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Geometric Typology of an Organically Developed Commercial Corridor: A Case Study of Anggrek Street, Maumere

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ABSTRACT

Organically developed commercial areas commonly exhibit diverse building geometries that influence the spatial character and visual quality of the urban environment. This study aims to identify and analyze the geometric typology of buildings along the Anggrek Street commercial corridor in Sikka Regency based on five geometric attributes: building position, orientation, basic form, form transformation, and visual inertia. A descriptive qualitative approach was employed through field observations of five representative buildings selected using purposive sampling to capture the diversity of geometric characteristics within the study area. The analysis adopted an architectural typology approach to examine the relationships among these geometric attributes in shaping the spatial character of the commercial corridor. The results indicate that the corridor is predominantly composed of semi-attached and attached building typologies, reflecting increasing land-use intensity. Building orientation facing the street corridor enhances urban legibility and the visibility of commercial activities. The basic forms are primarily rectangular and cuboid, which have evolved through additive and subtractive transformations in response to spatial requirements. Differences in visual inertia are influenced by mass composition, color, façade articulation, and signage. The findings demonstrate that the spatial character of the corridor is shaped primarily by geometric transformation rather than variations in basic building form. Unlike previous typological studies that primarily focus on planned commercial districts, this study develops an integrated framework consisting of five geometric attributes to interpret organically developed commercial corridors. This study contributes to the advancement of geometric typology research by providing empirical insights into organically developed commercial corridors in small emerging cities, offering a conceptual basis for future urban design and corridor planning.

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1. INTRODUCTION

Commercial corridors constitute an essential component of the urban spatial structure, functioning not only as centers of economic activity but also as elements that shape the visual identity of a city. Beyond facilitating commercial transactions, these areas reflect the interaction between social dynamics, cultural values, and the continuous adaptation of the built environment to changing spatial demands [1,2]. As urban areas evolve, commercial districts often undergo physical transformations that influence the geometric characteristics of buildings and, consequently, the overall spatial quality of the urban corridor.

Anggrek Street is one of the organically developed commercial corridors in Maumere City, Sikka Regency, East Nusa Tenggara Province, Indonesia. Located in Kota Uneng Village, Alok District, the corridor forms part of the Perumnas Maumere area and has gradually developed into a local commercial and service center. The corridor extends approximately 916.5 m and functions as an important connection between the city center and surrounding residential neighborhoods. All buildings fronting both the northern and southern sides of the corridor of the street were included in the field observation.

The selection of Anggrek Street as the study area was motivated by its distinctive pattern of urban development. Unlike formally planned commercial districts, the corridor has evolved incrementally without comprehensive urban design guidelines. As a result, the area exhibits considerable variation in building geometry, spatial configuration, and visual composition within a relatively short street corridor [3,4]. The corridor is predominantly occupied by mixed-use buildings that combine residential spaces with commercial functions, creating a complex urban environment characterized by continuous physical adaptation.

The evolution of Anggrek Street is closely associated with the post-disaster urban development of Maumere following the 1992 Flores earthquake and tsunami. The disaster triggered extensive urban restructuring, including the relocation of settlements from vulnerable coastal areas and the expansion of the city toward safer inland locations. Within this context, Anggrek Street gradually transformed into a strategic residential, commercial, and institutional corridor as part of Maumere's urban expansion [5]. This long-term adaptive development has generated various morphological phenomena, including building mass transformation, changes in spatial configuration, increasing building density, and visual fragmentation, making the corridor an appropriate case study for geometric typology analysis.

Previous studies on commercial area typology have predominantly focused on planned commercial districts in large metropolitan cities. In contrast, investigations of organically developed commercial corridors in small cities, particularly in Eastern Indonesia, remain limited. Small emerging cities often exhibit distinctive spatial dynamics, where building forms evolve incrementally in response to changing economic activities, land constraints, and individual development decisions. Consequently, the geometric characteristics of commercial buildings differ substantially from those found in planned urban environments.

Although numerous studies have examined commercial corridors from functional, architectural, and urban design perspectives, few have investigated geometric typology by integrating building position, orientation, basic form, transformation, and visual inertia within a single analytical framework, particularly in organically developed commercial corridors in small emerging cities.

Unlike previous studies that primarily classify commercial buildings according to function or architectural style, this study focuses on building geometric typology by integrating five geometric attributes: building position, orientation, basic form, form transformation, and visual inertia. This integrated approach provides a more comprehensive understanding of how geometric characteristics collectively shape the spatial identity of organically developed commercial corridors. Therefore, this research contributes to the advancement of architectural typology studies by extending the application of geometric typology to commercial corridors in small emerging cities.

Based on this background, the study aims to identify and analyze the geometric typology of buildings along the Anggrek Street commercial corridor through five principal geometric attributes: building position, orientation, basic form, form transformation, and visual inertia. The findings are expected to improve the understanding of the spatial characteristics of organically developed commercial corridors and provide a conceptual basis for future urban design and corridor planning.

Architectural typology provides an appropriate analytical framework for understanding the physical characteristics of the built environment. It classifies buildings according to recurring morphological attributes, enabling researchers to identify similarities, differences, and patterns of spatial development [6,7]. Rather than serving merely as a classification system, typology also functions as an analytical tool for interpreting the relationship between physical form and spatial organization [8].

Within the context of geometric typology, building characteristics can be examined through several interrelated geometric attributes, including building position, orientation, basic form, mass transformation, and visual inertia [9]. Building geometry is influenced by plot configuration, urban density, structural systems, and spatial requirements [10–12]. Building orientation determines accessibility, visibility, environmental responsiveness, and the relationship between buildings and the street corridor [13]. Meanwhile, additive and subtractive transformations reflect the continuous adaptation of building forms to functional requirements and spatial constraints [14]. Visual inertia complements these geometric attributes by describing the degree of visual dominance generated by building mass composition, proportion, façade articulation, color, and signage. Together, these five attributes provide a comprehensive framework for interpreting the geometric characteristics and spatial evolution of organically developed commercial corridors.

2. METHOD

This study employed a descriptive qualitative approach to identify and analyze the geometric typology of buildings along the Anggrek Street commercial corridor, Maumere City, Sikka Regency. The qualitative approach was selected because it enables an in-depth interpretation of spatial and visual phenomena based on the existing physical characteristics of the built environment.

