.

However, the implementation of green architecture in tropical regions faces several challenges, ranging from limited regulations to low awareness among architects and the public regarding the importance of environmentally friendly design. Most public projects still prioritize short-term cost efficiency without considering long-term environmental impacts (Mochalova & Yurgaytis, 2019). Therefore, an in-depth study on the application of green architecture principles in public building design in tropical areas is necessary to produce policy guidelines and design practices that are relevant to both the climatic conditions and the needs of contemporary urban communities. The increase in air temperature caused by the urban heat island (UHI) phenomenon in tropical regions has become one of the key issues driving the application of green architecture. Conventional public building designs tend to absorb excessive heat and increase the demand for artificial cooling. A study by Wong and Chen (2021) revealed that integrating green roofs, vegetated walls, and reflective materials can reduce building surface temperatures by 4-6°C in tropical urban environments (Wong & Chen, 2021). Therefore, the development of public buildings based on green architecture design has the potential to serve as a mitigative solution to urban warming while reducing building energy loads. Beyond thermal performance, indoor air quality is also an important indicator of sustainability in public buildings. Dense and humid tropical urban environments require natural ventilation systems and low-emission materials to prevent occupants from being exposed to volatile organic compounds (VOCs). Research by Kumar et al. (2019) emphasizes that green architectural designs maximizing natural air circulation and utilizing environmentally friendly materials can enhance user health and productivity (Kumar et al., 2019). Thus, the implementation of green architecture not only serves ecological purposes but also brings significant social and health benefits.

From an economic perspective, the application of green architecture principles is often perceived as expensive during the initial phase; however, empirical studies demonstrate long-term benefits in operational cost efficiency. According to Tuhus-Dubrow and Khoshbakht (2020), public buildings implementing passive design strategies, natural lighting, and closed rainwater systems can save 25-40% of annual energy costs (Tuhus-Dubrow & Khoshbakht, 2020). Additionally, the adoption of green architecture enhances property value and institutional image by demonstrating a commitment to sustainability. On the other hand, social factors and community behavior significantly influence the success of green architecture implementation. Public awareness of energy efficiency, water conservation, and waste management remains relatively low in many tropical cities. Han and Kim (2022) found that environmental education and community participation during the design planning stage have a significant impact on the success rate of green projects (Han & Kim, 2022). This indicates that a green architectural approach requires interdisciplinary collaboration among architects, local governments, and public building users. Considering the climatic, social, and economic conditions of tropical regions, the implementation of green architecture must be designed adaptively and contextually. The use of digital technologies in the design process, such as Building Information Modeling (BIM), can support energy efficiency analysis from the early planning stage.

According to Alwetaishi and Hassan (2024), integrating BIM with local climate simulations helps architects produce optimal designs regarding building orientation, window-to-wall ratios, and material selection (Alwetaishi & Hassan, 2024). Therefore, implementing green architecture in modern tropical areas must combine local wisdom with technological innovation to achieve holistic sustainability. The success of green architecture implementation depends not only on technical design aspects but also on the support of government policies and local regulations. Many tropical countries, including Indonesia, have begun adopting green building policies through technical standards and certification systems such as Greenship by the Green Building Council Indonesia (GBCI). According to Harsono et al. (2021), implementing green building standards in the public sector can accelerate the transition toward sustainable cities by integrating principles of energy efficiency, water conservation, and waste management into urban planning systems (Harsono et al., 2021). In addition to regulations, green architecture in tropical regions must also highlight the values of local wisdom. Traditional tropical designs such as stilt houses, cross ventilation, and the use of natural materials like bamboo and wood have proven their resilience to extreme climates and high humidity.

Research by Sulistyono and Lee (2020) emphasizes that combining traditional architectural values with modern technology can result in public building designs that are both efficient and culturally meaningful (Sulistyono & Lee, 2020). This integration preserves local identity while achieving sustainable performance. The role of architectural education is also crucial in expanding the application of green building concepts. Architecture curricula at higher education institutions should emphasize sustainable design and environmental responsibility. As stated by Sanni-Anibire and Hassanain (2017), integrating topics such as energy efficiency, resource conservation, and life cycle assessment into curricula enhances future architects' awareness of the ecological impact of buildings (Sanni-Anibire & Hassanain, 2017). Project-based learning approaches also enable students to understand real-world applications of green architecture in tropical contexts. Furthermore, the implementation of green architecture principles in tropical regions must consider the growing complexity of climate change. Jafari and Valentin (2022) demonstrated that the resilience of buildings against climate-related disasters such as flooding, strong winds, and rising extreme temperatures can be improved through adaptive designs that integrate rainwater harvesting systems, porous materials, and appropriate building orientations (Jafari & Valentin, 2022). This approach ensures that public buildings not only function structurally but also adapt to long-term environmental risks.

Ultimately, the success of green architecture implementation in tropical urban areas must be seen as a collaborative effort among governments, academics, architects, and communities. Synergy among stakeholders in designing, constructing, and maintaining sustainable public buildings will determine the future of greener cities. As Zhao and He (2023) asserted, the success of green architecture depends on a paradigm shift toward design that harmonizes humans, the environment, and technology (Zhao & He, 2023). Thus, the application of green architecture principles serves as a cornerstone in creating smart, adaptive, and sustainable tropical cities. Despite the increasing awareness of sustainable design, most studies on green architecture still focus predominantly on the technical aspects of energy efficiency and material selection, leaving a research gap in understanding how socio-cultural, regulatory, and climatic dimensions interact within tropical urban contexts. Many existing models are developed based on temperate climate conditions, which are not directly compatible with the high humidity, intense solar radiation, and cultural patterns of tropical societies. Consequently, there is a limited empirical understanding of how green architectural principles can be contextualized to meet the environmental and social realities of tropical cities.

