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Sustainability Index Mapping for Green Building of Vertical Housing in Ibu Kota Nusantara (IKN) Using the Multidimensional Scaling (MDS) Approach

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ABSTRACT

The study aims to assess the sustainability status of green buildings for vertical housing in Ibu Kota Nusantara (IKN). It responds to growing environmental, social, economic, infrastructure, and institutional challenges driven by rapid urban development. Using the Multidimensional Scaling (MDS) approach, combined with Monte Carlo simulations, the research evaluates five key dimensions of sustainability: environment, economy, social, infrastructure, and institution. Data were collected from expert respondents through purposive sampling and analyzed using leverage and stress value validation. The findings reveal that the vertical housing model in IKN falls within the highly sustainable category, with strong performance across all assessed dimensions. The study emphasizes the role of green building practices in supporting smart city goals, reducing carbon emissions, and enhancing urban livability. Results are expected to inform policy decisions and contribute to the formulation of effective sustainability strategies in large-scale urban development.

1. INTRODUCTION

Ibu Kota Nusantara (IKN) is supported by a strong legal framework, namely Law Number 3 of 2022 concerning IKN, including its planning, design, and physical development. The development of IKN requires clear design criteria set by the National Development Planning Agency, particularly for public infrastructure and housing provision for construction workers and state civil apparatus tasked with delivering public services. To fulfill its vision as a future center of culture and learning for the Indonesian people, all buildings in IKN are designed using smart building concepts. As a prerequisite to this smart infrastructure, all structures must align with IKN's vision of a smart city—beginning with the implementation of green building principles, particularly in vertical housing development.

The green building concept for vertical housing in IKN aims to achieve consistent and sustainable resource savings across water, energy, and building materials. The development plan focuses on minimizing environmental impacts through the adoption of eco-friendly technologies, renewable energy, and efficient waste management systems. This green building approach also supports the creation of a sustainable, integrated, and environmentally conscious community in line with the Society 5.0 vision [1]. By fostering healthier lifestyles and behaviors, green buildings are expected to drive broader sustainability efforts. The implementation of sustainable green buildings in IKN is motivated by environmental, economic, and social factors and is expected to play a pivotal role in curbing excessive resource consumption [2].

Rapid urbanization and population growth in IKN exert pressure on natural resources and the environment. Vertical housing offers a spatial solution that maximizes land use efficiency while protecting green areas. Therefore, developing a sustainability model for green buildings becomes crucial for guiding future vertical development in IKN. Heightened awareness of environmental issues and sustainable construction has emerged globally [3], and as a vital hub of economic and social activity, IKN is expected to lead by example in adopting sustainable vertical building models. Such models contribute significantly to resource conservation by integrating technology to optimize the use of water, energy, and materials in accordance with green building principles [4], while also enhancing resilience to climate change, including floods and extreme climate events.

Research on green building sustainability models in vertical housing is essential as it reflects both the challenges and opportunities in Indonesia's sustainable urban development. Green buildings are central to reducing carbon emissions and enhancing energy efficiency. They are designed to minimize natural resource use while improving occupants' quality of life. Prior studies have explored various dimensions—from environmentally friendly building structures that reduce annual heating and cooling energy use by 7.48%–56% and non-potable water load by 4.5%–25% [5], to the use of recycled concrete aggregate in warm mix asphalt [6], and green architectural design in public spaces like Performing Arts Centers [7]. Other studies have also explored sustainable architectural applications [8], affirming growing academic interest in green buildings.

Moreover, research has explored how the integration of natural elements with architecture contributes to sustainable design [9], proposed solutions to limited land and green space [10], and examined energy operations optimizing natural solar lighting [11], green wall systems [12], and low-carbon building materials [13]. Other studies have prioritized energy efficiency in institutional settings [14]. This study contributes theoretically by integrating the five sustainability dimensions—environmental, economic, social, infrastructure, and institutional—within the Sustainable Development framework [15-17]. Unlike previous studies which tend to focus solely on environmental or energy aspects, this research emphasizes the synergy among all five dimensions.

Key issues addressed through this research include resource pressures from urbanization, challenges in energy-efficient and eco-friendly vertical building designs, the need for green infrastructure that supports government and economic functions, growing public demand for sustainable housing, and the necessity for institutional collaboration among government, developers, and communities. Therefore, this study aims to analyze sustainability attributes and status to develop an integrated green building sustainability model for vertical housing in IKN. The goal is to enhance residents' quality of life, optimize urban management, and promote a more resilient and sustainable capital city.

2. LITERATURE REVIEW

The relocation of Indonesia's capital from Jakarta to a more strategic location—now known as the IKN—has attracted considerable attention from academics and policymakers. The literature on IKN highlights the complexity of challenges and opportunities related to the capital city's relocation. This strategic move was motivated by the need to resolve several pressing issues in Jakarta, including severe traffic congestion, high pollution levels, and environmental sustainability threats.