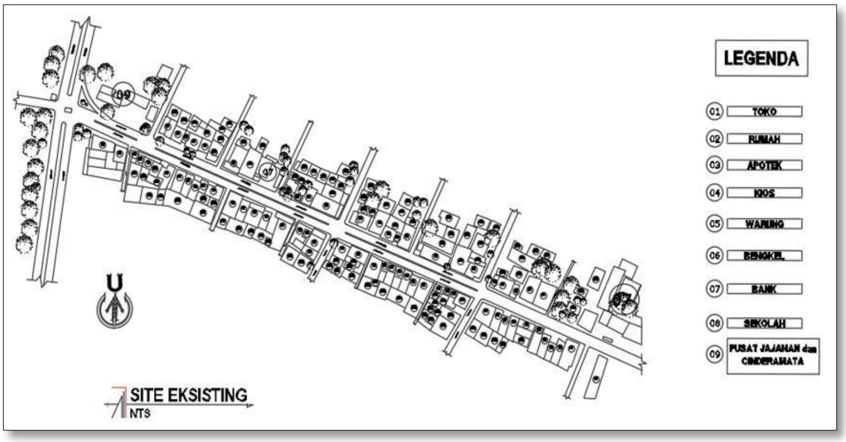

Figure 1. Location Map of the Anggrek Street Commercial Area

The study was conducted along the 916.5 m Anggrek Street commercial corridor, located in Kota Uneng Village, Alok District, Maumere City, Indonesia. The observation covered buildings facing both the northern and southern sides of the corridor. Field data were collected through direct observation, photographic documentation, field sketches, and visual recording of the physical characteristics of the buildings. The observations focused on five geometric attributes: building position, building orientation, basic building form, form transformation, and visual inertia.

Because not all buildings along the corridor represented different geometric characteristics, this study employed purposive sampling to select representative cases. Five buildings were chosen based on their ability to represent the range of geometric typologies identified during the preliminary field survey. The selection criteria included variations in building position, orientation, basic form, form transformation, and visual inertia. Following the preliminary field survey, field observations continued until no additional geometric typologies were identified, indicating that *typological saturation* had been achieved. Consequently, five representative buildings were selected through purposive sampling for detailed analysis. These representative buildings are presented in Table 1.

Table 1. Representative Buildings Selected for Geometric Typology Analysis

Building Code	Building Function	Representative Geometry	Geometric Characteristics
Red–Yellow Building (B1)	Commercial	Detached building	Simple rectangular geometry
Indomaret (B2)	Commercial	Semi-attached building	Additive mass transformation
Dunia Motor (B3)	Commercial	Attached building	Strong visual inertia
Green Building (B4)	Mixed-use	Vertical mass development	Attached with façade articulation
White House (B5)	Residential	Detached building	Symmetrical basic form

The five selected buildings adequately represented all geometric typologies identified within the study corridor. During the field investigation, no additional geometric characteristics were observed beyond those represented by the selected samples. Therefore, the selected buildings were considered sufficient to achieve the objectives of the study while allowing a more detailed comparative typological analysis.

The collected data were analyzed using an architectural typology approach through descriptive-comparative analysis. Each building was examined according to the five geometric attributes, after which similarities and differences among the samples were compared to identify recurring geometric patterns. The synthesis of these attributes was then used to interpret the spatial characteristics and geometric identity of the Anggrek Street commercial corridor.

The overall research procedure is summarized in **Figure 2**, which illustrates the sequence of research activities from problem identification, literature review, field observation, purposive sampling, geometric typology analysis, comparative analysis, and synthesis of the geometric characteristics of the study area.

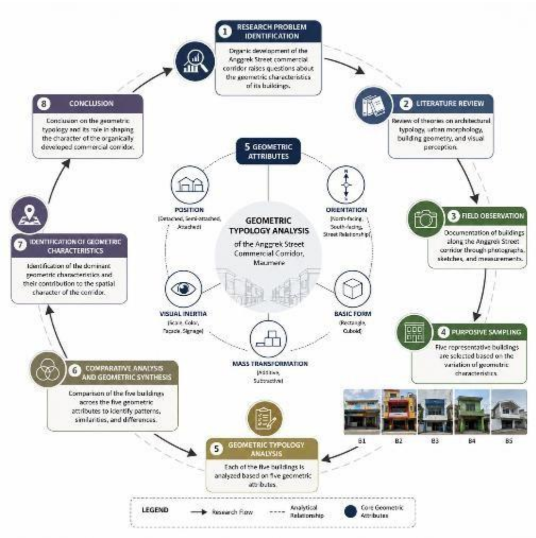

Figure 2. Research Flow Diagram

3. **RESULTS AND DISCUSSION**

The geometric typology of buildings along the Anggrek Street commercial corridor reflects the interaction between building form, land-use intensity, commercial activities, and the organic evolution of the urban corridor. Based on field observations, the geometric characteristics of the selected buildings were examined through five key attributes: building position, building orientation, visual inertia, basic building form, and building mass transformation.

a. Building Position

Field observations revealed three spatial relationships among buildings along the Anggrek Street commercial corridor: detached, semi-attached, and attached building configurations.

Figure 3. Example of a Detached Building (Two-Storey Residential House)

The detached building typology is represented by a two-storey white residential building that maintains open space on one or more sides of the structure. These open spaces enhance visual openness while allowing better access to natural daylight and cross-ventilation. According to Ching [17], detached buildings exhibit a higher degree of spatial independence because they maintain a more autonomous relationship with their surrounding environment.

Figure 4. Semi-Attached Buildings (Left: Dunia Motor; Right: Green Commercial Building)

The semi-attached typology is represented by buildings such as *Dunia Motor* and several mixed-use buildings that are connected to adjacent structures on one side while retaining limited open space on the other. This spatial configuration reflects a transitional stage in the evolution of the commercial corridor, where increasing land-use intensity encourages more efficient utilization of individual plots without completely eliminating open spaces around the buildings. Such a configuration demonstrates an adaptive response to growing commercial space demands while preserving access to natural lighting and ventilation. From the perspective of urban morphology, changes in spatial relationships between buildings represent an evolutionary process in urban form, in which increasing land-use intensity gradually produces a more compact urban fabric in response to economic growth and changes in land use [15].

Figure 5. Examples of Attached Buildings (Left: Indomaret; Right: Red-and-Yellow Shophouse)

The attached building typology is represented by the Indomaret building and several adjoining shophouses constructed with little or no spacing between adjacent structures. This arrangement creates a continuous street wall, resulting in a more compact urban form and a stronger spatial definition of the street corridor. Marshall [16] argues that commercial corridors with high land-use intensity commonly develop through continuous building frontages, reinforcing the enclosure and spatial definition of the street environment.