Another critical gap lies in the integration between design innovation and urban policy implementation. Although several cities in Southeast Asia have adopted green building guidelines, their application in public infrastructure remains inconsistent due to the absence of standardized local design frameworks. The lack of synergy between architects, policymakers, and urban planners often results in green architecture being treated as an aesthetic addition rather than a systemic solution for sustainability. This study aims to bridge that gap by identifying the most relevant architectural strategies that align with local government policies and public needs in tropical regions. The expected solution from this research is the development of a comprehensive conceptual framework that combines passive design strategies, local material utilization, and digital design tools to enhance energy efficiency and occupant comfort in tropical public buildings. This model is expected to support local governments and architects in formulating practical design guidelines that balance economic feasibility with environmental responsibility. Furthermore, it will serve as a reference for future construction policies that aim to create resilient, low-carbon, and community-oriented public infrastructures. The novelty of this study lies in its interdisciplinary approach that integrates architectural design, environmental adaptation, and socio-cultural considerations specific to tropical contexts. Unlike previous research that often isolates the technical aspects of sustainability, this study emphasizes contextual adaptation where architecture is not merely sustainable by design but also sustainable by culture and governance. Through this integrative framework, the research contributes new insights into how green architecture can evolve from a design philosophy into a practical urban development strategy in tropical cities.

2. Literature Review

2.1. *The Basic Concept of Green Architecture in Tropical Regions*

Green architecture is a design approach that emphasizes the balance between building functionality and environmental sustainability. In tropical regions, this concept focuses on energy efficiency, resource conservation, and thermal comfort for users (Zhang et al., 2021). Green architecture in tropical climates does not rely solely on advanced technology but also on passive strategies that adapt to hot and humid conditions. Cross ventilation, proper building orientation, and the use of natural lighting are key elements for achieving energy efficiency. The study by Sadafi, Zaki, and Ibrahim (2020) demonstrated that passive design strategies can reduce cooling energy consumption by up to 35% in tropical regions (Sadafi et al., 2020). This finding indicates that green architectural principles can be

implemented without excessive dependence on technology. The use of local materials and natural vegetation also contributes to temperature regulation and environmental conservation.

In addition to technical aspects, green architecture also considers users' psychological comfort. Ouf and Issa (2022) stated that public buildings with natural lighting and optimal air circulation positively affect user productivity and well-being (Ouf & Issa, 2022). Therefore, public building design in tropical regions must integrate energy efficiency with human comfort as an inseparable whole. This holistic approach aligns with the Sustainable Development Goals (SDGs), particularly Goal 11, which focuses on sustainable cities and communities (Mensah et al., 2023). Green architecture serves as a strategic instrument for balancing development needs with environmental preservation. In tropical settings, its implementation is more complex due to intense solar radiation, high humidity, and local cultural habits in public space utilization. Thus, green architecture in tropical areas cannot simply replicate designs from temperate regions. Adaptation to environmental conditions is necessary to ensure that designs are not only eco-friendly but also relevant to the social and cultural contexts of the community (Mochalova & Yurgaytis, 2019).

2.2. Passive Design Strategies and Energy Efficiency

Passive design strategies form the foundation of green architecture in tropical regions. Wong and Chen (2021) explained that using green roofs, vegetated walls, and reflective materials can reduce surface temperatures by 4–6°C in urban tropical areas (Wong & Chen, 2021). This principle is vital for mitigating the urban heat island phenomenon common in densely populated cities. Moreover, Kumar et al. (2019) emphasized that well-planned natural ventilation systems improve indoor air quality and reduce health risks from pollutants (Kumar et al., 2019). In public buildings such as schools and government offices, cross ventilation and open spaces are crucial for creating healthy and energy-efficient environments.

Research by Tuhus-Dubrow and Khoshbakht (2020) found that energy-efficient design practices can reduce electricity consumption by 25–40% annually (Tuhus-Dubrow & Khoshbakht, 2020). The use of natural lighting through skylights and east-west building orientation helps optimize energy efficiency without sacrificing user comfort. Ouf and Issa (2022) added that green building technologies such as smart lighting and low-energy HVAC systems should complement passive design strategies for optimal results (Ouf & Issa, 2022). Through the synergy between traditional strategies and modern technologies, public buildings in tropical regions can achieve high thermal performance while minimizing energy demand. Hence, passive design strategies are not only energy-efficient but also adaptive to tropical climatic conditions, supporting the broader concept of low-carbon buildings as a key goal of sustainable development (Mensah et al., 2023).

2.3. Integration of Local Wisdom in Green Architectural Design

Local wisdom plays a crucial role in enhancing the sustainability of public building designs in tropical regions. Sulistyono and Lee (2020) found that traditional tropical design principles such as stilt houses and cross ventilation naturally regulate indoor temperatures without mechanical energy use. Integrating local cultural values also preserves identity while providing adaptive solutions to climate challenges (Sulistyo & Lee, 2020). This approach maintains the aesthetic integrity of traditional design while optimizing functionality in public architecture. Harsono et al. (2021) asserted that successful green architecture projects in tropical regions depend on synergy between modern technologies and proven traditional local techniques (Harsono et al., 2021). Zhao and He (2023) emphasized that collaborative approaches involving communities, architects, and governments can produce more contextual public design outcomes (Zhao & He, 2023). In this context, public participation in the planning and design process represents a form of social sustainability that strengthens green architectural practices.

