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Integrating Ecology into Vertical Housing: Critical Success Variables for Green Building Adoption in IKN

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ABSTRACT

The transition to ecologically integrated vertical housing is pivotal to the sustainable development vision of Indonesia's new capital, Ibu Kota Nusantara (IKN). This study identifies and prioritizes the critical success variables influencing the implementation of green building initiatives within IKN's vertical housing projects. By employing the MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement), a structural analysis approach, the study evaluated inter-variable influences across five sustainability dimensions: environmental, social, economic, institutional, and infrastructural. A total of 91 expert respondents were selected through purposive sampling to assess the strength and dependence of 30 operational variables. The analysis reveals a clear hierarchy, identifying 11 determinant (driver) variables and 9 key (relay) variables as most critical to the system's success. Among the most influential drivers are policy synergy and fund allocation efficiency, which serve as foundational enablers. Meanwhile, community involvement and effective waste management were

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identified as highly sensitive relay variables that connect strategic policies to tangible outcomes. The research highlights that sustainable high-rise development in IKN requires not only green technology and regulation, but also multidimensional coordination, ecological sensitivity, and inclusive design strategies. The findings offer a practical framework for guiding decision-makers, planners, and developers in achieving ecologically resilient urbanization in tropical environments.

Keywords: IKN; Green Building; Ecological Integration; Vertical Housing; MICMAC; Sustainable Development; Urban Resilience; Policy Synergy

JEL Codes: Q01; R52; O44

1. Introduction

Indonesia is currently grappling with a complex dual challenge: it poses significant threats to the surrounding ecosystems, which are part of the Borneo biodiversity hotspot. These threats include the fragmentation of rainforests that are home to endemic species like the Bornean orangutan, the disruption of sensitive hydrological cycles in the Mahakam watershed, and increased carbon emissions from the acceleration of urbanization on one hand and the imperative to ensure environmental sustainability on the other. This is particularly critical in the context of the newly planned national capital, Ibu Kota Nusantara (IKN), which is envisioned as a green and smart city. As population growth drives the demand for land and housing, vertical development emerges as a rational solution to optimize limited space. However, the uncontrolled expansion of high-rise buildings without ecological safeguards poses significant threats to the surrounding ecosystems, including forest fragmentation, the loss of biodiversity corridors, and increased carbon emissions [1,2]. Without strategic planning, IKN could repeat the mistakes of other rapidly urbanizing cities that have sacrificed ecological resilience for short-term economic gains.

The urgency of integrating green building principles in vertical housing has been well-documented globally, particularly in the context of climate change mitigation and sustainable urbanism. According to Pan et al. [3], the success of green buildings is closely associated with multi-stakeholder collaboration, institutional synergy, and enforceable regulations. Similarly, Aguilar-Lacasaña et al. [4] highlight that ecological indicators, such as energy efficiency, water use, and green space ratio, must be embedded in high-rise planning to ensure environmental compatibility. Condie [5] introduces a human-centered dimension, asserting that ecological literacy among building occupants significantly determines long-term sustainability outcomes. Meanwhile, Feng et al. [6] demonstrate how technological innovations such as green roofs, passive ventilation, and AI-enabled energy monitoring systems drive performance. However, many of these studies are rooted in temperate or urban-industrial settings, making their applicability to IKN's unique tropical-forest environment questionable without contextual adaptation.

A particular concern in the Indonesian context is the persistent fragmentation of environmental and construction policies. Akgün [7] points out that the lack of policy integration between green building guidelines and spatial planning regulations creates ambiguity and weak enforcement. In tropical climates, the failure to account for local climatic conditions such as high humidity, intense rainfall, and solar radiation further undermines ecological performance [8]. In addition, Argente García et al. [9] emphasize the undervaluation of urban biodiversity integration, which is essential for maintaining ecological connectivity in rapidly densifying areas. Incentive structures, financing models, and land-use zoning also remain disjointed, as Wang [10] argues, limiting the private sector's willingness to invest in eco-innovation. Bardhan [11] and Puspitasari [12] further show that without long-term community engagement and maintenance strategies, the physical infrastructure of green buildings tends to degrade prematurely, diminishing their environmental benefits.

Despite these emerging insights, a significant research gap persists in understanding how these dynamics interact within a national capital development context, especially in archipelagic countries like Indonesia, where ecological sensitivity is heightened. Most international literature focuses on ecological retrofitting in existing cities rather than planning green integration from the outset.

Therefore, the implementation of ecologically sound vertical housing in IKN remains insufficiently conceptualized and empirically underexplored. This study addresses that gap by identifying and prioritizing critical success variables specifically relevant to IKN, considering its institutional structure, socio-ecological setting, and urban development trajectory. This study identifies and prioritizes critical success variables for ecologically integrated green buildings in vertical housing within Indonesia's future capital, IKN. Recognizing the city's unique ecological sensitivity, institutional context, and urban trajectory, the research adopts a systems thinking approach to map variable interactions. Using the MICMAC method (Matrix of Cross-Impact Multiplications Applied to Classification), the study analyzes expert-assessed interdependencies among ecological, infrastructure, institutional, and socio-economic dimensions. MICMAC enables the classification of variables based on their influence and dependence, helping uncover key leverage points for policy and planning. The resulting framework supports strategic interventions for sustainable high-density development and offers a replicable model for other ecologically vulnerable tropical cities by employing a systems thinking approach. The research not only maps causal linkages between variables but also uncovers leverage points for policy intervention. This makes the study both scientifically relevant and practically urgent for guiding sustainable transitions in Indonesia's future capital.

The primary aim of this research is to explore the critical variables that facilitate or hinder the implementation of ecologically integrated green buildings in vertical housing within IKN. It investigates four main dimensions—ecological, infrastructure, institutional, and socio-economic—to understand how these interrelated factors shape the feasibility and success of green building initiatives. To untangle these complex dynamics, this study employs the MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) method. This approach was chosen for its ability to analyze the web of interdependencies between numerous variables, identifying not just which factors are critical, but also revealing the underlying structure of influence and dependence that can guide strategic policy interventions. Through expert-based structural analysis, this study develops a contextualized model that informs stakeholders about where to focus interventions and policy reforms. The framework is designed to be scalable and adaptive, potentially offering a blueprint for other tropical cities facing similar urbanization-ecology dilemmas. The outcomes are expected to support evidence-based decision-making and encourage transdisciplinary collaboration among planners, architects, environmentalists, and community leaders. Finally, the ecological lens adopted in this study is not merely a complementary aspect but a foundational element of sustainable vertical housing in IKN. The city's location within a sensitive ecological zone—including forest ecosystems, critical watersheds, and endemic biodiversity—necessitates development models that go beyond low-energy design toward regenerative urbanism. Uncontrolled vertical expansion could lead to irreversible habitat fragmentation, water contamination, and microclimate alterations. By identifying key ecological integration variables—such as urban greening, bioclimatic architecture, and ecological zoning—this study contributes to shaping a new urban paradigm. This paradigm emphasizes the coexistence of high-density living with ecological preservation, thereby enhancing the city's long-term livability, resilience, and global standing as a model for green capital development.

2. Literature Review

2.1. A Socio-Ecological Systems Approach to Urban Resilience

This study conceptualizes IKN as an emerging Socio-Ecological System (SES), an integrated system of humans in nature where the delineation between the social and the ecological is considered artificial [13]. The SES perspective posits that cities are not just built environments but complex, adaptive systems where social components (governance, economy, culture, infrastructure) and ecological components (biodiversity, water cycles, climate) are deeply intertwined and mutually influential [14]. This approach is particularly suited for IKN, where the explicit goal of creating a "forest city" necessitates a holistic understanding of how human decisions, such as building design and policy implementation, directly shape ecological outcomes like biodiversity conservation and hydrological stability [15]. The study's multidimensional analysis is a direct application of the SES framework, which demands a transdisciplinary view to understand system dynamics.

Within this SES framework, the study's central goal is to enhance Urban Resilience. Urban Resilience Theory (URT) defines resilience as the ability of an urban system to absorb disturbances (e.g., climate change impacts, resource shocks, economic crises), reorganize, and adapt while retaining its essential functions, structure, and identity [16]. For IKN, this means developing a city that can withstand and recover from environmental pressures like increased flooding or biodiversity loss, while continuing to provide a high quality of life for its residents. The integration of ecological principles into vertical housing is thus framed as a core strategy for building this resilience. Green buildings contribute to the robustness of the urban system by reducing environmental stress, enhancing social capital, and creating more sustainable infrastructure networks.

2.2. Human-Nature Connection and Urban Metabolism in Green Building

To further explain the causal pathways between green buildings and urban resilience, two complementary concepts are employed. First, Human-Nature Connection Theory (HNCT) addresses the socio-cultural dimension of ecological integration. HNCT posits that fostering a cognitive, emotional, and physical connection between humans and nature can cultivate pro-environmental behaviors and improve psychological well-being. In the context of IKN, vertical housing that incorporates biophilic design elements does more than provide aesthetic benefits. It can enhance residents' ecological literacy and sense of stewardship, which are critical for the long-term success of sustainability initiatives and contribute to the social resilience of the community [17].