Several studies [18-20] emphasize the importance of sustainable urban planning and the integration of sustainability principles into IKN's development, such as the adoption of renewable energy, green building design, and sustainable environmental management. Vertical buildings offer an effective solution to urban land scarcity while improving spatial efficiency. The literature shows that vertical housing can accommodate population growth without encroaching on green space or contributing to urban sprawl. Such housing includes apartments, condominiums, and skyscrapers, which provide urban residents with the opportunity to live and work in compact, integrated environments. Moreover, vertical residences promote a more sustainable lifestyle by reducing travel needs, lowering carbon emissions, and improving access to public amenities [21]. Despite the growing body of literature on IKN, most studies remain general in nature. While they highlight the relevance of sustainability, few offer a multidimensional approach that simultaneously addresses environmental, economic, social, infrastructure, and institutional dimensions in a unified framework. Additionally, although global certification systems such as LEED and BREEAM are frequently mentioned, few studies provide context-specific models adapted to Indonesia's socio-political and geographic realities.

This study aims to fill that gap by developing a sustainability index model specifically for vertical housing in IKN. Using a Multidimensional Scaling (MDS) approach, this model quantifies sustainability status and identifies leverage attributes to inform policy priorities. In contrast to previous descriptive studies, this approach integrates sustainable development theory and smart city principles to offer both theoretical and practical insights into Indonesia's urban sustainability efforts. In addition, other scholars [22, 23], have stressed the importance of community participation in the planning and implementation of IKN to ensure its positive impact on local welfare. The implementation of green building principles is intended to encourage environmentally conscious behavior and lifestyle changes, emphasizing the wise and sustainable use of existing resources. Performance rating systems, such as LEED and BREEAM, are not the end goal but rather tools to move toward a broader vision of a healthy and prosperous society (well-being society). Therefore, green building implementation in vertical housing must consider a variety of sustainability dimensions.

Figure 1. Sustainable development theory

Sustainable development theory provides the core conceptual framework of this study. It stresses the need to balance economic, social, and environmental objectives to achieve long-term sustainability (see Figure 1). This concept was originally popularized in the 1987 "Our Common Future" report by the World Commission on Environment and Development—widely known as the Brundtland Report [15]. The theory's importance extends beyond national boundaries and has become a global standard for addressing pressing challenges such as climate change, ecological degradation, and poverty [16]. By integrating the three pillars—environment, economy, and society—sustainable development theory provides a holistic framework that promotes intergenerational equity.

The sustainability model proposed in this research is built upon this theoretical foundation, combining principles from green architecture and contemporary urban planning. It draws on globally recognized frameworks and adapts them to the Indonesian context. The green building concept, as defined by certifications like LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research

Establishment Environmental Assessment Method), offers practical guidance for designing energy-efficient, environmentally friendly buildings with optimized resource use. These certification systems evaluate energy consumption, water efficiency, and indoor environmental quality—making them highly relevant for vertical housing projects focused on sustainability. In addition, smart city development concepts contribute to this model by integrating green technologies into the management of vertical buildings. These technologies include energy monitoring systems, smart waste management, and digital infrastructure to enhance connectivity and urban efficiency. More importantly, they foster civic engagement by enabling communities to participate in sustainability initiatives. By synthesizing insights from green architecture, smart city practices, and sustainable development theory, this study offers a comprehensive model applicable to vertical housing development in IKN, and contributes toward achieving inclusive and environmentally responsible urban transformation.

3. METHODOLOGY

3.1 Research site

The research is conducted in the IKN, which is projected to become the new center of government and economic activity in Indonesia. By 2030, the per capita income is estimated to reach IDR 48 million per year, driven by ongoing development and infrastructure projects. In its initial phase, IKN is expected to accommodate approximately 200,000 residents, with the population projected to grow to 1 million by 2045. Although the current unemployment rate stands at around 6.2% [3], the green city development initiative is anticipated to generate new employment opportunities, particularly in the infrastructure and sustainable development sectors. Moreover, 55% of local residents have expressed interest in actively participating in urban sustainability management—including in waste, energy, and water management—demonstrating significant potential for the widespread implementation of green building concepts throughout IKN.

3.2 Respondent selection technique

Sampling was carried out using a non-probability purposive sampling method, based on predefined criteria. The selected respondents were experts and stakeholders directly involved or highly knowledgeable in the planning, implementation, and management of green building and sustainability practices in the IKN. These key informants were chosen due to their strategic roles in shaping sustainability-related decisions, policies, and implementation at both the technical and governance levels (Table 1). The inclusion of diverse categories—ranging from government officials, architects, and developers to local communities and technology providers—ensures that the sustainability model is assessed from a multidisciplinary and practical perspective. This selection strategy enhances the credibility of the data and ensures that the analysis reflects realistic challenges and opportunities in the context of IKN development.

3.3 Data collection technique

Data collection regarding the implementation of the green building concept, key variables, and sustainability models was conducted using survey techniques, structured questionnaire instruments, and focus group discussions. The questionnaire consisted of a series of statements elaborating on five key dimensions relevant to the development and management of IKN: environmental, social, economic, infrastructure, and institutional dimensions (Table 2). The respondents involved were selected experts in related fields. In addition to surveys, primary data were also gathered through interviews, observations, and documentation. Secondary data were obtained through literature reviews. The interviews were conducted with key informants to enrich and validate the research findings and to provide additional insights relevant to the study.