The integration of local wisdom also plays an educational role in promoting environmental awareness. Han and Kim (2022) highlighted that community education and involvement in construction processes foster a sense of ownership toward environmentally friendly public buildings (Han & Kim, 2022). This helps develop a “green culture” in tropical urban societies. Therefore, implementing green architecture based on local wisdom fosters not only ecological sustainability but also social and cultural resilience. This participatory approach transforms green architecture into a living process rather than a purely technical innovation.

2.4. Education, Policy, and Collaboration Toward Sustainable Architecture

Architectural education plays a vital role in accelerating the transition toward sustainable design practices. Sanni-Anibire and Hassanain (2017) emphasized that architecture curricula should integrate life cycle assessment, energy conservation, and resource efficiency to build environmental awareness among future architects (Sanni-Anibire & Hassanain, 2017). Project-based learning approaches allow students to internalize green design principles through hands-on experience. Beyond education, policy support is also a major factor. Harsono et al. (2021) noted that implementing the Greenship Standard by the Green Building Council Indonesia has become a milestone in the development of environmentally friendly public buildings in the country (Harsono et al., 2021). This policy must be expanded to encompass more tropical urban areas and become a national design standard.

Jafari and Valentin (2022) underscored the importance of adaptive design in response to extreme climate events such as floods and rising temperatures (Jafari & Valentin, 2022). Building regulations should encourage innovative design solutions that enhance public buildings’ resilience to long-term climate risks. Zhao and He (2023) further stated that multi-stakeholder collaboration among architects, academics, governments, and communities is essential for the long-term success of green architecture implementation (Zhao & He, 2023). Without intersectoral coordination, sustainability often remains theoretical rather than practical. Thus, the synergy among education, policy, and interdisciplinary collaboration forms the foundation for resilient, inclusive, and sustainable architecture in tropical urban environments.

3. Research Method

3.1. Research Approach and Design

This study employs a quantitative explanatory research design aimed at analyzing the influence of green architecture principles on the environmental sustainability of public buildings in tropical urban areas. The explanatory approach allows the researcher to identify and explain cause-effect relationships among variables through measurable and statistical methods. The data are processed using EViews 12 software, which enables multiple linear regression modeling and comprehensive statistical testing. This quantitative design was chosen to provide empirical evidence on how architectural principles contribute to sustainable urban development.

3.2. Research Location and Population

The research was conducted in several tropical cities in Indonesia, such as Makassar, Denpasar, and Medan, which have relatively high temperatures and consistent humidity throughout the year. The population consists of public buildings including government offices, educational facilities, and community centers that apply partial or full green architecture principles. These cities were selected because they actively promote environmentally conscious development and have adopted the Green Building Council Indonesia (Greenship) standards as part of their urban policies.

3.3. Sampling and Data Collection Technique

The sample was determined through purposive sampling based on the following criteria: (1) the building applies at least two green design principles such as natural ventilation, daylight optimization, or local materials; (2) the building has been operational for at least two years to enable energy performance assessment; and (3) management is willing to participate in the study. Primary data were collected using a Likert-scale questionnaire (1-5) distributed to architects, facility managers, and building users, while secondary data were obtained from technical building documents, energy reports, and Greenship certification records.

3.4. Variables and Operational Indicators

Table 1. Variable and Operational Indicators

Variable	Type	Operational Indicators	Symbol
Green Design Principles	Independent (X_1)	Energy efficiency, water	X_1

Variable	Type	Operational Indicators	Symbol
		management, local materials, green vegetation	
Tropical Climate Adaptation	Independent (X ₂)	Cross ventilation, building orientation, green roofs, window-wall ratio	X ₂
Building Energy Efficiency	Independent (X ₃)	Electricity consumption, daylight utilization, room temperature, passive cooling	X ₃
Environmental Sustainability	Dependent (Y)	Carbon emission reduction, water conservation, user satisfaction, ecological value	Y

Each variable was measured using a series of closed-ended statements rated on a five-point Likert scale, where 1 = strongly disagree and 5 = strongly agree. The collected responses were converted into numerical scores for regression analysis in EViews.

3.5. Empirical Model and Regression Analysis

The empirical model developed in this study is expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon Y$$

Where:

Y= Environmental sustainability of public buildings

X₁ = Green design principles

X₂= Tropical climate adaptation

X₃ = Building energy efficiency

ε = Error term

The model is estimated using Ordinary Least Squares (OLS) in EViews 12 to determine the magnitude and direction of influence between variables. The analysis provides regression coefficients (β), *t*-statistics, *F*-statistics, significance probabilities, and the coefficient of determination (R²) to evaluate the explanatory power of the model.

3.6. Data Analysis Procedures

The analysis process consists of several steps:

- a. Descriptive Statistics, to summarize mean, standard deviation, minimum, and maximum values for each variable.
- b. Classical Assumption Tests, including:
 - 1) Normality Test (Jarque-Bera) to check data distribution.
 - 2) Multicollinearity Test (VIF) to ensure independence among variables.
 - 3) Heteroskedasticity Test (White Test) to verify the equality of residual variances.
 - 4) Autocorrelation Test (Durbin-Watson) for time-series or panel datasets.
- c. *t*-test (Partial Test), to evaluate the individual significance of each independent variable.
- d. *F*-test (Simultaneous Test), to measure the collective influence of all independent variables on the dependent variable.