Second, the concept of Urban Metabolism provides a powerful analytical lens for understanding the physical impact of green buildings on urban resilience. Urban metabolism views the city as an organism that consumes resources (energy, water, materials) and produces waste (emissions, sewage, solid waste) [18]. A traditional, linear metabolism is unsustainable, whereas a circular metabolism, which minimizes inputs and recycles outputs, is more resilient. Green buildings directly contribute to a more circular and efficient urban metabolism. By design, they reduce energy and water consumption, utilize recycled or renewable materials, and minimize waste generation. Therefore, the success variables identified in this study, such as 'Energy Efficiency Conservation (EK2)', 'Use of Environmentally Friendly Construction Materials (LI1)', and 'Implementation of Waste Management (LI6)', are direct levers for optimizing IKN's urban metabolism, thereby reducing its ecological footprint and enhancing its resilience to resource scarcity and environmental degradation.

2.3. Literature Review and Research Contribution

The integration of ecological principles into urban development, particularly vertical housing, has gained increasing attention in recent years due to the urgent need for environmentally responsible urban expansion. Numerous studies have highlighted the relevance of ecological design, energy efficiency, and green infrastructure in improving the sustainability of high-density buildings. For example, Corton [19] emphasized the importance of incorporating vegetation and water-sensitive design into high-rise housing to reduce carbon emissions and mitigate the urban heat island effect. Similarly, Bardhan [11] discussed how integrating natural ventilation and daylighting strategies enhances indoor environmental quality while reducing energy dependency.

From a socio-ecological perspective, Aguilar-Lacasaña et al. [4] identified that stakeholder involvement and ecological literacy among residents are significant factors influencing the performance of green buildings. Pan et al. [3] also demonstrated that vertical greening and ecological façade technologies can significantly contribute to urban biodiversity and habitat provision in dense cities. A more technology-oriented approach was explored by Feng et al. [6], who integrated Internet of Things (IoT) sensors to optimize ecological building performance, suggesting that technological innovation supports both monitoring and adaptive management in green housing systems. In the context of tropical urbanism, Argente García et al. [9] pointed out that many green building frameworks overlook the importance of local climatic adaptation, leading to ineffective ecological performance. Likewise, Akgün [7] criticized the lack of context-specific standards and fragmentation in policy implementation as key obstacles to the success of ecologically integrated buildings in developing countries. A study by Bardhan [11] and Puspitasari [12] further examined the intersection of ecological systems and built environments, suggesting that the success of vertical housing depends not only on building technology but also on its ecological footprint across its life cycle.

The review across thematic domains—such as technological innovation, governance mechanisms, ecological design, and social participation—reveals both convergence and divergence in how green buildings are conceptualized and implemented. These studies collectively inform our current work by illustrating that successful green building strategies require an integrated approach across multiple dimensions. However, unresolved debates persist in the literature. First, while some studies emphasize the role of top-down policy enforcement, others highlight grassroots participation as more effective—suggesting a tension between institutional authority and community agency. Second, although technological solutions (e.g., IoT sensors, passive cooling) are widely promoted, their applicability in tropical, resource-constrained settings like IKN remains uncertain due to high implementation costs and maintenance challenges. Third, while economic incentives are known to stimulate green adoption, there is little consensus on which financial models are most effective in emerging economies. These unresolved issues reinforce the need for a context-specific, system-based analysis, as adopted in this study, to capture the complex interdependencies in IKN's unique socio-ecological landscape.

Moreover, financing and governance mechanisms are increasingly recognized as pivotal in promoting green buildings. Wang [10] investigated successful case studies in Southeast Asia and found that incentives, subsidies, and green certifications significantly influence the rate of ecological integration. Mcdermott [20] emphasized the role of regulatory consistency and inter-agency coordination in the implementation of ecologically sustainable high-rise projects. In summary, recent research supports the view that integrating ecology into vertical housing requires a multidimensional approach involving technology, governance, community participation, and environmental design. However, a persistent challenge, especially in developing countries, is the fragmentation of policy and the lack of context-specific standards. Many green building frameworks fail to adequately account for local climatic conditions, leading to suboptimal performance in tropical regions. Furthermore, inconsistent regulations and a lack of coordination between government agencies can undermine the implementation of sustainable projects. Financial mechanisms, such as incentives, subsidies, and green certifications, are also recognized as pivotal in driving the adoption of ecological integration by the private sector.

While this body of knowledge provides a valuable foundation, a significant research gap remains, which this study aims to fill. Most existing research focuses on retrofitting existing urban areas or is based on case studies from temperate climates. There is a scarcity of empirical work that identifies and prioritizes the critical success variables for integrating ecological principles into vertical housing from the ground up in the unique context of a new national capital being built in a tropical, high-biodiversity region. This study differentiates itself from existing research in several key ways: Context-specificity: Unlike generalist studies, this research develops a model of success variables tailored specifically to the unique socio-ecological, institutional, and political context of IKN. Systems-based approach: While many studies examine variables in isolation, this study uses the MICMAC method to analyze the complex web of interdependencies between variables. This reveals not just *what* is important, but *how* variables influence one another, identifying strategic leverage points for policy intervention that other studies may miss. Focus on foundational planning: This research addresses the challenges of greenfield development, focusing on how to embed ecological principles from the outset, rather than retrofitting them into an existing urban fabric. By addressing these gaps, this study makes a step towards a better understanding of the research problem, providing a scientifically robust and practically applicable framework to guide the sustainable development of IKN and other future cities in ecologically sensitive regions.

3. Methods

3.1. Research Location

The time and location of this research were in Indonesia's new capital city, specifically in IKN (Nusantara Capital City), from January to April 2024 (**Figure 1**). Nusantara is the future capital of Indonesia and is scheduled to be officially inaugurated on August 17, 2024, coinciding with the celebration of Indonesia's 79th Independence Day. IKN will replace Jakarta, which has served as the capital since 1961. One of the most significant challenges in constructing vertical housing in IKN is the contoured topography and the geotechnical characteristics of the area, which include soil layers that are highly susceptible to water influence, such as expansive glacial layers [1]. This condition leads to high costs for earthworks and requires careful consideration of the glacial layers and potential landslide hazards in foundation design.

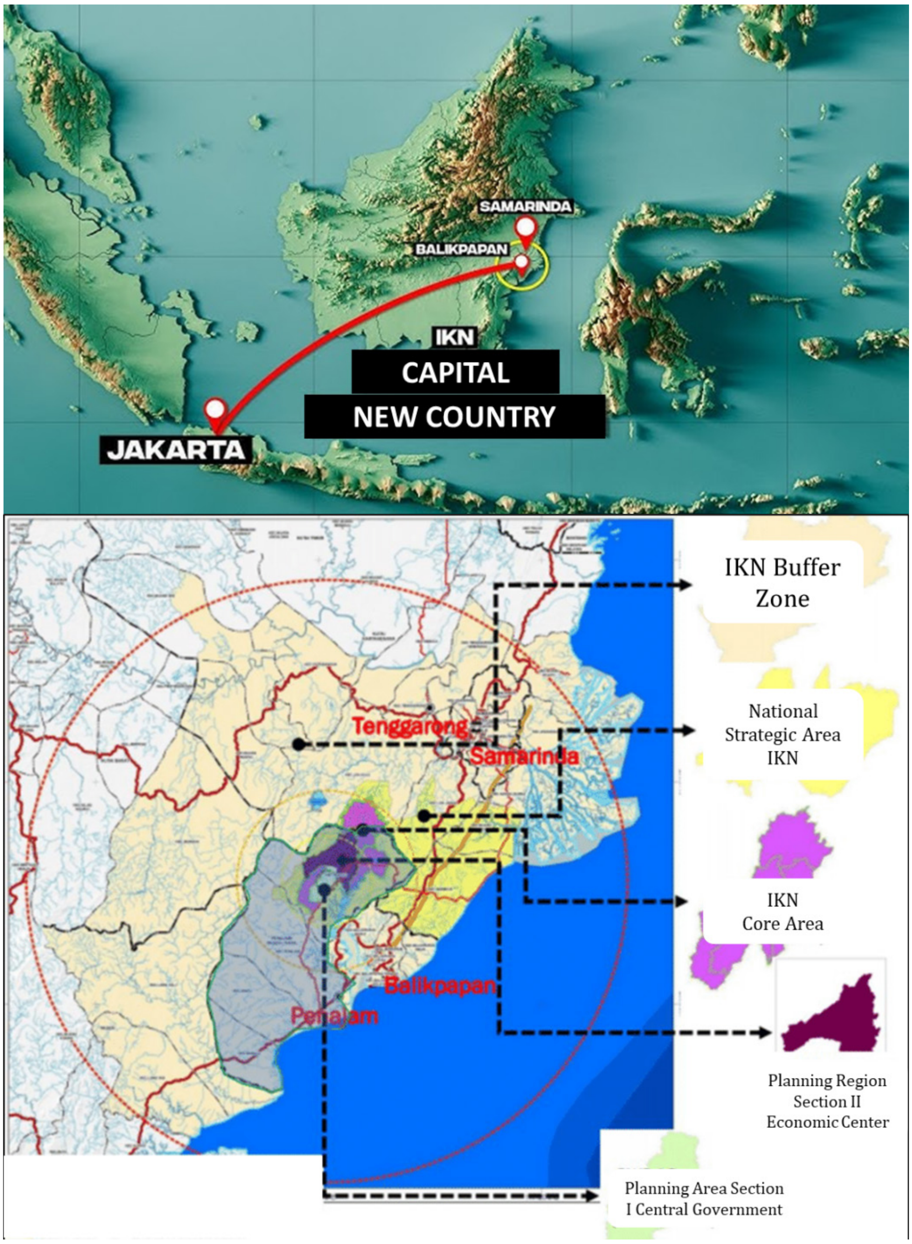

Figure 1. Research Location.