The predominance of semi-attached and attached buildings along the Anggrek Street corridor indicates that land-use intensity is one of the primary factors influencing the formation of the corridor's geometric typology. As commercial activities intensify, buildings tend to maximize plot utilization, reducing the distance between adjacent structures and creating increasingly compact spatial relationships. This pattern is characteristic of organically developed commercial areas, where building forms continuously evolve in response to increasing spatial demands and land development pressures [17,18].

These findings are consistent with previous studies on urban morphology, which indicate that organically developed commercial areas tend to evolve toward more compact building configurations as commercial intensity increases [15]. However, unlike planned commercial districts, the transformation observed along Anggrek Street occurred incrementally through individual building development rather than comprehensive urban planning.

b. Building Orientation

The buildings along the Anggrek Street commercial corridor exhibit a consistent orientation pattern, with their main façades facing the primary street corridor along the north and south directions. This configuration demonstrates the strong spatial relationship between buildings and the street, where the road functions as the principal organizing element of the corridor.

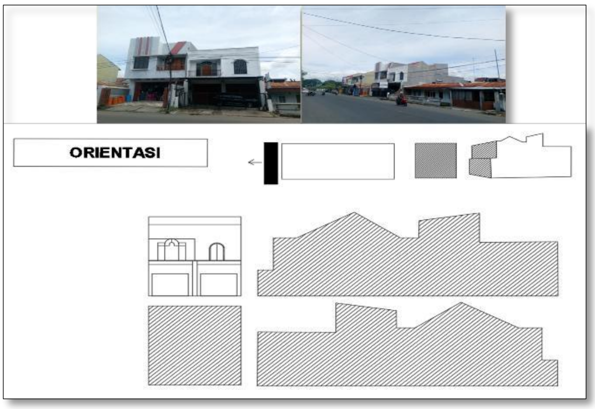

Figure 6. Geometric Analysis Based on Building Orientation

Field observations indicate that most buildings are consistently oriented toward the Anggrek Street corridor, with their primary façades directly facing the street. This uniform orientation highlights the role of the street as the dominant spatial element guiding building layout and supporting commercial activities. Consequently, commercial buildings locate their main entrances, display areas, and signage on the street-facing façade to maximize visibility, accessibility, and interaction with pedestrians and motorists.

According to Lynch [19], paths are fundamental components of urban structure that shape orientation, imageability, and movement patterns within a city. Along the Anggrek Street commercial corridor, the consistent street-facing orientation reinforces the dual function of the street as both a public space and an economic corridor connecting various commercial activities. Moreover, the alignment of building façades creates a continuous street wall, strengthening visual continuity and improving the legibility of the corridor. This finding is consistent with Carmona et al. [17], who argue that buildings with a coherent orientation toward the street contribute significantly to urban spatial quality, visual continuity, and the formation of corridor identity.

Beyond its role in defining urban space, building orientation also reflects adaptation to the tropical climate. With the primary façades oriented toward the north and south, the buildings are exposed to solar radiation from the east and west, increasing the potential for heat gain. To mitigate these effects, most buildings incorporate passive shading elements such as canopies, balconies, overhangs, secondary skins, and articulated façades. These elements not only enhance the architectural appearance of the buildings but also function as passive environmental strategies that reduce direct solar radiation and improve indoor thermal comfort. Koenigsberger et al. [20] emphasize that building orientation in tropical climates should be accompanied by appropriate shading devices to minimize solar heat gain and enhance thermal performance.

Although the buildings share a similar orientation, field observations reveal different geometric responses to climatic and functional requirements. The Indomaret building employs a wide-span canopy to protect the main entrance and commercial space from direct sunlight and rainfall. The red-and-yellow commercial building incorporates projecting balconies and articulated façade elements that simultaneously function as shading devices and reinforce the building's visual identity. In contrast, several residential and mixed-use buildings utilize open balconies, overhangs, and larger window openings to maximize daylight penetration and natural cross-ventilation. These variations demonstrate that, despite having a common orientation, each building adopts distinct design strategies in response to functional needs, local climatic conditions, and owner preferences. Such strategies are consistent with passive design principles that emphasize the integration of building orientation, shading devices, natural ventilation, and daylighting to improve thermal comfort while reducing cooling loads [21].

Overall, the orientation of buildings along the Anggrek Street commercial corridor is influenced not only by the street network as the primary organizing element of the urban fabric but also by the need to maximize commercial visibility and respond to local climatic conditions. The consistent orientation contributes to a highly legible street corridor, while variations in façade treatment demonstrate the adaptive capacity of individual buildings to satisfy both functional and environmental requirements. These findings suggest that building orientation plays a significant role in shaping the spatial character and geometric identity of the organically developed commercial corridor.

The findings of this study are consistent with previous research on commercial corridors, which emphasizes that buildings tend to orient their primary façades toward the street to maximize accessibility, visibility, and commercial exposure. Lynch [19] argues that streets (*paths*) function as the principal organizing elements of urban structure, influencing orientation patterns and users' perception of the urban environment. Similarly, Carmona et al. [17] reported that a consistent building orientation contributes to stronger street enclosure, improved urban legibility, and greater continuity of public space. The relatively uniform orientation observed along the Anggrek Street corridor therefore reflects a common morphological characteristic of commercial areas where economic activities are concentrated along the primary transportation network.

However, unlike many planned commercial districts where building orientation is controlled through urban design regulations, the Anggrek Street corridor demonstrates a more adaptive pattern. Although the buildings generally share the same orientation toward the street, individual owners have adopted different façade configurations, shading devices, and entrance arrangements according to functional needs and climatic considerations. This finding suggests that the spatial coherence of the corridor is achieved primarily through a common street orientation, whereas architectural expression remains largely determined by individual development decisions rather than coordinated planning.

c. Visual Inertia

Visual inertia refers to the ability of a building to maintain visual dominance when perceived from different viewpoints along an urban corridor. This dominance is determined by the interaction of geometric form, mass composition, building scale, color, materials, façade articulation, and the presence of signage that attracts the attention of street users. According to Ching [22], a building achieves visual emphasis when it exhibits greater contrast, scale, proportion, or spatial prominence than the surrounding elements. Similarly, Cullen [23] explains that the visual experience of an urban environment **(**serial vision**)** is created through variations in form, color, and visual hierarchy encountered along a street corridor.