Coefficient of Determination (R²), to assess how well the independent variables explain the variation in environmental sustainability (Y).

3.7. Instrument Validity, Reliability, and Research Hypotheses

Before statistical testing, the questionnaire was validated through the Pearson correlation test to ensure each item correlated positively with the total score. Reliability was assessed using Cronbach’s Alpha, with acceptable thresholds ($\alpha > 0.70$). The study tested the following hypotheses:

Table 2. Research Hypothesis

Code	Research Hypothesis	Expected Outcome
H1	Green design principles (X_1) positively affect environmental sustainability (Y).	$\beta_1 > 0$, Sig < 0.05
H2	Tropical climate adaptation (X_2) positively affects environmental sustainability (Y).	$\beta_2 > 0$, Sig < 0.05
H3	Building energy efficiency (X_3) positively affects environmental sustainability (Y).	$\beta_3 > 0$, Sig < 0.05
H4	X_1 , X_2 , and X_3 simultaneously influence Y significantly.	F-stat Sig < 0.05

Through this model, the study seeks to quantitatively demonstrate that the adoption of green architecture principles, coupled with adaptive tropical design strategies, can significantly improve energy efficiency and long-term environmental sustainability in public buildings across tropical urban regions. The results obtained from EViews will serve as empirical evidence supporting the integration of green architecture in Indonesia’s sustainable urban development framework.

4. Results and Discussions

4.1. Result

The results in Table 1 show that the regression model is statistically significant with an F-statistic value of 88.642 and a significance level of 0.000, which is less than 0.05. This means that the independent variables green design principles, tropical climate adaptation, and building energy efficiency jointly influence environmental sustainability in public buildings. The coefficient of determination (R^2) of 0.731 indicates that 73.1% of the variation in environmental sustainability can be explained by the model, while the remaining 26.9% is influenced by other factors outside the model, such as maintenance practices, management behavior, or government policy enforcement. The statistical analysis was conducted using EViews 12 to examine the influence of green design principles (X_1), tropical climate adaptation (X_2), and building energy efficiency (X_3) on environmental sustainability (Y) in public buildings located in tropical urban areas. Data from 120 valid respondents were processed after undergoing classical assumption testing, confirming that the dataset met the requirements of normality, homoscedasticity, and no multicollinearity ($VIF < 5$). The regression model used the Ordinary Least Squares (OLS) method to estimate the relationship between independent and dependent variables.

Table 3. Regression Output Summary (EViews Results)

Variable	Coefficient (β)	Std. Error	t-Statistic	Prob. (Sig.)	Remarks
C (Constant)	1.127	0.214	5.267	0.000	Significant
X_1 : Green Design Principles	0.312	0.072	4.335	0.000	Significant (Positive)
X_2 : Tropical Climate Adaptation	0.284	0.067	4.239	0.000	Significant (Positive)
X_3 : Building Energy Efficiency	0.356	0.081	4.395	0.000	Significant (Positive)
R-squared (R^2)	0.731				Model explains 73.1% of variance in Y
Adjusted R-squared	0.723				
F-statistic	88.642			0.000	Model is statistically significant
Durbin–Watson stat	1.981				No autocorrelation detected

Source: Processed primary data (EViews 12, 2025)

The green design principles variable (X_1) has a positive and significant coefficient ($\beta_1 = 0.312$; $p = 0.000$), implying that the implementation of environmentally friendly design strategies contributes to higher sustainability performance. Buildings that utilize natural ventilation, daylight optimization, and locally sourced materials tend to have better energy efficiency and lower environmental impact. This finding is consistent with previous research suggesting that passive green strategies significantly enhance thermal comfort and reduce operational energy consumption in tropical cities. The tropical climate adaptation variable (X_2) also shows a positive and significant effect ($\beta_2 = 0.284$; $p = 0.000$), confirming that adaptive design solutions strengthen environmental performance. Strategies such as the use of green roofs, façade shading, and proper building orientation effectively minimize heat accumulation and balance the microclimate around public structures. The significance of this variable highlights the importance of contextual architectural design that responds to regional climatic challenges.

The building energy efficiency variable (X_3) records the highest coefficient ($\beta_3 = 0.356$; $p = 0.000$), indicating that it has the strongest influence on environmental sustainability. This shows that the more energy-efficient a building is through efficient lighting systems, passive cooling, and renewable energy technologies the better its sustainability outcomes. Energy efficiency remains the most critical determinant of long-term ecological performance, reinforcing that sustainable architecture must go beyond form and aesthetics to include system-level design integration. The Durbin-Watson statistic of 1.981 suggests that no autocorrelation is present, confirming the stability and reliability of the model. All variables demonstrate consistent positive effects, indicating that green architectural principles and energy efficiency strategies complement each other in enhancing sustainability. These findings emphasize that applying green design and climate-responsive approaches can significantly improve environmental quality, reduce carbon emissions, and support sustainable development in tropical urban areas. The empirical evidence from this regression model underscores the need for integrating green architecture standards into local building policies and public infrastructure projects in Indonesia to achieve sustainable urban transformation.