3.2. The Material

Since this study is non-laboratory in nature and focused on stakeholder analysis, planning frameworks, and sustainability dimensions, no biological, chemical, or industrial materials were used. The main material utilized was a structured questionnaire, which was developed based on a literature review and validated by experts in ecological planning, sustainable construction, and urban governance. The questionnaire consisted of five dimensions—environmental, social, economic, infrastructure, and institutional—with a total of 30 operational variables. The expert respondents assessed inter-variable influence using a structured influence matrix, with values coded as 0 (no influence), 1 (weak), 2 (moderate), 3 (strong), and P (potential influence) [21]. To ensure validity, the questionnaire underwent a rigorous expert review process. A panel of five academics and three practitioners specializing in ecological planning, sustainable construction, and urban governance reviewed the draft for clarity, relevance, and comprehensiveness. Their feedback was used to refine the variables and their operational definitions. Following the review, a pilot test was conducted with ten respondents, who were not part of the main sample, to check for ambiguity in the questions and to ensure the influence matrix scale was clearly understood. Reliability of the constructs was not quantitatively assessed, as the MICMAC method relies on aggregated expert judgment rather than internal consistency scales.

3.3. Population and Sample

In this study, the population consists of all stakeholders involved in the development and management of IKN, including government elements, business actors, professionals, local communities, and other supporting institutions. Given the broad and heterogeneous nature of the population, this study employs a sampling technique to identify relevant samples. A sample is defined as a subset of the population possessing specific characteristics relevant to the research objectives [22–24]. The sample used in this study comprises 91 respondents who are experts in the field of IKN development and management. The group was composed of policymakers from national and regional agencies (30%), private sector developers and architects (25%), academics specializing in urban planning and environmental science (25%), and representatives from community and environmental NGOs (20%), ensuring a representative cross-section of key stakeholders. They were selected based on their experience, institutional authority, and academic expertise related to sustainable development and green building.

3.4. Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Universitas Brawijaya, Indonesia (IRB number: 146). Informed consent was obtained from all subjects involved in the study.

3.5. Experimental Design

The study used a descriptive-exploratory design aimed at determining the key success variables and sustainability priorities related to green building implementation in vertical housing in IKN. The population in this research includes all relevant stakeholders involved in the planning, execution, or evaluation of urban development, especially in sustainable infrastructure and vertical housing in IKN. The sample was selected using nonprobability purposive sampling involving 91 expert respondents, comprising policy-makers, urban planners, engineers, sustainability consultants, community leaders, academics, and private developers. Experts were required to meet pre-defined criteria, such as having at least five years of professional experience in their respective domains and verifiable involvement in projects or policy discussions related to IKN, ecological planning, or sustainable urban development in Indonesia. The data collection instruments used were:

a) A structured questionnaire with a Likert-type influence matrix scale for MICMAC.
b) Closed- and open-ended surveys to collect descriptive perception data.
c) Focus group discussions (FGD) to validate sustainability indicators.
d) In-depth interviews with key informants to enrich interpretative findings.

Each of the five dimensions—environmental, social, economic, infrastructure, and institutional—was broken down into variables based on theoretical, policy, and empirical sources [25–27]. Definitions and indicators of each variable are clearly operationalized in the questionnaire.

3.6. Analysis Data

The Micmac method (Cross Impact Matrix Multiplication Applied to Classification) is a software developed by the Institut d'Innovation Informatique pour l'Entreprise (3IE) [21], to update the structural analysis method from its previous qualitative form to a quantitative one [28]. In its operation, Micmac applies matrix properties [29]. The purpose of Micmac is to identify and analyze the main variables of a system. The advantage of Micmac compared to other structural methods is that it allows for grouping and hierarchical determination of strategic variables of a system and understanding their mutual influence. This feature is very beneficial in the policy-making process as it directs the policy focus, considering that policy focus often leads to irrelevant variables, resulting in failure. The explanations provided by Micmac analysis increase confidence and trust in the issues raised and present diverse assumptions [30]. The qualitative data gathered from the focus group discussions (FGDs) and in-depth interviews were analyzed using a thematic analysis approach. Audio recordings were transcribed, and the transcripts were systematically coded to identify recurring themes, patterns, and insights related to the success variables. This qualitative analysis served to triangulate and enrich the interpretative findings from the quantitative MICMAC analysis, providing deeper context to the inter-variable relationships. The operationalization of the Micmac method consists of several stages, namely: (1) Defining the problem, identifying internal and external variables; (2) Assessing the relationships between variables according to the level of influence and dependence, assessed with a ranking scale between: 0 = none, 1 = weak, 2 = moderate, 3 = strong, P = potential. The assessment results will qualify the intensity of influence between variables into groups of direct influence, indirect influence, and potential influence. Direct influence occurs if variable A affects variable B; indirect influence occurs if variable A influences B and B influences variable C, and thus C is indirectly influenced by A. Potential influence occurs if variable A should affect B, while no direct influence occurs if a variable does not affect another variable; (3) Analyzing the intensity of influence and dependence of variables determined by the position of variables on the influence and dependence quadrant map. **Figure 2** assists in analyzing the influence and dependency of system variables and categorizes them into five typologies, which include determinant variables, relay variables, depending variables, excluded variables, and regulatory variables. This research utilizes a list of strategic variables from five dimensions, consisting of environmental, economic, social, infrastructure, institutional, technological, conservation, and regulatory dimensions (**Table 1**).

While the MICMAC method offers valuable insights into variable interdependencies and system structure, it is not without limitations. One of its primary weaknesses lies in its reliance on expert judgment to assess influence-dependence relationships between variables. This can introduce subjectivity and bias, especially if expert perspectives are not sufficiently diverse. To mitigate this, our study employed purposive sampling to select a heterogeneous panel of 91 experts from various sectors—government, academia, private developers, and NGOs. In addition, the structured questionnaire was validated through a panel of reviewers and tested in a pilot study to ensure clarity and reduce interpretative ambiguity. While MICMAC does not provide statistically generalizable outputs, the approach remains appropriate for exploratory system-based planning, particularly when expert-based knowledge is prioritized to uncover leverage points in complex, multi-dimensional systems such as IKN.

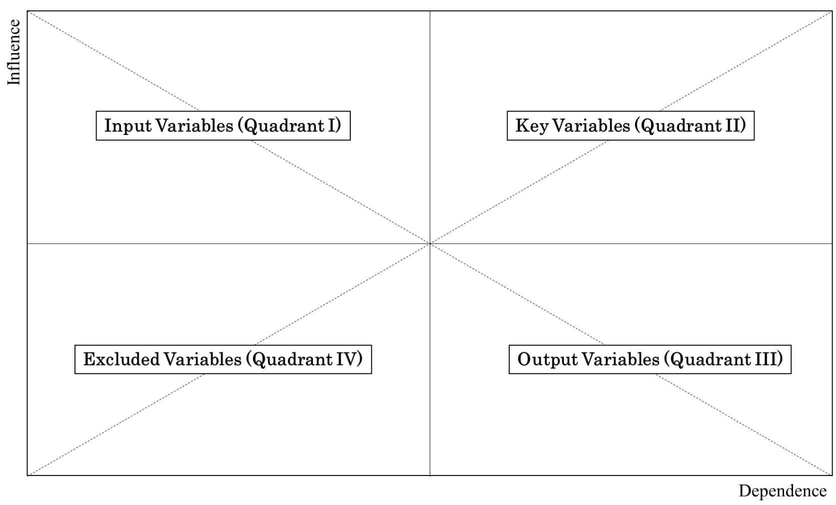

Figure 2. Quadrant Mapping.

Table 1. List of Strategic Variables for the Development of IKN Area.