Table 1. Respondents and key informants

Category	Description
Central and regional governments	The central and local governments have an important role in providing permits, regulations, and financial support for green building development projects. They can also be involved in urban planning and environmental policy.
Property investors and developers	Property investors and developers play a key role in the financing and management of development projects. The success of a project often depends on the financial support and effective management of this party.
Construction contractors and subcontractors	Construction contractors and subcontractors are responsible for carrying out the physical construction of green building in accordance with the design and specifications set. They are involved in the construction process and implementation of the green building concept.
Consultant planner and architect	Planning consultants and architects assist in the design of the green building concept that is environmentally friendly and in accordance with sustainability standards. They can provide guidance on the latest technologies and practices in green building design.
Local communities	Local communities are the parties directly affected by the construction of green building. Community involvement and support are important to support the sustainability of the project, and they can provide input on local needs and environmental sustainability.
Sustainability certification bodies	Sustainability certification bodies, such as the ones that handle green building certification, are involved in assessing and certifying green building projects to ensure compliance with sustainability standards.
Green technology provider	Green technology providers provide the latest solutions and equipment that support the implementation of green building concepts, such as energy efficiency technologies, water management, and other sustainable technologies.
Research and education institute	Research and educational institutions can be involved in providing the latest understanding and innovations in the field of sustainability that can be integrated in the green building project.

Table 2. Research dimensions and attributes

Dimension	Attribute	Source
Environment	Eco-friendly construction	[24-34]
	Efficiency of the use of construction materials (reduce)	
	Use of used construction (reuse)	
	Use of recycled construction materials	
	Water, air, and light quality	
	Quality of waste management	
Social	Involvement and perna and mastarakat	
	Community Empowerment	
	Community interaction space	
	Community welfare	
	Ornaments and landscaping	
	Buildings that support the preservation of local culture	
Economics	Sustainable for the economic sector	
	Energy Conservation	
	Use of local construction materials	
	Analysis of benefits related to the economic sector	
	Flexibility of indoor and outdoor layout	
	Efficiency of allocation of funds for development	
Infrastructure	Availability of health facilities	
	Toll road and highway development	
	Landfill Availability	
	Implementation of the provision of access and facilities for public transportation users	
	Availability of public facilities	
	The existence of electricity networks and internet access	
Institutional	Governance	
	The role of the apparatus	
	Regional regulations	
	Policy synergy	
	Coordination	
	Cooperative relationship	

3.4 Data analysis

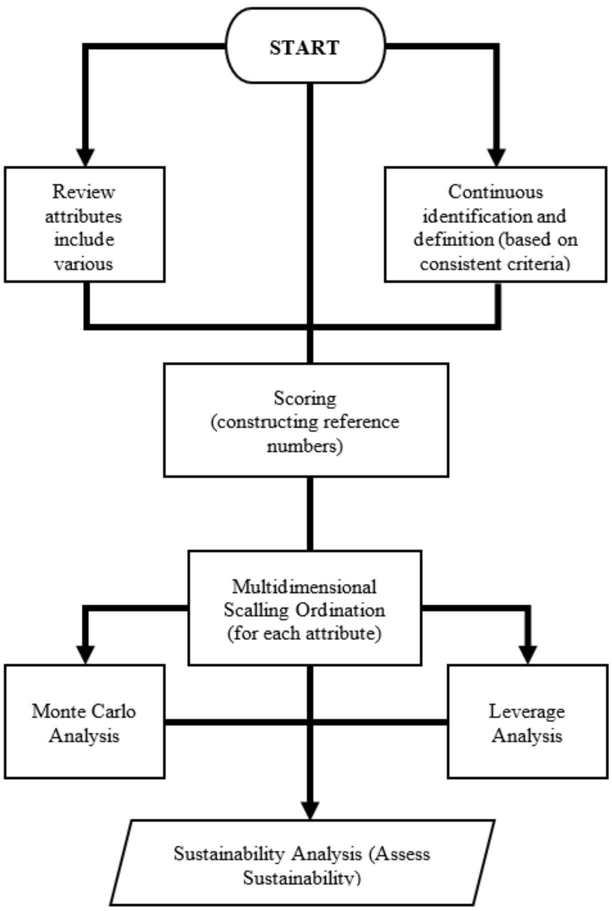

Figure 2. Stages of data analysis

To assess the condition and sustainability level of ecotourism management, as well as to develop future scenario projections, a sustainability analysis was conducted using the Rapid Appraisal for Multidimensional Analysis (Rap-MAD) approach. This analysis employed MDS, leverage analysis, and Monte Carlo simulation. The analysis also involved the calculation of the stress value and the coefficient of determination (R^2) to evaluate the goodness-of-fit of the ordination.

The use of MDS in the Rapfish framework was chosen because it yields more stable results compared to other multivariate techniques such as factor analysis or Multi-Attribute Utility Theory (MAUT) [35]. Leverage analysis was applied to identify sensitive attributes that significantly influence sustainability. The results of this analysis are expressed as the percentage change in Root Mean Square (RMS) when each attribute is omitted from the ordination. Attributes with the highest percentage change are considered the most sensitive, indicating their critical role in improving sustainability status. The processes of MDS and leverage analysis are schematically illustrated in Figure 2.

To operationalize the MDS method, each sustainability attribute was scored based on expert judgment using a Likert scale, then normalized and converted into a dissimilarity matrix. The matrix served as input for the ordination process using the Rapfish software, which visualizes relative sustainability status across dimensions. Monte Carlo analysis was performed by simulating random variations in the input data to test the stability of the MDS output and verify that the configuration is not sensitive to small data perturbations. A low S-Stress value (< 0.25) and high R^2 value (> 0.90) were used as indicators of model reliability. The leverage analysis identifies the most influential (sensitive) attributes based on the percentage change in the RMS when each attribute is omitted. These attributes provide insight into which variables should be prioritized to improve the sustainability index. The use of MDS in this study is preferred over other multivariate methods due to its robustness in handling non-linear and non-parametric data structures, which are common in sustainability assessments.