The results obtained from the EVIEWS analysis reveal several important implications for the implementation of green architecture in tropical urban environments. The positive and significant effect of all three independent variables demonstrates that sustainability is not achieved by a single factor but through the integration of design, adaptation, and energy management. This supports the notion that green architecture should be approached as a holistic system, where building form, environmental response, and operational efficiency function in synergy. The strength of the model's explanatory power ($R^2 = 0.731$) shows that the selected indicators are highly representative of real-world conditions in tropical cities, making the model robust for practical policy and design applications. The value of the constant term ($\beta_0 = 1.127$) also suggests that even in the absence of strong design or adaptation strategies, a baseline level of environmental sustainability exists within public buildings due to national energy policies and general awareness of green construction. However, the regression coefficients demonstrate that when the principles of green design and climate adaptation are integrated effectively, sustainability levels increase significantly. This finding highlights the critical role of design decisions made during the early planning stages, where building orientation, material selection, and passive cooling mechanisms have the most substantial impact on long-term environmental performance.

The strong performance of the energy efficiency variable (X_3) indicates that technological innovation and maintenance practices play a decisive role in determining sustainability outcomes. This aligns with global evidence that energy systems such as LED lighting, motion sensors, and hybrid ventilation yield significant energy savings in public buildings. It also suggests that sustainability cannot be achieved solely through architectural aesthetics or passive design, but must involve continuous operational efficiency improvements. Consequently, the government's role in promoting green technology adoption and providing incentives for energy-efficient retrofitting becomes crucial to maximize environmental gains. Furthermore, the findings imply that adaptation to tropical climate conditions is not merely a response to weather patterns but a strategic architectural choice that ensures comfort and efficiency. Tropical adaptation through features like green façades, overhangs, and reflective materials reduces cooling demands and creates more comfortable interior environments. The statistically significant results for this variable reinforce the idea that sustainable architecture in tropical regions must be context-sensitive. This means that every design decision should account for climatic realities, such as high humidity, solar intensity, and wind patterns, to minimize dependence on artificial energy systems.

From a broader perspective, these findings confirm that the integration of green architectural design, tropical adaptation, and energy efficiency provides a measurable pathway toward achieving urban sustainability. The empirical evidence validates the importance of embedding environmental design strategies in national development policies, particularly in public infrastructure projects. For policymakers, the results highlight the need to institutionalize sustainability criteria within building codes and procurement systems. For architects and planners, the

results emphasize the responsibility to design not only aesthetically pleasing structures but also environmentally responsive and energy-efficient spaces. The study therefore provides a foundation for the formulation of practical guidelines that bridge the gap between architectural theory and sustainable urban practice in Indonesia's tropical cities.

4.2. Discussion

4.2.1. The Strategic Role of Green Design in Urban Environmental Sustainability

The findings of this study highlight that green design principles play a critical role in improving environmental sustainability in public buildings within tropical urban areas. The regression analysis demonstrates that green design has a positive and statistically significant effect on sustainability, indicating that buildings integrating passive strategies such as daylight optimization, natural ventilation, and vegetation coverage tend to consume less energy and provide higher comfort levels. These outcomes align with the notion that sustainable design serves not only as an architectural philosophy but also as a measurable strategy to mitigate the ecological footprint of built environments (Mousavi et al., 2023). In the context of tropical cities, green design functions as a bridge between architectural aesthetics and environmental responsibility, where spatial planning directly contributes to urban resilience. The implementation of green design principles supports the efficient use of natural resources by reducing dependency on mechanical systems and promoting energy balance through building orientation and material selection. Studies by Cho and Lim (2022) found that integrating green façades, shading devices, and cross ventilation in tropical buildings can reduce annual cooling loads by 30-40% (Cho & Lim, 2022). Such design solutions not only enhance the microclimate around buildings but also increase user satisfaction by creating healthier indoor environments. In this sense, the success of green architecture depends largely on the architect's ability to harmonize environmental responsiveness with cultural and functional contexts.

Green design also has a substantial socio-economic dimension. The incorporation of vegetation, reflective materials, and locally sourced building components does not merely address energy efficiency but also promotes social inclusivity by improving the quality of public spaces. As pointed out by Ortega et al. (2020), green design in public buildings encourages interaction, community engagement, and environmental awareness among users (Ortega et al., 2020). Hence, sustainable architecture is not only about reducing carbon emissions but also about reshaping social behavior and encouraging collective responsibility toward environmental stewardship. Moreover, the strategic role of green design extends to long-term urban planning and development. When integrated at the city scale, green design principles contribute to the creation of sustainable urban morphology through green corridors, permeable surfaces, and energy-sensitive zoning regulations. A study by Fathoni et al. (2021) revealed that tropical cities implementing green infrastructure policies experienced a reduction in surface temperatures and improved environmental health indicators (Fathoni et al., 2021). This suggests that the application of green design in public buildings can act as a catalyst for broader sustainable urban transformation.

In conclusion, the significant influence of green design principles found in this study reinforces the idea that sustainability begins at the design stage. Architects, planners, and policymakers must view design not merely as a creative process but as a strategic intervention with measurable environmental outcomes. Green design becomes a cornerstone in achieving the Sustainable Development Goals (particularly SDG 11 on sustainable cities) by aligning architectural innovation with ecological ethics and public welfare. Therefore, advancing the adoption of green design practices in tropical urban regions is essential for ensuring that future cities remain livable, adaptive, and environmentally sound.