Dimension	Variables and Code	Measurement
Environment	Use of environmentally friendly construction materials (LI1)	• 0: Variable (A) has no influence on other variables (B) • 1: Variable (A) has a weak influence on other variables (B) • 2: Variable (A) has a moderate influence on other variables (B) • 1: Variable (A) has a strong influence on other variables (B) • P: Variable (A) has a potential influence on other variables (B)
	Implementation of efficient use of construction materials (reduce) (LI2)	
	Implementation of the use of used construction materials (reuse) (LI3)	
	Implementation of the use of recycled construction materials (recycle) (LI4)	
	Implementation of maintaining the quality of water, air and light (LI5)	
	Implementation of waste management (LI6)	
Social	Involvement and participation of the community (SO1)	
	Implementation of the construction of facilities that are responsive to gender, the disabled, and the marginalized (SO2)	
	Implementation of the provision of access and interaction space for the community (SO3)	
	Concern for community welfare (SO4)	
	Implementation of the arrangement of ornaments and landscapes (SO5)	
	Buildings that support the preservation of local culture (SO6)	
Economy	This project pays attention to aspects of sustainable construction for the economic sector (EK1)	
	Energy efficiency conservation (EK2)	
	Use of local construction materials (EK3)	
	Study of benefits related to the economic sector (EK4)	
	Spatial flexibility in and outside the building (EK5)	
	Efficiency of fund allocation for development (EK6)	
Infrastructure	Availability of health facilities (IN1)	
	Development of toll roads and highways (IN2)	
	Availability of TPA (IN3)	
	Implementation of provision of access and facilities for public transportation users (IN4)	
	Availability of public facilities (IN5)	
	Electricity network and internet access (IN6)	
Institutional	Governance (KE1)	
	Role of apparatus (KE2)	
	Regional level regulations (KE3)	
	Policy synergy (KE4)	
	Coordination (KE5)	
	Cooperative relations (KE6)	

Source: See references [31–33].

4. Result and Discussion

4.1. System Stability Test

The system stability test in MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) aims to evaluate how stable or vulnerable a system is to changes in certain variables. MICMAC classifies variables based on direct and indirect influence. The system stability test is conducted by simulating changes in specific variables to observe their impact on the overall system. The results of the system stability test in MICMAC (**Table 2**) show that in the first iteration, the influence value reached 86% and the dependence value 95%, indicating that in the early stages, the system was not yet fully stable but already showed a relatively strong relationship among the existing variables. According to Godet [21], if the system stability level exceeds 80%, the classification of strategic variables in system management can be considered valid. In the second iteration, both influence and dependence reached 100%, signifying that all variables in the system had reached equilibrium and were interacting optimally. The maximum level of stability implies that there are no longer significant changes in the relationships among variables after the second iteration, meaning that the system has achieved full stability. This maximum stability indicates that the model developed in this analysis has high reliability and can be trusted to represent the dynamics of factors influencing the sustainability of vertical housing development in the Nusantara Capital City (IKN).

Table 2. System Stability Test.

Interaction	Influence	Dependence
1	86%	95%
2	100%	100%

4.2. Strategic Variable Mapping

Strategic variable mapping is the process of analyzing and identifying key factors that influence the success or failure of an organization or project. In the context of strategic management, it involves identifying variables that have a significant impact on organizational goals and performance. Strategic variable mapping enables organizations to focus on the most influential aspects and to formulate appropriate strategies. Furthermore, it helps organizations anticipate changes in the organizational or industry environment, allowing them to respond more quickly and effectively [34]. In conclusion, strategic variable mapping is a critical step in strategic planning that allows organizations to understand and manage the key factors shaping their operational context.

Strategic variable mapping using the MICMAC approach is an analytical method used to understand the interrelationships and roles of variables within a complex system. Each variable is evaluated based on its level of influence on other variables and its level of dependence within the system. The objective of the mapping is to identify key variables that have a significant impact on system dynamics, thus serving as a foundation for more strategic decision-making [29]. The results of the mapping are visualized in a graph that displays the position of each variable in four main categories: input variables, key variables, output variables, and excluded variables.

In the context of green building development for vertical housing in the Nusantara Capital City (IKN), strategic variables were grouped using the MICMAC method to help identify the main factors determining the sustainability of the project, such as government policy, energy efficiency, the use of environmentally friendly materials, and construction technologies that support sustainability principles [35,36]. The relationships among variables allow for the formulation of more effective strategies to support the implementation of sustainable development policies. **Figure 2** shows the variables grouped into the four quadrants.

As shown in **Figure 3**, the research results indicate that there are 11 variables in Quadrant I, 9 variables in Quadrant II, 7 variables in Quadrant III, and 3 variables in Quadrant IV (**Table 3**).

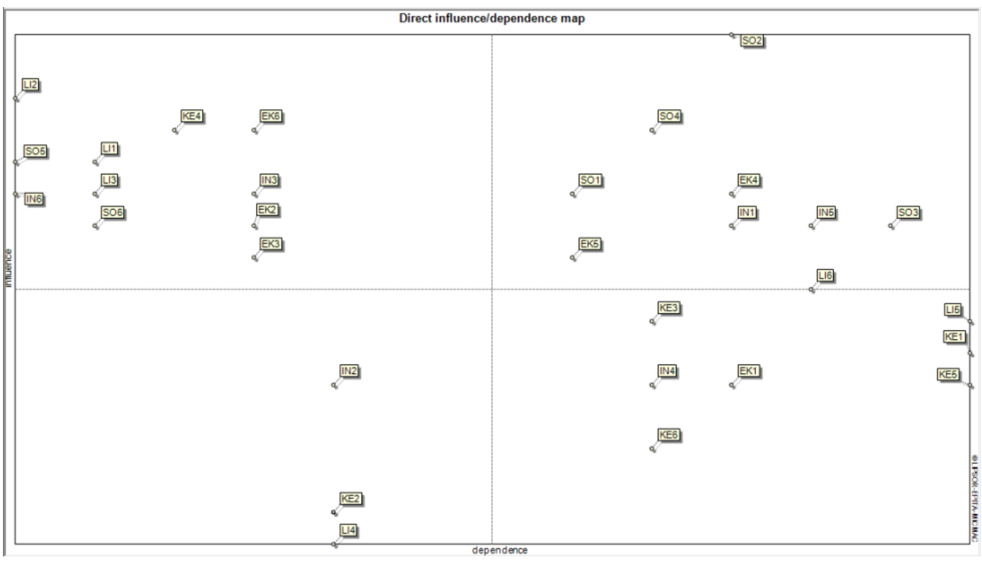

Figure 3. Pemetaan Variable Strategies.

Table 3. MICMAC Quadrant Analysis: Ecological and Sustainability Implications of Critical Success Variables.