3.5 Research framework

Figure 3 illustrates the conceptual framework outlining the evolution of development paradigms toward a more holistic and integrative approach to sustainable development. Historically, development paradigms have undergone significant transformations. The modern development paradigm of the 1940s to 1970s emphasized economic growth and industrialization. This was followed by the participatory paradigm of the 1970s–1980s, which began to involve communities more actively in the development process. In the 1980s, the sustainable development paradigm emerged, integrating economic objectives with environmental and social sustainability. During this same period, the post-development paradigm arose as a critique of the dominance of Western development values, while the empowerment paradigm focused on enhancing the capacity of local communities.

The sustainable development paradigm that forms the core of this framework is aligned with global goals such as the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) initiated in 2005. This paradigm has been further reinforced by contemporary studies [17, 36], which broaden the scope of sustainable development pillars to include environmental, economic, ecological, institutional, and infrastructural aspects. Each of these pillars plays a crucial role in ensuring the sustainability of development systems.

These pillars are visualized into five key dimensions of sustainable development: environmental, economic, social, institutional, and infrastructure. These dimensions are interrelated and mutually reinforcing, providing both a theoretical and practical foundation for the design and implementation of sustainable development policies. As such, the framework underscores that modern development strategies must move beyond a narrow focus on economic growth to achieve a balanced integration of social, ecological, institutional, and infrastructural considerations—essential for realizing inclusive and sustainable well-being.

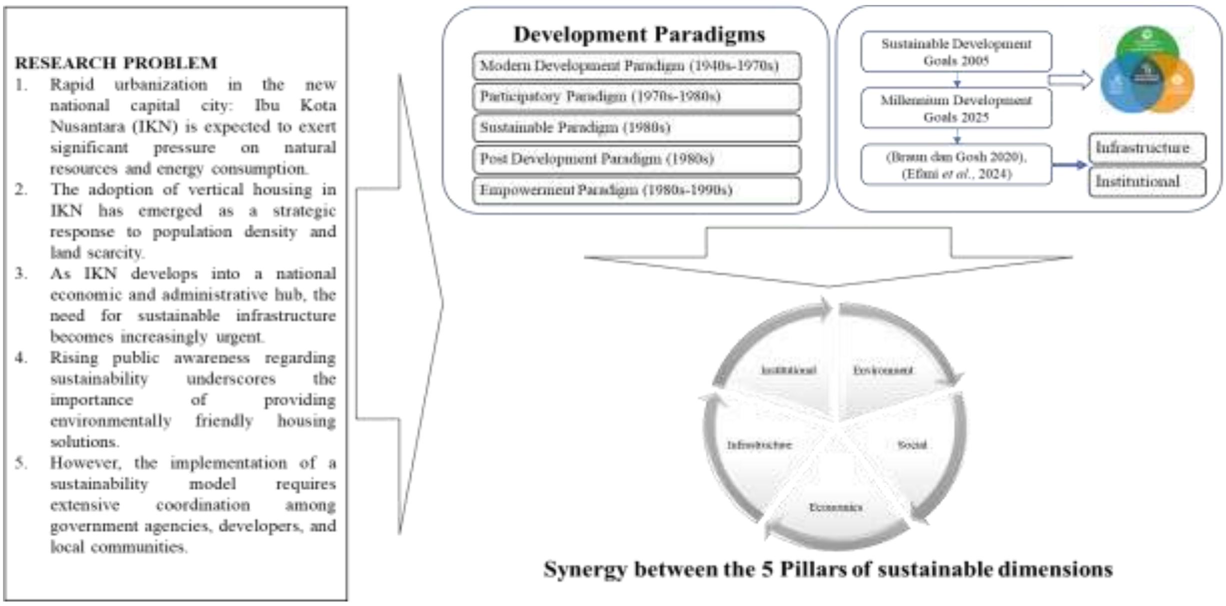

Figure 3. Research framework

4. RESULTS AND DISCUSSION

4.1 Validation test (R-square and stress value)

Table 3. Results of the MDS green building validation test for vertical buildings in IKN

Sustainability Dimension	Parameters	
	R^2	Stress Value
Environment	94.18%	0.17
Economics	94.44%	0.14
Social	94.31%	0.15
Infrastructure	94.14%	0.14
Institutional	94.39%	0.11

Validity testing is a process used to determine the extent to which an instrument or measurement method accurately and validly measures what it is intended to measure. The coefficient of determination (R^2) indicates the proportion of variance in the data that can be explained by the dimensions being analyzed. A high R^2 value—above 90%—suggests that the model demonstrates excellent accuracy in explaining the relationship between sustainability indicators and the tested dimensions. Furthermore, a stress value below 0.25 indicates good mapping quality [37].

The results of the validation test analysis show a very high level of validity (Table 3), with R^2 values exceeding 94%, indicating that the findings are reliable for assessing the sustainability of vertical residential development in the IKN [3]. Additionally, the stress values for all continuous dimensions are below 0.25, suggesting that the positioning of each dimension within the multidimensional space accurately reflects actual conditions. This reinforces the credibility of the analysis results. The reliability of the model ensures that the interpretation of findings can serve as a solid foundation for the formulation of more sustainable development policies and strategies.