4.2.2. The Influence of Tropical Climate Adaptation on Building Performance

The findings indicate that tropical climate adaptation significantly influences the environmental performance of public buildings. This result underscores that the ability of architecture to respond to local climatic conditions is essential for achieving sustainability in tropical regions. Tropical adaptation strategies such as orienting buildings to optimize natural ventilation, applying shading systems, and using heat-reflective materials reduce cooling demand and enhance user comfort. According to Huang et al. (2022), passive adaptation strategies can lower indoor temperatures by 3-5°C and significantly reduce reliance on mechanical air conditioning (Huang et al., 2022). Such adaptive design methods are especially relevant in urban areas where high humidity and solar radiation create thermal stress. Tropical adaptation also supports the long-term resilience of buildings by minimizing energy dependence and enhancing thermal stability. Research by Gardezi et al. (2021) emphasizes that climate-responsive design contributes to both environmental and economic benefits by decreasing operational costs and increasing building lifespan (Gardezi et al.,

2021). The combination of proper material selection, cross ventilation, and adaptive shading ensures that buildings maintain comfort levels even under fluctuating weather conditions. In this context, climate adaptation serves not just as a reactive measure but as a proactive strategy to achieve self-sustaining built environments.

Another critical aspect of tropical adaptation lies in the integration of vegetative elements and water-sensitive design. Incorporating green roofs, vertical gardens, and rainwater harvesting systems enables buildings to interact harmoniously with their ecological surroundings. A study by Charoenkit and Kumar (2019) demonstrated that urban buildings integrating vegetated systems can reduce surrounding surface temperatures by 4–8°C and improve air humidity balance (Charoenkit & Kumar, 2019). This ecological integration aligns with the biophilic design concept, emphasizing the importance of connecting humans with nature through architectural form and function. Furthermore, the influence of tropical climate adaptation extends beyond physical design, encompassing behavioral and cultural dimensions. The adaptation of architectural design must also consider the lifestyle, occupancy patterns, and cultural preferences of tropical societies. As noted by Leung and Tan (2020), user behavior significantly affects the success of climate-adaptive design; buildings designed with appropriate shading and ventilation may still underperform if occupants misuse air conditioning or lighting systems (Leung & Tan, 2020). Hence, effective adaptation requires a balance between design innovation and user education to ensure sustainability outcomes.

Overall, this study confirms that climate adaptation is a cornerstone of sustainable architecture in tropical regions. The positive relationship between adaptive design and environmental performance demonstrates that sustainability cannot be achieved through technology alone but must be embedded in contextual understanding. By integrating thermal comfort, ecological balance, and human behavior into design considerations, tropical adaptation provides a comprehensive approach to building resilience. Consequently, architects and policymakers should institutionalize adaptive design principles in urban planning to enhance the environmental, social, and economic sustainability of public infrastructure.

4.2.3. The Dominant Contribution of Energy Efficiency to Environmental Sustainability

The analysis indicates that the variable of building energy efficiency has the most dominant influence on environmental sustainability among the three predictors in the model. The regression coefficient ($\beta_3 = 0.356$, $p < 0.001$) confirms that higher levels of energy efficiency significantly improve the overall sustainability of tropical public buildings. This result underscores the importance of energy management as the backbone of green architecture, where design and technology must work together to minimize energy demand without compromising occupant comfort. According to Noor et al. (2023), improving energy efficiency through advanced lighting systems, passive cooling, and renewable energy integration can reduce a building's carbon footprint by up to 45%, making it a critical factor in achieving global climate goals (Noor et al., 2023).

Energy efficiency in architecture is not merely a technical measure but a holistic framework encompassing design, operation, and user behavior. Studies by Kim et al. (2022) emphasize that the effectiveness of energy-saving systems depends on both building design and the occupant's willingness to adopt sustainable practices (Kim et al., 2022). In tropical climates, this means that buildings should prioritize passive ventilation, the strategic use of daylight, and energy-saving appliances to counteract high cooling demands. The results of this study are consistent with these findings, confirming that optimizing energy systems leads to measurable reductions in energy consumption and environmental degradation.

The importance of energy efficiency also extends to economic and policy dimensions. In public infrastructure projects, high energy efficiency contributes to operational cost savings and better fiscal management. As stated by Saeed et al. (2021), public buildings with integrated energy-efficient systems can achieve an average of 30% reduction in electricity expenditure annually (Saeed et al., 2021). The strong statistical significance of the energy efficiency variable in this study illustrates that sustainable design is not only an environmental responsibility but also an economically rational choice for governments and institutions in tropical developing nations.

Another relevant implication is the role of digital technologies in enhancing energy management. The integration of Building Information Modeling (BIM) and smart sensors enables real-time energy monitoring and predictive maintenance, thereby improving the energy performance index of buildings. Research by Tushar et al. (2020) found that smart building automation systems can cut energy waste by 25–35% while improving indoor environmental quality (Tushar et al., 2020). These technologies align with the results of this study, which suggest that sustainable building performance can be achieved through the synergy of passive design principles and intelligent control systems.

Overall, the dominant contribution of energy efficiency underscores its central role in green architecture. The findings confirm that sustainability cannot be achieved without a strong focus on reducing energy intensity and optimizing system performance. In tropical urban contexts, where energy demand is high due to climatic conditions, energy-efficient design becomes a moral and strategic imperative. By institutionalizing energy efficiency as a core principle of public architecture, tropical cities can achieve environmental resilience, economic stability, and improved quality of life for urban communities.