	Variable and Code	Ecological and Sustainability Implications
Quadrant I: Input/Determinant Variables (High Influence, Low Dependence)	Use of environmentally friendly construction materials (L11)	Reduces embodied carbon and resource depletion, lessening pollution from manufacturing. In IKN's context, prioritizing certified local timber and bio-composites supports sustainable forestry and protects regional biodiversity [37].
	Implementation of efficient use of construction materials (reduce) (L12)	Minimizes waste generation, conserves natural resources, and lowers project costs. Directly supports a circular economy model by reducing the demand for virgin materials and the ecological footprint of construction.
	Implementation of the use of used construction materials (reuse) (L13)	Decreases landfill burden and the energy required for producing new materials. Promotes innovation in deconstruction and material life-cycle management, a core tenet of sustainable urban metabolism.
	Implementation of the arrangement of ornaments and landscapes (S05)	When using native flora, this directly creates micro-habitats, supports local pollinators, and enhances ecological connectivity. *Contr*ibutes to biophilic design, which improves residents' well-being and connection to nature [38].
	Buildings that support the preservation of local culture (S06)	Fosters social sustainability and place identity. Integrating traditional architectural motifs that are adapted to the tropical climate (e.g., natural ventilation features) can reduce energy demand for mechanical cooling [39].
	Energy efficiency conservation (EK2)	Directly reduces operational greenhouse gas emissions and lowers energy costs for residents. A key driver for mitigating climate change and enhancing the city's energy security and resilience [40].
	Use of local construction materials (EK3)	Supports the regional economy, reduces transportation-related carbon emissions, and ensures materials are suited to the local climate. Can create supply chains for sustainably harvested resources in Kalimantan [41].
	Efficiency of fund allocation for development (EK6)	A critical enabler for all green initiatives. Ensures that capital is available for higher upfront cost technologies (e.g., advanced water recycling, high-performance insulation), making sustainability economically viable for developers.
	Availability of TPA (Final Disposal/Landfill Site) (IN3)	A foundational element of environmental health. Proper landfill design and management prevent soil and water contamination, which is critical for protecting IKN's surrounding sensitive ecosystems and watersheds.
	Electricity network and internet access (IN6)	Essential for operating smart building systems that monitor and optimize energy and water use, enabling data-driven sustainability management and enhancing urban resilience.
	Policy synergy (KE4)	The master enabler of ecological integration. Aligns green building codes with spatial planning, environmental protection, and economic policies, creating a coherent and enforceable regulatory landscape that prevents loopholes and encourages investment.
Quadrant II: Key/Relay Variables (High Influence, High Dependence)	Implementation of waste management (L16)	Acts as a central node in the urban metabolism. Dependent on funding (EK6) and policy (KE4), it directly influences water quality (L15), public health (IN1), and ecosystem integrity by reducing pollution and promoting resource recovery.
	Involvement and participation of the community (S01)	Fosters social acceptance and long-term stewardship of green infrastructure. Community involvement can lead to more culturally and ecologically appropriate designs and ensure that public spaces meet residents' needs.
	Development of facilities that are responsive to gender, the disabled, and the marginalized (S02)	A core tenet of social sustainability and equity. Ensures that the benefits of green urbanism, such as access to healthy environments and public spaces, are distributed fairly across all segments of the population [42].
	Implementation of the provision of access and interaction space for the community (SO3)	Enhances social cohesion and well-being. Well-designed green spaces serve as community hubs, promoting physical activity and mental health, which are key components of a resilient urban society.
	Concern for community welfare (SO4)	A high-level social goal that is both a driver and an outcome of sustainable design. Dependent on good governance, it influences the prioritization of health-centric infrastructure like clean air and water systems.
	Study of benefits related to the economic sector (EK4)	Dependent on project implementation, this variable provides the feedback necessary to justify and scale up green building investments. It quantifies returns on investment, influencing future policy and funding decisions.[7]
	Spatial flexibility in and outside the building (EK5)	Promotes long-term building adaptability, reducing the need for future demolition and reconstruction, thereby saving embodied carbon and resources. It is a strategy for future-proofing the built environment.
	Availability of health facilities (IN1)	A key component of social resilience. Dependent on funding and planning, its quality is influenced by the overall environmental health of the city (e.g., clean air and water) promoted by other green variables.
	Availability of public facilities (IN5)	Interacts strongly with social and ecological goals. Green public facilities (parks, community centers) provide ecosystem services (cooling, water management) and social benefits (recreation, community building).

Table 3. *Cont.*

	Variable and Code	Ecological and Sustainability Implications
Quadrant III: Output/Dependent Variables (Low Influence, High Dependence)	Implementation of maintaining the quality of water, air and light (L15)	A primary outcome of successful ecological integration. This is a result of effective waste management (L16), use of non-toxic materials (L11), and energy-efficient design, rather than a driver in itself.
	This project pays attention to aspects of sustainable construction for the economic sector (EK1)	An outcome variable reflecting the successful implementation of input variables like energy efficiency (EK2) and material choice (EK3). Its success is dependent on the initial strategic decisions made.
	Implementation of provision of access and facilities for public transportation users (IN4)	A dependent variable that relies on integrated urban planning and policy synergy (KE4). It supports low-carbon mobility but is an output of a larger sustainable transport strategy, not an independent driver.
	Governance (KE1)	Represents the operational functioning of the system. Good governance is an outcome of clear policy (KE4), effective apparatus (KE2), and stakeholder coordination (KE5), and is highly dependent on these inputs.
	Regional level regulations (KE3)	These are the instruments that codify the strategic direction set by policy synergy (KE4). They are dependent on higher-level policy decisions and cannot be effective in isolation.
	Coordination (KE5)	An outcome of established governance structures (KE1) and cooperative relations (KE6). It is essential for implementation but is dependent on the pre-existence of a framework for collaboration.
	Cooperative relations (KE6)	The result of successful community engagement (S01) and institutional design. These relationships are an output of a well-managed system, not an initial driver.
Quadrant IV: Excluded/Autonomous Variables (Low Influence, Low Dependence)	Implementation of the use of recycled construction materials (recycle) (L14)	While beneficial, its systemic influence is low. The decision to use recycled materials is often a project-specific choice dependent on availability and cost, operating somewhat independently of the core strategic drivers.[1]
	Development of toll roads and highways (IN2)	Operates largely outside the system of building-level sustainability. While it impacts regional connectivity, it does not directly drive or depend on the ecological performance of vertical housing projects.[1]
	Role of apparatus (KE2)	Represents the function of individual actors within the system. While important for execution, their role is defined by the larger governance (KE1) and policy (KE4) frameworks, giving them low independent influence on the system's structure.[1]

Strategic variable mapping is the process of analyzing and identifying key factors that influence the success or failure of an organization or project. In the context of strategic management, strategic variable mapping involves identifying variables that have a significant impact on the goals and performance of an organization. This process allows organizations to focus on the most influential aspects and formulate appropriate strategies. Moreover, strategic variable mapping helps organizations anticipate changes in the business or industry environment, enabling them to respond more quickly and effectively [34]. In conclusion, strategic variable mapping is a crucial step in strategic planning that allows organizations to understand and manage the key factors shaping their operational context.

Strategic variable mapping in MICMAC is an analytical approach used to understand the interrelationships and roles of variables within a complex system. Each variable is assessed based on its level of influence on other variables and its dependence within the system. The aim of the mapping is to identify key variables that significantly impact the dynamics of the system and can serve as a foundation for more strategic decision-making [29]. The results of the mapping are visualized in a graph that shows the positions of variables within four main categories: input variables, key variables, output variables, and excluded variables. In the green building development of vertical housing in Nusantara Capital City (IKN), strategic variables are categorized using the MICMAC method to help identify the main factors determining project sustainability—such as government policy, energy efficiency, the use of environmentally friendly materials, and construction technologies that support sustainability principles [35,36]. The relationships among variables enable the formulation of more effective strategies to support the implementation of sustainable development policies. **Figure 2** shows the variables grouped into the four quadrants. As shown in **Figure 3**, the research findings indicate that there are 11 variables in Quadrant I, 9 variables in Quadrant II, 7 variables in Quadrant III, and 3 variables in Quadrant IV (**Table 3**). The research results show that strategic variables in the implementation of green buildings in vertical housing at IKN can be categorized into four quadrants based on their level of influence and urgency. Quadrant I (Input Variables) includes factors that form the foundation of sustainable development, particularly in the efficient use of resources and materials. These variables include the implementation of construction material use efficiency (reduce), the use of environmentally friendly construction materials, and the use of reused materials (reuse). In addition, social and infrastructure aspects also play a role, such as the implementation of ornament and landscape planning, buildings that support the preservation of local culture, and the availability of electricity networks and internet access. Environmental infrastructure is also a concern, including the availability of final waste disposal sites (landfills), efficient allocation of construction funds, energy conservation, use of local construction materials, and policy synergy in green building implementation.

Quadrant II (Key Variables) comprises the main factors that determine the success of green building implementation and community well-being. These include the development of facilities responsive to gender, people with disabilities, and marginalized groups, as well as concern for community welfare. Active community involvement and participation are also key factors, supported by the provision of access and spaces for interaction that allow for communication and social activities. From an economic perspective, assessing the benefits related to the economic sector and spatial flexibility of interior and exterior spaces becomes a priority. Supporting infrastructure, such as the availability of healthcare facilities, public amenities, and effective waste management, also serves as a key element in the sustainability of development. Quadrant III (Output Variables) includes factors that result from the implementation of green buildings and contribute to the sustainability of the project. These variables include local-level regulations governing green building governance, coordination among stakeholders, and collaborative relationships to ensure policy sustainability. Additionally, the implementation of water, air, and light quality control is essential for maintaining a healthy environment. From the economic side, the project must also consider sustainable construction aspects to support the economic sector. Other supporting infrastructure, such as access and facilities for public transport users, is important to ensure sustainable accessibility for communities. Quadrant IV (Excluded Variables) includes those with lower influence or less relevance to the sustainability of green buildings in IKN. Factors in this category include the development of toll roads and highways, the role of government officials in policy implementation, and the use of recycled construction materials. While these factors may contribute to sustainable development, their impact on green buildings is more limited compared to the main variables in the other quadrants.

4.3. Influence and Dependence: Direct vs. Indirect Impacts

Dependence among variables refers to the relationship or interaction between one variable and another within a system or model. This interdependence can affect changes in the behavior or conditions of the variables within the system. In systems analysis, variable dependence plays a crucial role in understanding system complexity and dynamics. In this study, the influence and dependence among variables are analyzed through two types: direct influence (Direct Graph) and indirect influence (Indirect Graph), as illustrated in **Figures 4** and **5**. The results show that the main variables directly influencing the sustainability of vertical housing in IKN include policy synergy (KE4), efficient fund allocation (EK6), construction material use efficiency (LI2), and the preservation of local culture (SO6). Policy synergy between central and regional governments is a key determinant of system sustainability, while efficient funding has broad impacts on sustainability aspects, including energy efficiency and the use of environmentally friendly materials. Moreover, efficient use of construction materials greatly affects sustainability from both environmental and infrastructure perspectives, while cultural preservation supports social sustainability and enriches the cultural value of vertical housing development.