4.2 Monte Carlo test

The Monte Carlo test is an innovative statistical approach that utilizes simulation through the use of random numbers to understand and evaluate mathematical models or complex systems. In the context of sustainability analysis, Monte Carlo simulations are employed to assess the stability and resilience of model outcomes in response to variations or uncertainties in input data. The following are the results of the Monte Carlo test (Figure 4 and Table 4).

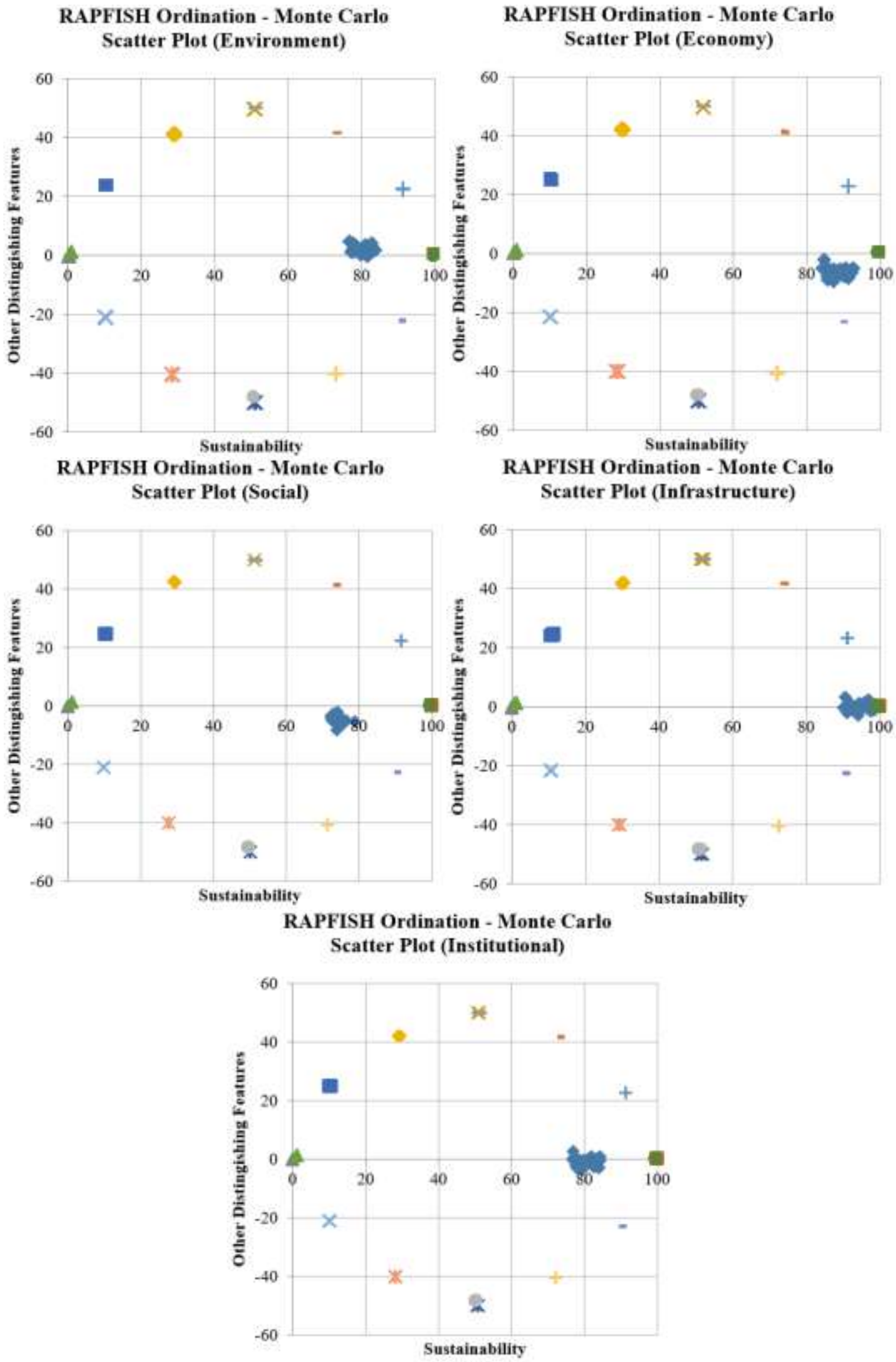

Figure 4. Monte Carlo ordinations

Overall, the average difference between the Rapfish and Monte Carlo results remained within an acceptable range of less than 5% [37]. Combined with low stress values, this indicates that the sustainability mapping results were not significantly distorted by uncertainty. The Monte Carlo analysis further confirms that the sustainability model for vertical residential development in IKN demonstrates strong resilience to variations in input data. Therefore, the results of this analysis can be considered valid and reliable, serving as a solid foundation for long-term policy formulation and strategic planning in sustainable development.

Table 4. Monte Carlo test results

Dimension Sustainability	Sustainability Index		Difference (%)	Status
	Score Rapfish (%)	Monte Carlo (%)		
Environment	81.75	80.35	1.40	Highly
Economics	92.97	90.19	2.78	Highly
Social	76.03	74.02	2.01	Highly
Infrastructure	96.70	96.54	0.16	Highly
Institutional	84.55	81.93	2.62	Highly
Average		87.06		Highly

4.3 Sustainability status of the green building development dimensions in vertical residential areas

The sustainability of vertical buildings in IKN is a crucial component in promoting environmentally friendly practices, economic efficiency, and improved social welfare. Efforts to maintain sustainability have been carried out through ecological, economic, social, infrastructural, and institutional approaches (Figure 5). The following are key findings related to the sustainability status of vertical residential development in IKN.