Field observations indicate that buildings along the Anggrek Street commercial corridor exhibit varying degrees of visual inertia. Commercial buildings characterized by dominant red, yellow, and black color schemes demonstrate the highest level of visual inertia. Their strong color contrast, bold mass composition, extensive façade surfaces, and vertical emphasis establish these buildings as prominent visual landmarks within the corridor. Beyond reinforcing the architectural identity of the buildings, these visual attributes also enhance their attractiveness to road users, thereby strengthening their commercial function.

Table 1. Comparison of Visual Inertia among Buildings along Anggrek Street

Building	Dominant Color	Scale	Signage	Visual Inertia
Red–Yellow Building (B1)	Very High	High	Medium	Very High
Indomaret (B2)	High	Medium	Very High	High
Dunia Motor (B3)	Medium	High	High	Medium–High
Green Building (B4)	Medium	Medium	Low	Medium
White House (B5)	Low	Medium	None	Low

Buildings B1 and B2 exhibit the highest degree of visual inertia because they combine strong color contrast, dominant building mass, and highly visible signage. In contrast, B5 demonstrates the lowest level of visual inertia due to its neutral color palette, simple geometric form, and the absence of commercial visual elements.

Although the Indomaret building has a relatively simple geometric form, it achieves a high level of visual inertia through the application of a recognizable corporate identity, including standardized color schemes, large-scale signage, and a distinctive façade composition. Carmona et al. [17] argue that façade articulation, color, and signage are essential components in enhancing urban legibility and reinforcing users' visual orientation within commercial environments.

Unlike B1 and B2, the Dunia Motor building demonstrates a moderate to high level of visual inertia. Its visual prominence is primarily derived from the scale of the building mass, the large commercial signboard, and the broad façade openings. However, its more restrained color palette produces a lower degree of visual contrast than the Red–Yellow Building and the Indomaret building.

The green commercial building (B4) exhibits a moderate level of visual inertia. Although its façade color is visually distinctive, the relatively simple mass composition and smaller signage reduce its overall visual dominance within the street corridor.

Conversely, the two-storey white residential building (B5) displays the lowest level of visual inertia. Its neutral colors, simple geometric composition, limited façade articulation, and absence of commercial signage prevent it from becoming a dominant visual element within the corridor. This observation suggests that visual dominance is determined not only by building size but also by the combination of color, façade articulation, visual identity, and architectural expression.

The comparison among the five representative buildings demonstrates that visual inertia is strongly associated with the architectural expression of commercial activities. Commercial buildings generally exhibit higher visual inertia because they employ contrasting colors, prominent signage, and expressive façades designed to attract public attention. In contrast, residential buildings prioritize geometric simplicity and functional efficiency, resulting in lower visual prominence. These findings indicate that visual inertia should be understood not merely as a geometric characteristic but also as an adaptive architectural response to commercial requirements and marketing strategies within the corridor.

Nevertheless, the individually developed visual expressions observed along the Anggrek Street corridor have produced an uncoordinated visual hierarchy. As each building emphasizes its own architectural identity, the corridor lacks a coherent visual character at the urban scale. This finding is consistent with Carmona et al. [3], who emphasize that the visual quality of urban environments depends on the consistency of building relationships, façade harmony, and the coordinated management of visual elements throughout the streetscape.

The variation in visual inertia observed among the five representative buildings supports previous studies emphasizing that visual dominance within commercial corridors is determined not only by building size but also by the combined effects of façade articulation, color contrast, signage, and mass composition. Ching [22] explains that visual emphasis emerges from differences in proportion, scale, and contrast, whereas Cullen [23] argues that the sequence of visually dominant elements contributes significantly to the serial visual experience of urban streets. The present findings reinforce these theoretical perspectives by demonstrating that commercial buildings achieve greater visual prominence through the deliberate integration of architectural and graphic elements.

Nevertheless, the Anggrek Street corridor differs from many contemporary commercial environments where visual identity is regulated through façade guidelines or streetscape design controls. The observed variations in color, signage, and façade treatment indicate that visual inertia develops independently at the individual building scale. Consequently, while several buildings function as strong visual landmarks, their cumulative effect is a fragmented visual hierarchy rather than a coherent streetscape. This finding highlights the importance of integrating individual building identity with broader urban design objectives to improve the visual quality of organically developed commercial corridors. Therefore, visual inertia should be understood not only as an individual architectural property but also as a component of collective streetscape identity.

d. Basic Building Form

Based on field observations of the five representative buildings, the basic building forms along the Anggrek Street commercial corridor are predominantly characterized by simple geometric shapes, particularly rectangular and cuboid forms. Although the buildings differ in function and façade expression, they share a relatively consistent basic geometry that has evolved through various forms of mass transformation in response to functional requirements.

Buildings B1 (Indomaret) and B5 (the two-storey residential house) exhibit simple cuboid forms with symmetrical mass compositions and minimal geometric transformation. These characteristics contribute to a high degree of visual legibility, as the buildings retain their original proportions and geometric clarity. According to Ching [22], rectangular and cuboid forms represent the most stable geometric configurations because they provide order, balance, and efficiency in spatial organization. Their geometric simplicity also facilitates construction while allowing flexibility in the arrangement of interior spaces.

In contrast, Buildings B2 and B3 demonstrate additive transformations of the basic form through the incorporation of projecting façades, balconies, canopies, and additional vertical volumes. These modifications create more dynamic mass compositions without altering the primary geometric identity of the buildings. Ching [22] explains that additive transformation enables buildings to accommodate new functional requirements while preserving their fundamental geometric characteristics. Within commercial buildings, such transformations generally serve to expand usable space and enhance visual attractiveness to street users.

Building B4 exhibits a more complex basic form generated through the composition of multiple rectangular volumes arranged both horizontally and vertically. Although its mass composition is more articulated than the other case studies, the building still maintains a clear underlying geometric order. This finding indicates that the geometric complexity observed along the Anggrek Street corridor results primarily from the composition and transformation of simple forms rather than from the use of fundamentally different geometric shapes.

From the perspective of urban morphology, the predominance of rectangular forms reflects the strong relationship between building geometry and plot configuration along the corridor. Most buildings occupy relatively narrow and elongated plots, making rectangular forms the most efficient solution for maximizing land utilization. Oliveira [18] argues that basic building forms evolve as an adaptation to plot configuration, cadastral subdivision, and the functional development of urban areas. Consequently, the consistent use of rectangular geometry observed in this study suggests that the physical characteristics of the plots have exerted a greater influence on building form than individual architectural preferences.