The complexity of variable interrelationships also highlights the importance of understanding indirect dependencies. Indirect dependence in this system indicates that some variables, such as governance (KE1), material use efficiency (LI2), and fund allocation efficiency (EK6), have widespread impacts on other variables through intermediary pathways. For example, improvements in governance and fund efficiency influence other variables even if not directly. These relationships are complex and non-linear, forming a network of interactions that must be considered in planning for sustainable vertical housing development in IKN.

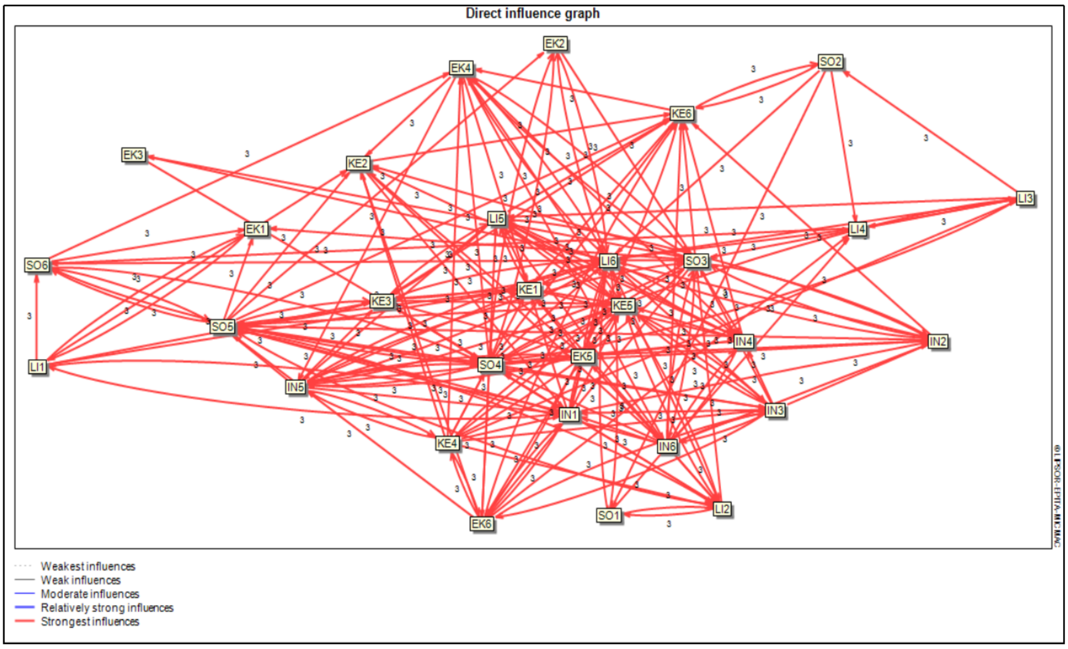

Figure 4. Influence of Direct Dependence.

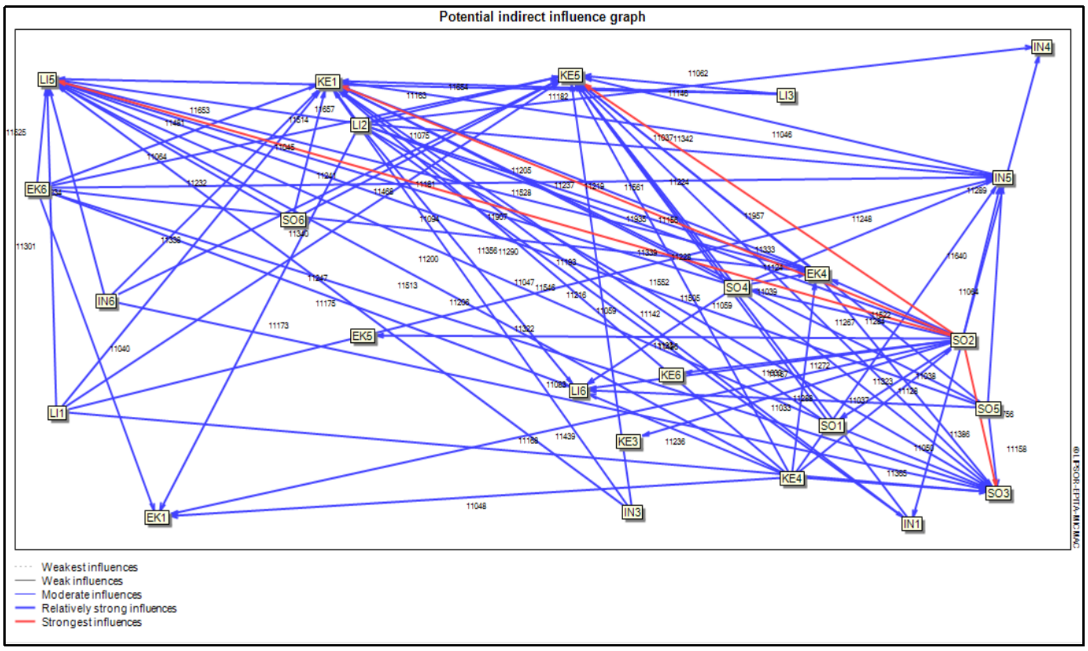

Figure 5. Effect of Indirect Dependence.

Some variables act as intermediaries in indirect dependence pathways, such as the availability of public facilities (IN6), which may not be directly affected by environmental policies but rather through pathways such as Fund Efficiency (EK6) → Policy Synergy (KE4) → Availability of Public Facilities (IN6). This illustrates that changes in fund allocation can influence policies, which in turn affect public facility provision. Furthermore, there are strong linkages between social variables such as cultural preservation (SO6) and economic and infrastructure factors, indicating that social sustainability is not an isolated element but is interconnected with governance policies and supporting facilities. Therefore, the planning approach for vertical housing in IKN must be multidimensional, encompassing social, economic, and environmental aspects in one integrated system. The reciprocal relationships between variables are also a key factor in the sustainability of this system. For example, policy synergy (KE4) and fund efficiency (EK6) interact mutually in determining project sustainability. In addition, the use of green materials (LI1) is closely related to aesthetics and the preservation of local culture, which supports social sustainability. Energy efficiency (EK2) is also related to the availability of public facilities (IN6), impacting infrastructure quality and support networks.

Based on the analysis of direct and indirect influence graphs, it can be concluded that the success of sustainable vertical housing development in IKN greatly depends on a holistic policy approach. More effective policy interventions and investments should focus on strengthening policy synergy, fund efficiency, efficient material use, and cultural preservation. With a deeper understanding of the interaction patterns among variables, development planning can be more targeted and maximize sustainable impact. The implementation of integrated policies and sound governance systems will help strengthen social, economic, and environmental resilience in vertical housing development in IKN. In addition, regular monitoring and evaluation should be prioritized to ensure that the strategies applied remain relevant to the dynamics of development and community needs. Thus, vertical housing development in IKN can serve as a sustainability model that considers not only ecological aspects but also social and cultural dimensions.

The influence–dependence analysis clarifies direct and indirect ecological impacts. Variables like efficient fund allocation (EK6) directly affect infrastructure investments – for instance, enabling advanced waste treatment plants – which in turn indirectly improve ecosystem outcomes (pollution control, water quality). Similarly, improving water efficiency (LI1) has a direct regulatory benefit in conserving water but also indirectly reduces energy use: studies show that cutting potable water use (through measures like dual-flush toilets or greywater reuse) can reduce pumping and heating loads, yielding concomitant energy savings. For example, one study found that dual-flush toilets, greywater reuse, and rainwater harvesting can cut potable water use by ~30–60%, which in turn cuts building energy consumption by avoiding the energy needed to treat and pump that water. Another example: deploying high-efficiency cooling and insulation can directly slash building energy demand (up to ~32–44% in tropical contexts), indirectly reducing urban heat-island effects. Clarifying these pathways helps planners understand that bolstering direct drivers (like budgeting efficiency or material standards) leads to indirect ecological benefits (e.g., less waste or emissions).

4.4. Key Variables for the Successful Implementation of Green Buildings in Vertical Housing in IKN

The factors in Quadrant 1 (Input Variables) are the primary driving elements for the sustainability of vertical housing in the Nusantara Capital City (IKN) because they have a significant influence on the system but are not highly dependent on other variables. The variables in this quadrant span several aspects: environmental, social, infrastructure, economic, and institutional. From an environmental perspective, efficiency in construction material use through the reduce concept (LI2) plays a key role in optimizing limited resources [43], reducing waste, and minimizing project costs [44]. The use of environmentally friendly construction materials (LI1) is a sustainability standard that can be directly applied by developers or building designers [45]. Moreover, the implementation of reuse in construction (LI3) positively impacts the reduction of natural resource exploitation and construction waste, particularly by repurposing materials like steel or concrete in new projects [46].