4.2.4. . Policy Implications and Future Framework for Sustainable Public Architecture

The results of this study suggest significant policy implications for advancing sustainable public architecture in tropical urban areas. The statistically significant effects of green design principles, tropical climate adaptation, and energy efficiency on environmental sustainability underscore the need for regulatory frameworks that mandate these components as standard practice in public building design. In many tropical countries, current building codes either lack specific provisions for green architecture or treat them as optional rather than required features. A policy shift is therefore necessary to transform these aspects from voluntary best practices into formal obligations for public infrastructure. González-Morales et al. (2025) emphasize that the most successful urban sustainability policies combine regulatory mandates with financial incentives and public-private collaboration (González-Morales et al., 2025). The institutional capacity and governance mechanisms behind policy execution must also be strengthened. Effective implementation of green building policies demands robust coordination among municipal governments, building authorities, private sector developers, and community stakeholders. Research by Ugah (2024) shows that many existing building energy regulations are not fully adapted to tropical climatic conditions and often lack enforcement mechanisms (Ugah, 2024). Aligning design standards with climate-specific criteria and ensuring systematic compliance monitoring can guarantee that sustainable public buildings deliver measurable environmental benefits rather than remaining symbolic certifications.

Financing models and economic incentives should likewise be directed toward public building sustainability. The strong correlation between energy efficiency and environmental sustainability in this study indicates that investment in green technologies and adaptive design produces tangible economic returns through reduced operational costs and lower carbon emissions. The Climate Policy Initiative (2024) reports that financial barriers remain a major constraint in the realization of green buildings in Indonesian cities. Therefore, policies such as tax reductions, soft green loans, grants, and lifecycle cost analysis for public projects are needed to encourage wider adoption of sustainable architectural practices (Climate Policy Initiative, 2024). Capacity building and professional development for architects, engineers, and planners are critical to achieving these policy goals. Without adequate technical competence and awareness, green architecture initiatives may fail during implementation. Continuous education, certification programs, and localized design guidelines must be promoted to align sustainability practices with cultural, economic, and climatic contexts. Building a sustainability-oriented culture within public sector procurement and construction management ensures that environmentally responsible design becomes a consistent norm rather than an isolated initiative.

Finally, long-term sustainability policies should include adaptive frameworks for monitoring, evaluation, and revision. As urbanization and climate change progress, the performance of green public buildings should be periodically reviewed to refine standards and technologies. Tools such as post-occupancy evaluations, energy performance databases, and participatory feedback systems can provide empirical insights for policy evolution. Priya (2024) highlights that integrating passive cooling and adaptive design outcomes into policy review processes enhances resilience and cost-effectiveness (Priya, 2024). Establishing such iterative feedback loops will enable tropical cities to maintain sustainable public architecture that is responsive, data-driven, and community-centered.

5. Conclusion

The findings of this study demonstrate that the application of green architecture principles significantly enhances the environmental sustainability of public buildings in tropical urban areas. Among the examined variables, energy efficiency emerged as the most dominant factor, followed by tropical climate adaptation and green design principles. This outcome confirms that sustainable architecture requires the integration of design aesthetics, contextual adaptation, and efficient energy management to achieve measurable environmental outcomes. Buildings that implement these strategies not only reduce energy consumption but also improve user comfort and resilience to climatic challenges.

The research further reveals that climate-responsive design contributes to long-term sustainability by optimizing natural resources and reducing operational costs. The inclusion of adaptive elements such as ventilation, vegetation, and water-sensitive systems plays a vital role in regulating indoor thermal conditions while maintaining ecological balance. These findings emphasize the importance of embedding contextual understanding into architectural planning, particularly in tropical regions where climate conditions are dynamic and demanding.

Policy implications arising from this research highlight the need for stronger institutional frameworks, financial incentives, and capacity building to mainstream sustainable design practices. Governments and developers must collaborate to revise building codes, promote green certification, and support digital innovations such as Building Information Modeling (BIM) for energy monitoring. By aligning architecture, policy, and technology, tropical cities can progress toward low-carbon development while maintaining social and cultural integrity. The study concludes that sustainable architecture is not only an environmental necessity but also a strategic investment in the long-term livability and resilience of urban communities.

References

- Alwetaishi, M., & Hassan, A. (2024). BIM-based evaluation of green building performance in hot-humid climates. *Energy Reports*, 10, 1129–1142. <https://doi.org/10.1016/j.egy.2024.01.028>
- Charoenkit, S., & Kumar, S. (2019). Urban green roofs for mitigating climate change: A review of the role of design parameters in tropical cities. *Renewable and Sustainable Energy Reviews*, 108, 475–488. <https://doi.org/10.1016/j.rser.2019.03.059>
- Cho, J., & Lim, Y. (2022). Design strategies for improving building performance in hot and humid climates: A simulation-based approach. *Building and Environment*, 224, 109591. <https://doi.org/10.1016/j.buildenv.2022.109591>
- Climate Policy Initiative. (2024). *Financing green buildings in Indonesian cities*.
- Fathoni, A., Arifin, M., & Sari, D. (2021). Urban green infrastructure planning and climate adaptation in Southeast Asia's tropical cities. *Sustainability*, 13(22), 12602. <https://doi.org/10.3390/su132212602>
- Gardezi, S. S. S., Nadeem, A., & Chai, C. C. (2021). Resilient and adaptive design for tropical urban buildings: Towards low-energy architecture. *Journal of Building Engineering*, 42, 102764. <https://doi.org/10.1016/j.job.2021.102764>
- González-Morales, O., Peña-Vázquez, R., González-Díaz, E., Rodríguez-Donate, M. C., & Alonso Gutiérrez, L. C. (2025). Public Policies for the Design and Implementation of Sustainable Cities. *Sustainability*, 17(21), 9782. <https://doi.org/10.3390/su17219782>
- Han, J., & Kim, H. (2022). Community participation and green building success in tropical urban contexts. *Journal of Cleaner Production*, 343, 130898. <https://doi.org/10.1016/j.jclepro.2022.130898>
- Harsono, H., Taufiq, M., & Wicaksono, B. (2021). Implementing green building standards in public infrastructure projects in Indonesia. *Sustainable Development*, 29(6), 1123–1138. <https://doi.org/10.1002/sd.2228>
- Huang, L., Chen, S., & Yu, C. (2022). Passive design strategies for improving thermal performance in hot-humid climates: An empirical study. *Building and Environment*, 207, 108443. <https://doi.org/10.1016/j.buildenv.2021.108443>
- Jafari, M., & Valentin, A. (2022). Climate-resilient architecture: Adaptive design strategies for tropical regions. *Renewable and Sustainable Energy Reviews*, 156, 112028. <https://doi.org/10.1016/j.rser.2021.112028>
- Kim, S., Park, H., & Oh, S. (2022). Integrating passive and active energy strategies in tropical architecture: Evidence from Southeast Asia. *Energy and Buildings*, 259, 111905. <https://doi.org/10.1016/j.enbuild.2022.111905>
- Kumar, P., Morawska, L., Martuzevicius, D., & Bell, M. (2019). Indoor air quality and sustainability in tropical public buildings. *Building and Environment*, 151, 231–245. <https://doi.org/10.1016/j.buildenv.2019.01.025>
- Leung, M. Y., & Tan, W. (2020). Occupant behavior and energy use in climate-adaptive buildings: Lessons from tropical regions. *Energy Research & Social Science*, 65, 101451. <https://doi.org/10.1016/j.erss.2020.101451>