In addition to plot configuration, the basic building form also reflects adaptation to commercial activities. Retail buildings require flexible interior layouts for merchandise display, customer circulation, and storage, making rectangular plans particularly suitable for efficient spatial organization. This observation supports the argument of Rapoport [24], who states that building form is the outcome of interactions among human activities, functional requirements, environmental conditions, and socio-economic development.

Overall, the findings demonstrate that the Anggrek Street commercial corridor exhibits a high degree of consistency in basic building form. The visual diversity of the corridor is generated primarily through mass transformation and façade articulation rather than through variations in basic geometry. These findings indicate that the geometric identity of the corridor is shaped not by differences in fundamental building forms but by the ways in which individual buildings transform their basic geometry in response to spatial demands, commercial activities, and the gradual organic evolution of the corridor.

e. Building Form Transformation

Field observations reveal that all five representative buildings along the Anggrek Street commercial corridor have undergone varying degrees of building form transformation. Rather than altering their fundamental geometric forms, these changes occur primarily through additive and subtractive transformations, allowing the buildings to respond to functional requirements, land constraints, and the continuous evolution of commercial activities.

Additive transformation is the most dominant form of geometric modification observed within the study area. Buildings B2 and B3 demonstrate volumetric expansion through the addition of balconies, canopies, secondary skins, Aluminium Composite Panel (ACP) cladding, and upper-level building masses. These interventions generate more dynamic mass compositions while increasing the amount of usable commercial space. In addition to accommodating functional requirements, these architectural elements strengthen the buildings' visual identity and improve their recognition within the commercial corridor.

Conversely, subtractive transformation is evident in nearly all observed buildings through recessed entrances, façade setbacks, terraces, open balconies, enlarged window openings, and carved façade elements. These modifications reduce portions of the original building volume to improve daylight penetration, natural cross-ventilation, and the transition between public and private spaces. In commercial buildings, subtractive transformations also enhance accessibility by creating more open and inviting interfaces between indoor activities and the street corridor.

According to Ching [22], form transformation is a process of modifying basic geometric configurations while preserving their primary identity. Buildings may evolve through addition, subtraction, or dimensional modification, enabling them to accommodate changing functional requirements without losing their underlying geometric characteristics. This concept is clearly reflected along the Anggrek Street corridor, where relatively uniform basic forms have gradually evolved into diverse architectural compositions through continuous geometric transformation.

From the perspective of urban morphology, these transformations represent an incremental process of spatial adaptation driven by changing commercial demands and urban growth. Oliveira [18] argues that building form evolves through the interaction between plot configuration, functional change, and the broader dynamics of urban development. This evolutionary process is evident along Anggrek Street, where commercial buildings have expanded vertically and horizontally while retaining the original configuration of their plots.

Building form transformation is also strongly influenced by the economic objectives of property owners. The addition of balconies, canopies, façade panels, and other architectural features not only increases building capacity but also enhances commercial visibility and strengthens business identity along the corridor. Rapoport [24] argues that changes in building form reflect the continuous interaction between human activities, socio-economic conditions, and the physical environment. Consequently, building transformation should be understood as an adaptive response to both functional and economic pressures rather than merely an architectural modification.

The findings indicate that building transformation along the Anggrek Street commercial corridor is highly adaptive but largely occurs through individual development decisions. Each building has evolved according to the specific needs of its owner without the guidance of an integrated urban design framework. As a result, although the buildings originate from relatively similar basic forms, successive transformations have produced considerable variation in mass composition, proportion, and façade articulation. These observations suggest that the visual character of the corridor is influenced more by the cumulative effects of building transformation than by differences in the original geometric forms.

Overall, building form transformation constitutes the principal mechanism underlying the geometric typology of the Anggrek Street commercial corridor. Beyond accommodating spatial and commercial requirements, the transformation process shapes the visual identity, spatial character, and morphological evolution of an organically developed commercial corridor. These findings demonstrate that the geometric character of the corridor is defined not by static building forms but by their continuous adaptation to changing urban and economic conditions.

The building transformations documented in this study are consistent with previous urban morphology research, which describes building evolution as a gradual adaptation to changing functional demands and urban development processes. Oliveira [18] explains that building forms evolve incrementally through interactions among plot configuration, land-use change, and socio-economic development. Similarly, Rapoport [24] argues that architectural transformation reflects the continuous adaptation of the built environment to human activities and changing cultural and economic conditions. The additive and subtractive transformations observed along Anggrek Street therefore represent a typical evolutionary process within organically developed commercial environments.

However, the transformation pattern identified in this study differs from that commonly observed in planned commercial districts. Rather than following coordinated design regulations, modifications along the Anggrek Street corridor occur independently according to the preferences and economic capacities of individual property owners. This process has produced considerable diversity in mass composition, façade articulation, and building proportions despite the relatively uniform basic building forms. Consequently, the corridor's geometric identity is shaped not by standardized architectural forms but by the cumulative effects of incremental transformations that have occurred over time.

These findings demonstrate that building transformation functions as the primary mechanism driving the morphological evolution of the corridor. While this adaptive process enhances spatial flexibility and supports commercial growth, it also generates increasing visual diversity that may reduce overall streetscape coherence in the absence of integrated urban design guidelines. Consequently, future corridor development should balance architectural adaptability with urban design consistency to preserve both commercial vitality and visual coherence.

4. CONCLUSION

The geometric typology of buildings along the Anggrek Street commercial corridor demonstrates that the spatial character of the area has evolved through the interaction of five principal geometric attributes: building position, orientation, basic form, building form transformation, and visual inertia. The predominance of semi-attached and attached buildings reflects increasing land-use intensity, while the consistent orientation of building façades toward the street reinforces the role of the corridor as the primary organizing element of commercial activities and urban movement.

Although the buildings share similar rectangular and cuboid basic forms, their architectural character is primarily differentiated through continuous building form transformation. Additive and subtractive modifications, including balconies, canopies, façade articulation, and recessed spaces, represent adaptive responses to commercial expansion, functional requirements, climatic conditions, and spatial constraints. Consequently, the geometric identity of the corridor is shaped more by the transformation of basic forms than by differences in the original building geometry.

The analysis also reveals that variations in visual inertia are influenced by mass composition, façade articulation, color, scale, and signage. Commercial buildings generally exhibit stronger visual dominance than residential buildings, contributing to the corridor's commercial identity while simultaneously producing a fragmented visual environment due to the absence of integrated urban design control.