From a social standpoint, supporting green buildings involves integrating ornament and landscape planning (SO5) in urban design to create comfortable and high-quality environments for residents [47] while incorporating local cultural elements (SO6) into vertical architectural design helps prevent aesthetic homogenization and strengthens area identity [8]. These social perspectives contribute to building environments that are not only functional but also possess aesthetic and social value, independent of other variables. In terms of infrastructure, the availability of electricity and internet access (IN6) is essential for modern vertical housing, especially in developing areas like IKN [48]. The presence of an effective landfill (TPA) (IN3) is a critical factor in urban waste management, ensuring a clean environment and supporting the green city concept [49].

The economic aspect includes the efficient allocation of funds for development (EK6), a key factor in ensuring project sustainability through optimal budgeting [49]. Energy conservation (EK2), such as the use of LED lighting and energy-efficient cooling systems, contributes to reduced energy consumption and lower long-term operating costs [50]. The use of local construction materials (EK3) not only supports the regional economy but also reduces carbon emissions from transportation, making it a policy that can be directly adopted by developers [51]. The institutional aspect, in the form of policy synergy (KE4) between central and local governments, plays a crucial role in ensuring smooth implementation without overlapping regulations [51,52]. This policy harmony provides a strong foundation for sustainability strategies without relying on other factors.

In summary, the factors in Quadrant 1 serve as the main drivers for planning and policy development in IKN, as they significantly influence sustainability without requiring intervention from other variables. Environmental factors push for resource efficiency and waste reduction; social factors enhance quality of life and cultural identity; infrastructure factors ensure the sustainability of basic services; economic factors support cost efficiency and local economic sustainability; and institutional factors ensure policy implementation certainty. Thus, primary focus in development planning in IKN must focus on strengthening these factors so that sustainability strategies can be implemented directly and effectively.

Quadrant 2 (Key Variables) includes the development of facilities responsive to gender, people with disabilities, and marginalized groups (SO2), as well as the provision of access and spaces for community interaction (SO3), which are crucial for social inclusiveness and well-being, without relying on other policies. The same applies to the availability of healthcare facilities (IN1) and public facilities (IN5), fundamental elements in supporting the quality of life for residents, which have a strong impact on the system yet are not directly influenced by external factors [53]. Economic benefit assessments (EK4) and flexibility in interior and exterior spatial design (EK5) are also vital in determining the competitiveness and adaptability of vertical housing to residents' needs. These variables strongly influence resource efficiency and economic sustainability, but their implementation tends to be strategic rather than reactive. Additionally, waste management implementation (LI6) is critical to environmental sustainability, where effective management impacts ecosystem preservation without direct reliance on other variables.

Quadrant 3 (Output Variables) in MICMAC analysis includes factors that do not have a dominant influence on the system but are highly dependent on stronger variables. These variables cannot stand alone and tend to follow the dynamics of existing policies (KE3), regulations, and governance (KE1), meaning any national or regional policy changes directly impact these variables across institutional, economic, environmental, and infrastructure aspects [54]. Hence, the sustainability of vertical housing in IKN heavily depends on the effectiveness of regulations and coordination at the governmental and stakeholder levels (KE6). Institutional variables like regional green building regulations lack full autonomy and are subject to national-level policy. Governance is part of a system highly dependent on policy and institutional coordination—if the central government changes management strategies, regional governance systems must adjust accordingly [54,55]. The same applies to coordination and collaboration among stakeholders, which only functions effectively with clear regulations and strong policy synergy. Without regulatory alignment, cross-sector cooperation between government, private entities, and the public may face obstacles that hinder green building implementation in IKN [56].

From an environmental angle, maintaining water, air, and light quality (LI5) is highly dependent on environmental policies and resource governance [57]. Achieving good environmental quality in vertical housing requires an integrated management system supported by consistent regulations. From an economic perspective, a sustainable construction approach (EK1) in vertical housing cannot function independently and must align with broader policies [58]. The provision of access and facilities for public transport users (IN4) is also essential for sustainability, but requires policy synergy. Overall, variables in Quadrant 3 show that vertical housing sustainability in IKN depends heavily on effective regulation, stakeholder coordination, and consistent government policy [59]. If variables in other quadrants—especially those with dominant influence—are managed well, Quadrant 3 variables will develop optimally. Conversely, uncoordinated regulation or policy changes may destabilize these factors, hindering the sustainability of vertical housing in IKN. Therefore, the necessary strategy is to strengthen green development regulations and policies, improve inter-agency coordination, and ensure that each policy implemented remains consistent with the core sustainability goals [60].

Quadrant 4 (Excluded Variables) describes those with low influence and low dependence on the analyzed system. While important in specific contexts, they do not play a dominant role in the system's main dynamics and tend to operate independently. In the context of vertical housing sustainability in IKN, the variables in Quadrant 4—such as toll road and highway development (IN2), the role of government officials (KE2), and the use of recycled construction materials (LI4)—have limited impact. Toll road and highway development, while essential for ensuring connectivity between vertical housing and other facilities, does not directly affect green building sustainability. This type of infrastructure is usually planned and budgeted separately, and is not dependent on other system variables. The role of government officials in sustainability policy implementation is important but not central in determining the design or application of green building technologies. Officials mainly serve as policy executors, and their influence on the sustainability system is relatively limited. Meanwhile, the use of recycled construction materials, although supportive of sustainability efforts, does not play a central role in the system. The decision to use recycled materials often depends on developer policy and is not heavily influenced by other variables. Furthermore, recycled materials are not always feasible for large-scale use in all projects. Thus, while these three variables are relevant, changes in them will not significantly alter the sustainability system of vertical housing in IKN.

From an economic perspective, the identification of key variables such as energy efficiency conservation (EK2), fund allocation efficiency (EK6), and the use of local materials (EK3) demonstrates the financial rationality of green building implementation. These variables indicate that sustainable vertical housing not only reduces long-term operational costs but also improves local economic circulation by promoting regional supply chains. Efficient fund allocation ensures that limited financial resources are optimally used for technologies that yield long-term returns, such as energy-saving installations and water recycling systems. Moreover, economic benefit assessments (EK4) allow developers and policymakers to evaluate the return on investment, which strengthens the case for scaling green housing policies. This economic meaning reinforces the idea that ecological integration and economic viability are not mutually exclusive but are mutually reinforcing pillars of resilient urban development.

To strengthen the ecological relevance of each strategic variable, this study explicitly links them to measurable environmental outcomes in the context of IKN. For instance, the variable Energy Efficiency Conservation (EK2) is directly related to the reduction of operational emissions, thereby mitigating the urban heat island effect and lowering the ecological footprint of high-rise residential buildings. The use of Local Materials (EK3) reduces the carbon intensity of construction through shorter supply chains and promotes regional circularity, particularly when renewable or biodegradable resources such as bamboo or compressed earth blocks are utilized. Furthermore, Water Treatment (EK7) contributes to ecological restoration by reducing the discharge of untreated effluent into rivers and coastal ecosystems, which are critical habitats for biodiversity in East Kalimantan. These projected ecological benefits are supported by empirical evidence.

4.5. Inter-Variable Role: Influence of Dependency

The implementation of sustainability in vertical housing in the Nusantara Capital City (IKN), based on findings from the direct influence graph, heavily relies on policy synergy, optimized fund allocation, efficient material usage, local cultural preservation, governance strengthening, and the availability of public facilities. Policy synergy (KE4) serves as the main foundation for ensuring aligned regulations between central and regional governments [61]. This policy integration can be achieved through stakeholder coordination forums, where issued regulations provide incentives for developers applying green building principles and disincentives for projects that do not meet sustainability standards. Additionally, spatial planning policies should aim to balance residential, commercial, and green areas to ensure that vertical housing development is not only land-efficient but also aligned with a healthy and inclusive urban ecosystem. Efficient fund allocation (EK6) through green financing schemes can support sustainable projects, including green bonds and low-interest loans dedicated to environmentally certified projects [62]. Applying the circular economy model in the construction sector can also reduce long-term costs by recycling building materials and implementing operational efficiencies, thereby reducing environmental impact and enhancing project profitability.

The sustainability of vertical housing is also significantly influenced by efficient use of construction materials (LI2), which can be realized through regulations mandating the use of low-carbon footprint materials such as recycled concrete, FSC-certified wood, and bio-composite materials. These materials must also meet international sustainability standards and certifications to ensure that all aspects of development contribute to energy efficiency and carbon emissions reduction [63]. Beyond technical and economic aspects, local cultural preservation (SO6) is essential for building socially sustainable vertical housing. Architectural design can incorporate elements of local Kalimantan culture. Regarding urban governance (KE1), the formulation of a Vertical Housing Sustainability Master Plan in IKN is a strategic step to ensure structured development, with clear implementation stages, achievement targets, and evaluation mechanisms. Governance transparency must also be improved by involving the public and stakeholders through public consultation systems and digital feedback platforms, ensuring that decisions reflect the needs and aspirations of all affected parties.