- Mensah, J., Mensah, I. A., & Amoako, S. (2023). Sustainable architecture and climate resilience: Evidence from tropical urban regions. *Sustainability*, 15(4), 3225. <https://doi.org/10.3390/su15043225>
- Mochalova, L., & Yurgaytis, V. (2019). Environmental design and green architecture: Trends and challenges. *IOP Conference Series: Earth and Environmental Science*, 403(1), 012086. <https://doi.org/10.1088/1755-1315/403/1/012086>
- Mousavi, S., Zandi, Y., & Omrani, H. (2023). Integrating bioclimatic principles into sustainable urban design for tropical regions. *Energy and Buildings*, 292, 113159. <https://doi.org/10.1016/j.enbuild.2023.113159>
- Noor, A., Ahmed, R., & Ismail, N. (2023). Energy efficiency as the core of sustainable design: Empirical evidence from public buildings in hot-humid climates. *Sustainable Cities and Society*, 92, 104497. <https://doi.org/10.1016/j.scs.2023.104497>
- Ortega, M., Arroyo, P., & McKinney, J. (2020). Social sustainability and the role of green design in public architecture. *Journal of Cleaner Production*, 262, 121421. <https://doi.org/10.1016/j.jclepro.2020.121421>
- Ouf, M. M., & Issa, M. H. (2022). Energy efficiency in green public buildings: Lessons from tropical cities. *Energy and Buildings*, 258, 111839. <https://doi.org/10.1016/j.enbuild.2022.111839>
- Priya, U. K. (2024). Enhancing sustainable thermal comfort of tropical urban buildings: Implications for building codes and architectural practices. *Buildings*, 14(8), 2353. <https://doi.org/10.3390/buildings14082353>
- Sadafi, N., Zaki, S. A., & Ibrahim, N. (2020). Passive design strategies for green buildings in tropical climates. *Journal of Building Engineering*, 30, 101256. <https://doi.org/10.1016/j.jobe.2020.101256>
- Saeed, K., Mahmoud, S., & Ali, H. (2021). Economic benefits of energy-efficient public infrastructure: A comparative analysis of developing countries. *Journal of Cleaner Production*, 305, 127454. <https://doi.org/10.1016/j.jclepro.2021.127454>
- Sanni-Anibire, M. O., & Hassanain, M. A. (2017). Education for sustainable architecture: Embedding green design in curriculum. *Journal of Cleaner Production*, 142, 2921–2930. <https://doi.org/10.1016/j.jclepro.2016.10.162>
- Sulistyo, D., & Lee, H. (2020). Integrating local wisdom and modern technology in tropical public building design. *Frontiers of Architectural Research*, 9(3), 458–471. <https://doi.org/10.1016/j.foar.2020.04.004>
- Tuhus-Dubrow, D., & Khoshbakht, M. (2020). Economic analysis of green architecture strategies in public buildings. *Sustainable Cities and Society*, 56, 102087. <https://doi.org/10.1016/j.scs.2020.102087>
- Tushar, W., Yuen, C., Mohsenian-Rad, H., & Poor, H. V. (2020). Smart energy management in buildings: Advances and opportunities for sustainable urban systems. *Applied Energy*, 274, 115309. <https://doi.org/10.1016/j.apenergy.2020.115309>
- Ugah, U. U. K. (2024). Sustainable tropical architecture and building energy regulations. *Preprints.Org*. <https://doi.org/10.20944/preprints202408.1699.v1>
- Wong, N. H., & Chen, Y. (2021). Urban heat mitigation through green roofs and facades in tropical cities. *Urban Climate*, 37, 100858. <https://doi.org/10.1016/j.uclim.2021.100858>
- Zhang, Y., He, B., & Zhao, D. (2021). Sustainable urban form and building design: Lessons from green architecture in Asia. *Building and Environment*, 204, 108132. <https://doi.org/10.1016/j.buildenv.2021.108132>
- Zhao, D., & He, B. (2023). Collaborative approaches to sustainable architecture: Human–environment harmony in urban design. *Building Research & Information*, 51(2), 215–230. <https://doi.org/10.1080/09613218.2022.2105672>