4.3.1 Environmental dimension

The environmental sustainability score is 81.75%, which places this dimension in the highly sustainable category. This indicates that vertical residential development in IKN has generally adopted environmentally friendly construction practices. Notable efforts include the use of sustainable materials and the implementation of waste reduction strategies. The reuse of recycled construction materials is also encouraged to minimize environmental impact [6]. However, the application of reuse strategies remains limited, which contributes to the score not reaching an even higher level. Air quality is considered good, suggesting that both emissions control and ventilation systems have been effectively planned. On the other hand, water quality still presents challenges, particularly in terms of water source conservation and wastewater treatment. Overall, the score of 81.75% reflects that various environmental strategies have been implemented successfully, but further improvement is required in water resource management and the broader adoption of reused materials to achieve optimal environmental sustainability.

4.3.2 Economic dimension

The economic dimension achieved a sustainability score of 92.97%, placing it in the highly sustainable category. This reflects strong financial and economic planning in the vertical residential development in IKN. A key strength is the efficient allocation of funds, demonstrating optimal financial management throughout project execution. Moreover, building designs have incorporated flexibility to accommodate various socio-economic functions, thereby enhancing economic resilience. Additional contributing factors include energy conservation measures and the use of local construction materials, which help reduce transportation costs and promote the local economy [38, 39]. The project has also contributed strategically to the economic growth of the surrounding region. However, long-term sustainability could be further enhanced by fostering more inclusive economic opportunities for local communities. In summary, the score of 92.97% indicates a strong economic foundation, although future initiatives should focus on long-term inclusive economic development.

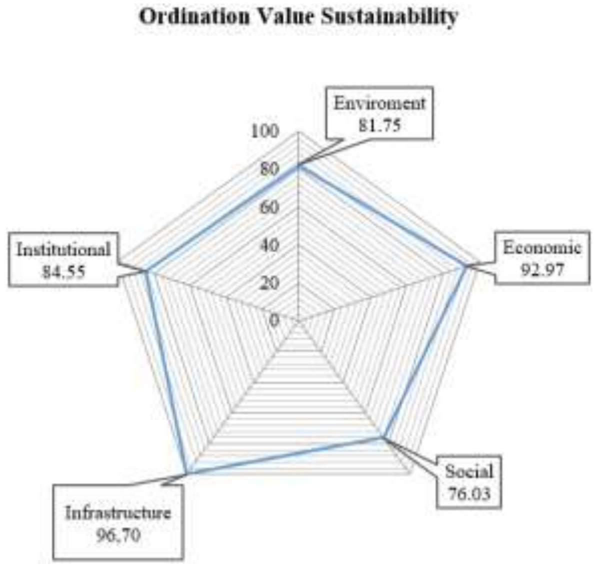

Figure 5. Kite diagram of the sustainability status of green building development in vertical residential areas of IKN

4.3.3 Social dimension

The social dimension attained a sustainability score of 76.03%, also categorized as highly sustainable, though there remains room for improvement. One of the most positive indicators is the availability of community interaction spaces that promote cultural preservation. This highlights the project's effort to respect and maintain local cultural values within the built environment. However, several aspects still require enhancement, including community participation, empowerment, and social welfare. While communities have been involved in the development process, the depth of their participation remains limited. Further strategies are needed to broaden the impact of empowerment programs and ensure equitable benefits [40]. Overall, the social sustainability score indicates a solid foundation in community engagement and cultural consideration, but additional attention is necessary to strengthen community involvement and welfare outcomes.

4.3.4 Infrastructure dimension

The infrastructure dimension received a perfect sustainability score of 100%, signifying full alignment with sustainability standards. All indicators under this dimension show that infrastructure development strongly supports vertical residential sustainability. Key features include the availability of health facilities that ensure access to basic services for residents [41], and the construction of toll roads and highways that facilitate efficient mobility. Additionally, the existence of final disposal sites (TPAs) demonstrates organized waste management systems. The provision of public facilities, electricity, and internet access further supports sustainable urban living. This perfect score confirms that infrastructure planning in IKN has successfully addressed all essential aspects, providing a robust foundation for a livable, functional, and future-ready urban environment.

4.3.5 Institutional dimension

The institutional dimension achieved a sustainability score of 84.55%, placing it within the highly sustainable category. This reflects the significant role of governmental support, regulations, and policy synergy in the vertical development of IKN. Institutional sustainability is bolstered by the active involvement of local authorities and the alignment of regional regulations with vertical development goals [42]. Nevertheless, challenges remain in governance and intersectoral collaboration. Certain indicators reveal gaps in coordination and policy effectiveness, suggesting the need for stronger partnerships between government agencies, developers, and communities. Although the institutional framework is already performing well, strengthening governance mechanisms and cooperative arrangements can further enhance institutional capacity to support sustainable vertical development in IKN.