Another critical aspect is the availability of public facilities (IN6), which enhances the quality of life for residents. Furthermore, green spaces and blue infrastructure, such as vertical gardens, green roofs, and rainwater management systems, should be integrated into housing design to maintain ecological balance within the urban area [11]. Overall, the success of sustainable vertical housing in IKN does not solely rely on technical construction aspects, but also on policy strategies, governance, and continuous community participation. By optimizing policy synergy, fund efficiency, environmentally friendly material use, cultural preservation, and tech-based governance, vertical housing in IKN can become a model of development that is not only ecological and economical but also inclusive and globally competitive.

In the vertical housing sustainability system in IKN, indirect dependencies indicate that certain variables may not directly affect others but still contribute significantly through intermediary pathways. This underscores the importance of understanding how policy, economic, social, and infrastructure elements are interlinked in a complex network. To implement effective strategies, a systematic approach is required—one that considers the domino effects of changes in one variable on others. A key example of indirect dependency is the role of urban governance (KE1) in enhancing vertical housing sustainability. While governance may not directly improve energy efficiency or the social viability of housing, through supportive policies for better fund allocation (EK6) and regulatory synergy (KE4), governance can impact the provision of green infrastructure and public facilities (IN6). Efficient fund allocation (EK6) serves not only as a financial driver but also as an intermediary for improving public facilities and social sustainability. Environmental policies may not directly affect the availability of public facilities (IN6), but through effective funding mechanisms (EK6) and policy coordination (KE4), public facilities can be sustainably developed [49].

Efficient construction material use (LI2) also shows indirect dependency on social and economic sustainability. The use of environmentally friendly materials—such as recycled concrete or certified wood—not only benefits ecological aspects but also improves long-term energy efficiency and reduces building operating costs. Local cultural preservation (SO6) also demonstrates indirect dependency on spatial planning policies and funding efficiency. Vertical housing projects that incorporate cultural elements into their designs are more likely to be accepted by communities when regulations support incentives for developers who prioritize cultural approaches [27]. This success, as demonstrated in community-based models, is highly dependent on a participatory design process that positions the community as the primary subject, not merely an object of development [64]. Building landscapes and ornamentation (SO5) reflecting local values will strengthen regional identity and deepen residents' social attachment to vertical housing, thus supporting long-term social sustainability.

Public facility availability (IN6) exhibits indirect dependency patterns on economic and policy factors. The provision of amenities such as green spaces, integrated public transport, and blue infrastructure not only depends on physical planning but also on budget allocation and policy coordination. Understanding these indirect dependency patterns means that strategies for vertical housing development in IKN must be holistic and integrated, emphasizing the role of intermediary variables that amplify sustainability impacts. Adaptive regulation, transparent governance, and innovation in financing and technology must be combined to ensure that all development aspects work synergistically toward long-term goals. Thus, the implementation of sustainable vertical housing in IKN should not only be ecological but also capable of creating a resilient, inclusive, and globally competitive urban ecosystem.

4.6. Policy Instruments, Monitoring, and Trade-offs

Building on the key drivers above, we recommend concrete policy instruments. Regulatory mandates could require all new buildings above a threshold size to meet green standards (including ecological criteria), not just large commercial projects. Local governments should adopt stricter building codes that integrate IKN's net-zero and biodiversity goals. For example, planning regulations could enforce minimum green cover and wildlife corridors, prohibit development in priority conservation areas, and discourage non-native plantings. Incentives are also vital: subsidies or tax breaks for using certified local materials and for installing renewable energy systems would leverage natural assets (e.g., abundant tropical forests for sustainable wood) and advance net-zero targets. These incentives should be designed to shorten the supply chain by prioritizing materials from local community-based enterprises or cooperatives [65]. This not only ensures material authenticity but also directly enhances the income and economic resilience of the surrounding community, preventing economic leakage. Explicit biodiversity guidelines – such as requiring native species in landscaping and penalizing invasive species – will help restore natural systems as part of urban design.

An adaptive management framework should accompany these policies. This framework should be institutionalized through a formal multi-stakeholder collaboration model involving government, private developers, academia, and community representatives to ensure transparent decision-making and effective conflict resolution, as proven crucial in sustainable ecosystem management [66]. We stress performance monitoring of actual ecological outcomes (energy use, water savings, species counts) in buildings over time. Prior studies confirm that monitoring and feedback measurably improve building performance. Thus, IKN authorities could implement mandatory post-occupancy evaluations and "green audits" to adjust practices. These evaluations must be expanded to include socio-economic indicators, such as local labor absorption rates, the success of small enterprises connected to building operations, and resident satisfaction with the implementation of cultural values, aligning with empowerment principles. If targets (e.g., water use per capita, on-site renewable generation) are missed, regulations can be adaptively tightened. This ensures that ambitious policy translates to real-world impact. In applying these strategies, planners must acknowledge trade-offs. For instance, vertical green walls and landscaping improve cooling (reducing energy use and enhancing well-being) but increase irrigation demand. In tropical IKN, we therefore recommend coupling greening with water reuse: rainwater harvesting and greywater recycling can supply irrigation and toilet flushing, delivering ~73% overall water savings while still maintaining lush vegetation. Similarly, emphasizing local materials reduces emissions but may strain limited certified supplies. Policies might temporarily supplement with well-assessed imported green materials while scaling up local forestry certification programs. Importantly, energy-saving measures (like air conditioning) must be balanced against their carbon intensity: Singapore's experience shows that green building mandates can shrink operating costs (~11.6% reduction), but without cleaner energy, electricity demand can still rise. Hence, integrating renewable electricity (part of IKN's 2045 plan) will align energy efficiency with emission cuts.

5. Conclusions

The study reveals that the success of green building implementation in vertical housing in Ibu Kota Nusantara (IKN) is determined by nine critical variables across social, economic, infrastructure, and environmental dimensions.

These include the provision of inclusive facilities that respond to gender, disability, and marginalized populations, along with meaningful community engagement in planning and governance. Equitable access to public services, healthcare, and communal spaces significantly enhances resident well-being. Economically, the long-term viability of vertical green housing depends on flexible spatial design and comprehensive investment benefit assessments. Environmentally, the adoption of circular economy principles, particularly in effective waste management, is essential to minimize ecological degradation and promote sustainable urban growth. This research offers a strategic framework for policymakers, urban planners, and developers to align vertical housing development with the ecological and social mandates of IKN as a green and inclusive capital city. The findings support the formulation of targeted regulations, public investment strategies, and multi-stakeholder collaborations that enhance urban resilience while safeguarding biodiversity and ecosystem services. It also contributes to the evolving discourse on tropical green urbanism by incorporating context-specific success variables applicable to archipelagic and biodiversity-rich nations like Indonesia. The study is limited by its reliance on expert perceptions, which may introduce subjectivity and bias in the identification and prioritization of success variables. Furthermore, the research focuses specifically on the IKN context, and while its framework offers replicability, broader generalizations to other urban environments should be approached cautiously. Future studies are encouraged to validate these findings through longitudinal case studies and empirical assessments post-implementation.

The study is limited by its reliance on expert perceptions, which may introduce a degree of subjectivity into the influence assessments, despite efforts to ensure a diverse panel. The purposive sampling method, while appropriate for this type of exploratory research, means the findings are contextually rich but not statistically generalizable to a wider population. To build upon this structural analysis, future research should prioritize empirical validation and quantitative assessment, as suggested by the review process. The following research avenues are recommended: post-implementation studies are crucial to track the actual performance of green buildings in IKN. This should involve collecting empirical data on energy and water consumption, indoor air quality, biodiversity indicators in and around buildings, and impacts on local water systems to validate the predicted benefits. Detailed case studies are needed to quantify the economic trade-offs of various green technologies and design strategies within the IKN context. This research would provide developers and investors with robust data on the return on investment for specific interventions, such as vertical greening systems versus high-performance glazing. As IKN develops, comparative studies analyzing the effectiveness of different policy instruments (e.g., mandates vs. incentives) in driving green building adoption would offer valuable insights for adaptive management and for other nations planning similar large-scale urban projects.

Author Contributions

Conceptualization, I.S. and M.K.; methodology, I.S. and A.E.; software, I.S.; validation, I.S., M.K., and A.E.; formal analysis, I.S. and A.E.; investigation, I.S.; resources, I.S.; data curation, I.S.; writing—original draft preparation, I.S.; writing—review and editing, I.S., A., and A.E.; visualization, I.S. and A.E.; supervision, M.K. and A.E.; project administration, A.; funding acquisition, I.S. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Universitas Brawijaya, Indonesia (IRB number: 146).

Informed Consent Statement

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

Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions of the respondents.

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Conflicts of Interest

The authors declare no conflict of interest.

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