Overall, this study demonstrates that the geometric typology of the Anggrek Street commercial corridor is the product of continuous spatial adaptation associated with the organic growth of a small emerging city. By integrating five geometric attributes into a single analytical framework, this research extends the application of geometric typology in the study of organically developed commercial corridors. The findings provide a conceptual reference for future urban design strategies aimed at improving visual coherence, spatial quality, and the sustainable development of commercial corridors.

This study is limited to five representative buildings located within a single commercial corridor. Consequently, the findings cannot be generalized to all commercial areas in small cities. Future studies are recommended to investigate a larger number of buildings and compare multiple commercial corridors to obtain a broader understanding of geometric typology in organically developed urban environments.

From an urban design perspective, the findings suggest that future development of organically evolved commercial corridors should prioritize geometric coherence while maintaining the adaptive characteristics that support local commercial activities. Such an approach may improve both spatial quality and corridor identity without limiting the flexibility of individual building development.

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Overall Thermal Transfer Value (OTTV) Analysis of the Banten Provincial Language Office Building

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ABSTRACT

This study evaluates the thermal performance of the building envelope at the Banten Provincial Language Office through an analysis of the Overall Thermal Transfer Value (OTTV). The objective of this study is to calculate the OTTV value and identify the facade elements that contribute the greatest heat load to ensure compliance with the SNI 03-6389-2020 standard (maximum 35 W/m²). The primary method used was a mixed-methods approach employing a case study methodology, which involved field observations, analysis of construction drawings, and an OTTV spreadsheet calculator provided by the Ministry of Public Works and People's Housing (PUPR). The main results show that the current OTTV value is 69.43 W/m², which does not meet the national standard. The east facade contributes the highest heat gain (85.10 W/m²) due to a window-to-wall ratio (WWR) of 54.72% and 8 mm-thick clear glass. Building orientation, materials, glass type, opening area (WWR), and the use of shading systems are critical factors in calculating the OTTV value. Modifying the glass material by using Stopray Double Glass on the east and north facades successfully reduced the total OTTV value by 50.02% to 34.70 W/m². This material intervention proved effective in meeting national energy conservation standards.

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1. INTRODUCTION

As awareness of climate change and sustainability issues grows, the phenomenon of global warming caused by high energy consumption requires serious attention across various sectors. The Directorate General of New, Renewable, and Energy Conservation at the Ministry of Energy and Mineral Resources reports that the building sub-sector, which includes commercial and residential categories, accounts for 18% of total national energy consumption, making it the third-largest consumer after the industrial and transportation sectors. Therefore, the application of energy-efficient green building principles is a key component of energy efficiency strategies as well as the fulfillment of emission reduction targets in the building sector [1]. This makes energy efficiency a top priority that must be widely implemented, including in the field of construction [2].

The implementation of energy efficiency is crucial in our efforts to reduce the impact of environmental damage. It also plays a major role in maintaining the availability of energy sources, particularly those derived from non-renewable resources [3]. To mitigate the effects of excessive energy use, efforts must be made through development that incorporates the concept of energy-efficient or green buildings; this concept has a highly positive impact on energy conservation [4].

Essentially, green building is a concept that emphasizes the importance of conserving natural resources such as energy and water. The application of this concept is not limited to the construction of new buildings but can also be applied to optimize existing buildings [5]. According to the standards of the Green Building Council Indonesia (GBCI), one of the key criteria in the green building category is the effort to improve energy efficiency and promote sustainable energy conservation [6].

In tropical countries like Indonesia, energy conservation poses a unique challenge for architects when designing buildings. Buildings in this region often struggle to meet thermal comfort standards. This is due to environmental variables such as high air temperatures, relative humidity, solar radiation, and air velocity, which often do not support ideal indoor conditions [7]. There are two sources of heat load handled by HVAC systems: heat load from outside the building and heat load from inside the building. Heat load originating from the building envelope is quantified by a parameter known as the Overall Thermal Transfer Value (OTTV) [8].

OTTV is closely related to the building envelope. The building envelope is the outermost layer that is directly exposed to sunlight. This element serves as the primary pathway for heat radiation to enter the building, given that most thermal energy is transferred through this component [9]. The building envelope plays a crucial role in regulating energy consumption within the building. Generally, heat transfer in the building envelope involves three basic elements: solar radiation penetrating through glass, heat transfer (conduction) through solid walls, and heat conduction occurring in window or opening areas [10].

The challenge in achieving energy efficiency standards for institutional and public service buildings in Banten Province relates to the aesthetic design of building facades and envelopes, which are often not optimally integrated with the building's thermal performance parameters. At the ITB Ahmad Dahlan Karawaci educational building in Tangerang, Banten, it was found that the newly renovated institutional building still has an OTTV value of 52,66 W/m² on its facade/building envelope. [11].

The Banten Provincial Language Office building is a new structure that was officially inaugurated on December 30, 2024. It is located on Jalan Ciemas Raya Banjaragung, Blok Kibali, Sumur Putat, Cipocok Jaya District, Serang City, Banten. This building serves as a public service center for language and literature [12]. The selection of the Banten Provincial Language Office as the subject of study was based on the characteristics of its building envelope, which is dominated by transparent elements, as well as the orientation of the building's longest side facing east and the use of an external shading system applied to the building.

Through an analysis of the Overall Thermal Transfer Value (OTTV) in accordance with SNI 6389:2020, this study aims to examine the performance of building envelopes in supporting energy conservation efforts. This is achieved by controlling the heat flow entering the building in tropical climates such as those found in the city of Serang. According to [13] minimizing heat transfer is one of the key strategies in energy-efficient building design. The building envelope plays a crucial role in controlling indoor temperatures, thereby directly influencing the workload of the cooling system. Therefore, the overall thermal performance of a building heavily depends on the design and materials that constitute its envelope elements. This study uses Overall Thermal Transfer Value (OTTV) analysis to measure the amount of heat entering through exterior walls and window openings.

Through this approach, elements such as building orientation, façade material composition, opening area (window-to-wall ratio), and the presence of shading systems will be identified and analyzed. The evaluation results are expected to provide an objective picture of the energy performance of the Banten Provincial Language Office building to improve energy efficiency and the implementation of energy-efficient architecture or green building.