4.4 Leverage analysis of sustainability attributes in vertical residential green building development

Leverage value represents the degree of influence that a particular attribute has on the overall sustainability index. A high leverage value indicates that an attribute significantly affects the sustainability performance within a specific dimension—environmental, economic, social, infrastructure, or institutional [43]. These values are derived from sensitivity analysis within the Rapfish method, which tests how changes in individual attributes influence the sustainability index (Table 5):

Table 5. Sensitive attributes in each sustainability dimension

No.	Sustainability Dimension	Sensitive Attributes
1	Environment	• Reuse (7.23) • Water. air. and light quality (6.34)
2	Economics	• Sustainable for the economy (7.02) • Efficiency of development funding (2.18)
3	Social	• Community Welfare (5.44) • Community Empowerment (5.42)
4	Infrastructure	• Public transportation access & facilities (0.00303) • Landfill Availability (0.00302)
5	Institutional	• Coordination (6.38) • Governance (4.60)

The environmental dimension of vertical building sustainability in IKN has a score of 81.75, indicating that the environmental aspect of vertical development in this area falls within the "very good" category. Although this score reflects optimal sustainability, several highly sensitive factors still require further attention to ensure long-term environmental sustainability. Based on leverage analysis results, three main attributes significantly influence the environmental dimension: the use of reused construction materials, water quality, and the use of recycled construction materials.

The reuse of construction materials has the highest leverage in the environmental dimension. This indicates its substantial impact on enhancing the sustainability of vertical development in IKN. Reuse includes repurposing building materials still fit for use, such as structural steel, timber, glass, and bricks salvaged from demolished structures [44]. Applying this concept yields several environmental benefits: reducing construction waste, which contributes significantly to pollution, and conserving natural resources such as sand, stone, and wood typically extracted in large quantities.

The second attribute with high leverage is water quality, which is crucial in vertical buildings due to its influence on environmental sustainability and residents' well-being. One of the main challenges in IKN's vertical development is managing wastewater and conserving water resources [3]. As residential density increases, so does water demand. If unmanaged, this can result in water scarcity and stress on aquatic ecosystems. Therefore, implementing efficient wastewater treatment technologies is essential to allow water recycling for secondary purposes, such as irrigation, cooling systems, and other non-potable uses.

The third key attribute is the use of recycled construction materials, which plays a vital role in sustainable development. This approach reduces dependency on virgin raw materials by reusing concrete, steel, and plastics in new construction [6]. Recycling helps lower carbon emissions and energy consumption in the construction sector. By reducing the need for energy-intensive manufacturing processes, emissions can be significantly minimized. The three high-leverage attributes—reuse, water quality, and recycling—emphasize that environmental sustainability in vertical residential construction in IKN heavily depends on efficient, eco-friendly resource management strategies [45].

The economic dimension of vertical building sustainability in IKN scores 92.97, showing that this aspect is also rated "very good." However, some sensitive attributes require further attention. Leverage analysis identifies three main influential attributes: the sustainability of the economic sector, efficiency in fund allocation, and spatial planning flexibility.

The sustainability of the economic sector is a key factor, emphasizing the importance of vertical buildings contributing to long-term economic benefits. Such developments not only generate jobs in construction but also stimulate related sectors such as transportation, trade, and services [7]. Substantial investment in infrastructure and real estate fosters the growth of business ecosystems, ensuring a balance between housing supply and demand. Moreover, green economic practices, such as adopting renewable energy and resource-efficient designs, enhance investment attractiveness while reducing operational costs [5]. Accessibility to business and industrial zones is also crucial to reducing travel expenses and optimizing labor mobility.

Efficient fund allocation is another determinant of economic sustainability. Employing advanced construction technologies, such as modular and prefabricated methods, can cut costs and construction time. The use of Building Information Modeling (BIM) improves planning accuracy, reduces material waste, and minimizes errors. Financial strategies must incorporate diverse funding sources, including government budgets, private investment, and public-private partnerships. Operational costs can also be optimized through energy-saving technologies, the use of local materials, and efficient water systems. Supporting infrastructure—including transport, drainage, and sanitation—must balance cost-efficiency and long-term quality.

Spatial flexibility, both interior and exterior, plays a crucial role in ensuring economic viability. Adaptive designs allow mixed-use functions within one building complex, combining residential, commercial, and public spaces. Such configurations support economic activities and enhance the value of the property. Public amenities such as coworking areas and recreation zones increase appeal and offer added value. Smart building technologies further support efficient space use, cutting energy consumption. The trend toward co-living and shared spaces underscores the need for flexible design. Economic sustainability in IKN's vertical development depends on strategies that prioritize long-term economic impacts, budget efficiency, and adaptable spatial planning.

The social dimension of vertical building sustainability in IKN greatly influences affordability and urban quality of life. A key attribute here is community welfare. Sustainable vertical buildings must improve residents' quality of life through access to health services, education, employment, green spaces, adequate sanitation, and a secure living environment. Social stability also depends on public facilities such as social centers, recreational spaces, and accessible transport. Prioritizing community welfare in planning and management results in inclusive, healthy, and socio-economically supportive housing [46].

Community interaction spaces are also vital. Vertical housing often struggles to foster social cohesion due to limited shared areas. Providing parks, playgrounds, activity centers, and coworking spaces can address this. These areas encourage community bonding and active social participation [47]. Well-designed interactive spaces reduce social disparities and promote environmental stewardship. Designs must emphasize comfort, accessibility, and support diverse activities.