This study aims to determine the Overall Thermal Transfer Value (OTTV) of the building envelope of the Banten Provincial Language Office, as well as to identify the factors influencing this OTTV value. The building under study is a new structure; therefore, it is not yet known whether it meets the criteria for an energy-efficient building in accordance with applicable national standards. In this context, the OTTV value is used as an initial evaluation parameter to assess energy efficiency and conservation through the building envelope. This approach was implemented as part of efforts to apply the concept of green architecture, specifically in terms of energy efficiency and conservation in new buildings in tropical climates, particularly in the city of Serang, Banten Province.

2. METHOD

The method used in this study is a mixed-methods approach, which combines qualitative and quantitative methods through the collection of primary and secondary data. The subject of this study is the Banten Provincial Language Office building, located at Jalan Ciemas Raya Banjaragung Blok Kibali, Sumur Putat, Cipocok Jaya Subdistrict, Serang City, Banten. The observations were conducted from October 2025 to January 2026.

1. The quantitative data analysis involves calculating the Overall Thermal Transfer Value (OTTV) of the exterior envelope of a conditioned (air-conditioned) building. This calculation process uses the official Microsoft Excel Spreadsheet Formula Calculator from the Indonesian Ministry of Public Works and Public Housing (PUPR), based on the national standard SNI 6389:2020. The quantitative variables calculated include the total facade area, the window-to-wall ratio (WWR), and the building envelope materials, which consist of opaque wall conduction, glass conduction, and opening radiation.

Table 1. SHGC and U-Value of Glass Materials (source: PT. Asahimas Flat Glass Tbk)

Glass material code	SHGC	U-Value
Clear Glass 8 mm	0,81	5,70

2. The qualitative data analysis was conducted to identify the characteristics of the existing conditions of the Banten Provincial Language Office building. The process began by identifying and mapping spaces equipped with air conditioning systems/AC, specifically on the second and third floors, which were the primary focus of the OTTV calculations. The document study was conducted on the complete architectural working drawings (floor plans, elevations, sections, and facade details) obtained directly from the design consultant, Studio Kertas Bening Arsitek, with the purpose of analyzing the characteristics of the building envelope/facade, the construction details of the exterior shading devices, and the site's orientation relative to the sun's path in Serang City.

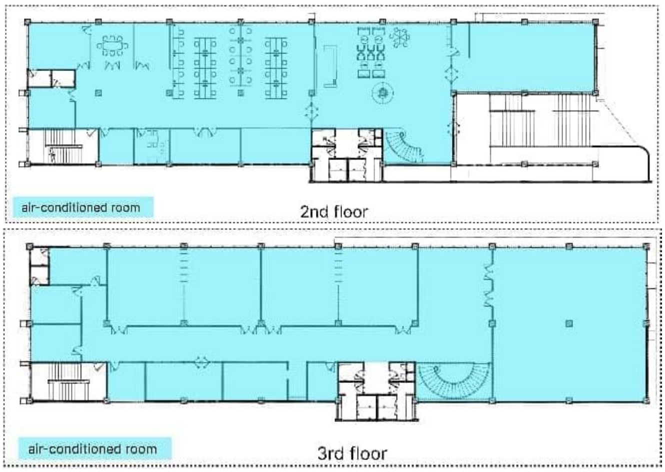

Figure 1. floor plan of the air-conditioned room (source: author, 2026)

Table 2. Solar radiation factor (SF, W/m²) for the city of Serang, Banten (source: National Standards Agency, SNI 6389:2020)

City	N	NE	E	SE	S	SW	W	NW
Serang	162	168	173	142	123	172	224	205

2.1. Overall Thermal Transfer Value (OTTV)

The OTTV calculation is a method used to measure the amount of heat transfer entering through a building envelope. This measurement covers all components of the building envelope, including walls and glass/windows (openings) [14]. According to the National Standardization Agency's SNI 6389:2020, the OTTV value calculation applies only to air-conditioned building envelopes with a maximum calculated value of 35 W/m² [15].

The formula for calculating the OTTV value embedded in the calculator spreadsheet is based on the following equation:

$$\text{OTTV} = \boldsymbol{\alpha\,[U_w \times (1 - WWR) \times TD_{Ek}] + (U_f \times WWR \times \Delta T) + (SC \times WWR \times SF)}$$

$$\text{OTTV} = \text{Wall Conduction} + \text{Glass Conduction} + \text{Glass Radiation}$$

OTTV = Overall thermal transmittance of an exterior wall with a specific orientation (W/m²);
α = Solar radiation absorptance;
Uw = Thermal transmittance of an opaque wall (W/m²·K);
WWR = Ratio of window area to total exterior wall area for the specified orientation;
TDEK = Equivalent temperature difference (K);

SF = Solar radiation factor (W/m²);
SC = Shading coefficient of the window system
Uf = Thermal transmittance of the window system (W/m²·K);
ΔT = Design temperature difference between the exterior and interior.

3. RESULTS AND DISCUSSION

Based on observations of the materials used in the building envelope of the Banten Provincial Language Office, namely: 150 mm-thick lightweight bricks and 8 mm-thick clear glass openings. The glass in the windows and doors is equipped with horizontal and vertical external shading devices and the building envelope incorporates a combination of aluminum composite panels.

Based on the data obtained, the facade of the Banten Provincial Language Office is dominated by the use of glass combined with external shading systems. The glass material plays a crucial role in influencing the amount of heat transfer into the building's interior.

Figure 2. Building envelope of the Banten Provincial Language Office (source: author, 2026)

Figure 3. (a) Type of openings and shading on the north elevation (source: author, 2026)

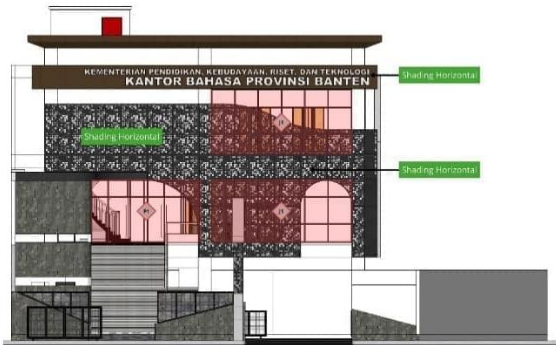

Figure 4. (b) Type of openings and shading on the south elevation (source: author, 2026)

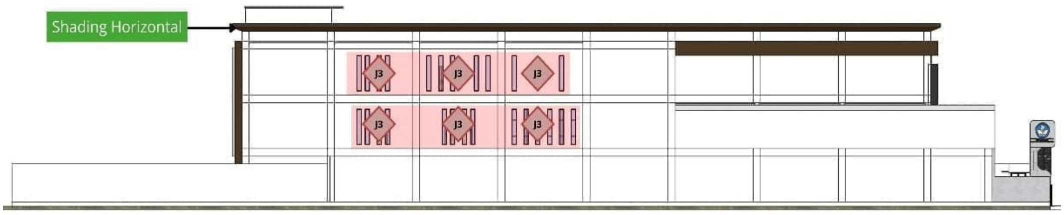

Figure 5. (c) Type of openings and shading on the west elevation (source: author, 2026)

Figure 6. (d) Type of openings and shading on the east elevation (source: author, 2026)

The building's orientation has an important role in determining the heat transfer or solar radiation entering the building, with the building's longest sides facing east and west and the shortest sides facing north and south.