Community empowerment underpins social sustainability. Empowering residents through skills training, business opportunities, and environmental initiatives like urban farming enhances their engagement in managing their living environment [48]. Empowered communities are more self-sufficient, resilient, and better equipped to face socio-economic challenges. Prioritizing welfare, interaction, and empowerment transforms vertical housing into a socially sustainable model that benefits all societal levels.

The infrastructure dimension is critical to ensuring efficiency, accessibility, and comfort in vertical housing. Scoring 100%, infrastructure in IKN has been designed to holistically meet transportation, waste management, and public facility needs. A major component is public transport accessibility. Integrating vertical buildings with mass transit reduces private vehicle dependency, lowers emissions, and improves mobility [49]. Facilities such as bus stops, pedestrian paths, and bike lanes are essential to sustainable transport systems, enabling easy access to economic, social, and educational centers.

Landfills are another key aspect of sustainable waste management. Effective systems must include source-level waste segregation, recycling programs, and advanced treatment technologies. Well-managed landfills minimize environmental pollution [50]. Adopting bioconversion, eco-friendly incinerators, and composting improves efficiency and environmental safety. Adequate waste facilities preserve environmental quality and promote responsible waste management.

Public facilities—such as green spaces, healthcare, education centers, places of worship, and shopping areas—enhance livability and support social sustainability [51]. Well-distributed facilities reduce travel distances, save energy, and lower emissions. Infrastructure that supports diverse community needs ensures vertical residences in IKN remain inclusive, self-sufficient, and sustainable.

The institutional dimension of vertical development in IKN is also highly influential, with a sustainability score of 84.55%. Strong institutions ensure systematic and effective development aligned with sustainability principles. One key factor is coordination, with a leverage of 6.38. Effective collaboration between central/local governments, developers, and communities enables integrated development. Coordination helps streamline permits and resource allocation, ensuring timely implementation [52]. Governance, with a leverage of 4.60, is another crucial factor. Transparent and accountable management systems, community participation, and digital monitoring ensure alignment with sustainability goals. Strong governance enables regular policy evaluations and continuous improvements.

Regional regulations serve as the legal foundation supporting institutional strength. Clear, well-structured policies guide planning, construction, and operation phases [53]. Regulations encouraging eco-friendly practices, climate-responsive spatial planning, and energy-water efficiency are essential. Localized regulations ensure relevance to regional conditions [54]. By enforcing structured regulations, vertical building processes can be better managed, investments de-risked, and sustainability programs effectively executed. Strong institutions—supported by coordination, governance, and regulations—are pillars of sustainable vertical development in IKN, delivering long-term benefits to society and the environment.

4.5 Implication and global comparisons

The high sustainability scores across all five dimensions suggest that the vertical residential development in IKN aligns well with global sustainability targets. However, while local implementation is robust, further insight can be drawn by comparing these findings with international benchmarks. For instance, the reuse of construction materials and energy-efficient infrastructure mirrors best practices in sustainable building seen in countries like Germany and Singapore, where vertical housing policies integrate circular economy principles and smart urban planning.

From a policy standpoint, Singapore's "Green Mark" certification system offers a useful comparative model. It emphasizes not only green design but also post-occupancy evaluation and community feedback, which could enhance IKN's institutional framework. Similarly, in Scandinavian countries, the strong involvement of local communities and the institutionalization of participatory urban governance could serve as a benchmark for improving the social and institutional dimensions found in this study.

Moreover, the 100% infrastructure sustainability score in IKN aligns with Japan's approach to compact cities, which emphasize multimodal public transport integration and walkable urban design. These practices reinforce the need for IKN's vertical housing to not only be sustainable in construction but also in everyday accessibility and livability. The comparison indicates that while IKN has reached a highly sustainable threshold, embedding international post-construction evaluation, real-time energy tracking, and usercentric feedback systems could elevate long-term sustainability performance.

In conclusion, the findings present a valuable baseline for the ongoing development of IKN. Incorporating global best practices such as performance-based monitoring, green technology incentives, and participatory urban planning will not only strengthen each sustainability dimension but also position IKN as a leading model of vertical green housing in Southeast Asia.

5. CONCLUSIONS

The sustainability status of vertical residential green buildings in Indonesia's new capital city (IKN) indicates promising potential across environmental, economic, social, infrastructure, and institutional dimensions. While these findings suggest alignment wit sustainability principles commonly found in international frameworks, such as LEED or BREEAM, it is important to interpret such implications with caution. This study adopts a conceptual and exploratory approach based on expert judgment and secondary data; thus, claims of international comparability remain hypothetical and require further empirical validation. The success of green buildings in this context is largely determined by five key sustainability dimensions. Environmentally, the use of reused construction materials and efforts to enhance water, air, and natural lighting quality are central to creating healthy, environmentally conscious living spaces. Economically, the long-term viability of projects and the efficient allocation of development funds are essential for attracting investment and ensuring lower operating costs. Socially, the provision of access to green spaces, public facilities, and active community involvement promotes welfare and local empowerment. From the infrastructure perspective, integrated public transportation and effective waste management systems are vital in reducing environmental impacts. Institutionally, transparent and well-coordinated governance among stakeholders ensures that sustainability policies are implemented consistently and effectively. These limitations underscore the need for future longitudinal research, direct environmental performance monitoring, and stakeholder engagement, especially as IKN's regulatory and infrastructural contexts continue to evolve. Only through continued field-based assessment and inclusive policy feedback can the sustainability claims made in this study be validated and refined over time.

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