Table 3. Fenestration System Code (source: author, 2026)

Code	Size Opening	Opening Location	Opening Orientation	Number of Opening Units
Type J1	660 x 300 cm	2nd and 3rd floors	East, West, and South	19 Unit
Type J2	443 x 300 cm	2nd floor	North	1 Unit
Type J3	40 x 280 cm	2nd and 3rd floors	West	25 Unit
Type J4	322 x 300 cm	2nd and 3rd floors	North and East	3 Unit
Type P1	660 x 300 cm	2nd floor	South (Entrance)	1 Unit

3.1. Identification of Wall and Fenestration System Specifications

The following is Table 4, which identifies the specifications for exterior walls, exterior window systems, and exterior shading systems based on the existing conditions of the Banten Provincial Language Office building.

Table 4. Identify the specifications of the exterior walls
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

Jumlah Tipe Konstruksi Dinding	1

Type	Konstruksi
EW 1	Bata Ringan
-	
-	
-	
-	
-	
-	
-	
-	

The exterior walls of the Banten Provincial Language Office building use a single type of primary wall construction lightweight brick for the entirety of the building envelope, with a wall thickness of 150 mm, coded as EW 1.

Table 5. Identification of exterior window system specifications
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	Kode Tipe Konstruksi Sistem Fenestrasi	Nama	SHGC	U Value (W/m²K)	Peneduh Luar	Kode Spesifikasi Peneduh Luar (lihat tabel 3,4,5)	Keterangan
1	F1	Clear Glass 8 mm	0,81	5,70	yes	SV1	Peneduh luar vertikal / sirip - sirip ACP
2	F2	Clear Glass 8 mm	0,81	5,70	yes	SH1	Peneduh luar horizontal overhang ACP
3	F3	Clear Glass 8 mm	0,81	5,70	yes	SH2	Peneduh luar horizontal overstek atap ACP
4	F4	Clear Glass 8 mm	0,81	5,70	no		
5	F5	Clear Glass 8 mm	0,81	5,70	yes	SE1	Peneduh kombinasi ceiling (perpustakaan)
6	F6	Clear Glass 8 mm	0,81	5,70	yes	SH3	Peneduh Horizontal perforated parsial S1
7	F7	Clear Glass 8 mm	0,81	5,70	yes	SH4	Peneduh Horizontal perforated parsial S2
8	F8	Clear Glass 8 mm	0,81	5,70	yes	SH5	Peneduh Horizontal perforated parsial S3
9	F9	Clear Glass 8 mm	0,81	5,70	yes	SH6	Peneduh Horizontal perforated parsial S4
10	F10	Clear Glass 8 mm	0,81	5,70	yes	SH7	Peneduh Horizontal perforated parsial S5
11	F11	Clear Glass 8 mm	0,81	5,70	yes	SE2	Peneduh kombinasi ceiling entrance
12	F12	Clear Glass 8 mm	0,81	5,70	yes	SH8	Peneduh Horizontal perforated parsial T1
13	F13	Clear Glass 8 mm	0,81	5,70	yes	SH9	Peneduh Horizontal perforated parsial T2
14	F14	Clear Glass 8 mm	0,81	5,70	yes	SH10	Peneduh Horizontal perforated parsial T3
15	F15	Clear Glass 8 mm	0,81	5,70	yes	SH11	Peneduh Horizontal perforatedparsial T4
16	F16	Clear Glass 8 mm	0,81	5,70	yes	SH12	Peneduh Horizontal perforated parsial T5
17	F17						
18	F18						

All components of the glazing system at the Banten Provincial Language Office use 8-mm-thick clear glass. This material has a solar heat gain coefficient (SHGC) of 0.81 and a U-value of 5.70. The glazing system is classified into two categories: openings equipped with a shading system and openings without a shading system.

Table 6. Details of the horizontal external shading element
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	Kode Peneduh Luar Horisontal	panjang (P1) [m]	tinggi (H) [m]	kemiringan [derajat]	Scef Utara / Selatan	Scef Barat / Timur	Scef TimurLaut / BaratLaut	Scef Tenggara / BaratDaya
1	SH1	0,83	3	0	0,877	0,875	0,863	0,857
2	SH2	1,4	1,9	0	0,692	0,657	0,655	0,629
3	SH3	3,24	4,2	50	0,667	0,458	0,532	0,500
4	SH4	3,24	1,9	50	0,658	0,396	0,476	0,443
5	SH5	1,38	1,1	50	0,658	0,397	0,476	0,443
6	SH6	1,62	1,5	50	0,658	0,406	0,483	0,449
7	SH7	4,16	2,1	50	0,658	0,396	0,476	0,443
8	SH8	3,24	4,2	50	0,667	0,458	0,532	0,500
9	SH9	2,82	3,5	50	0,663	0,447	0,509	0,477
10	SH10	1,86	1,9	50	0,660	0,424	0,492	0,459
11	SH11	2,82	3,5	50	0,663	0,447	0,509	0,477
12	SH12	1,404	1,14	50	0,658	0,397	0,476	0,443
13	SH13				-	-	-	-
14	SH14				-	-	-	-

Table 7. Details of vertical external shading elements
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	Kode Peneduh Luar Vertikal	panjang (P1) [m]	lebar (W) [m]	kemiringan [derajat]	Scef Utara / Selatan	Scef Barat / Timur	Scef TimurLaut / BaratLaut	Scef Tenggara / BaratDaya
1	SV1	0,3	0,6	0	0,775	0,905	0,791	0,791
2	SV2				-	-	-	-
3	SV3				-	-	-	-
4	SV4				-	-	-	-
5	SV5				-	-	-	-

Table 8. Details of the combined external shading element
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	Kode Peneduh Luar Vertikal	panjang (P1) P1 (m)	tinggi (H) H (m)	panjang (P2) P2 (m)	lebar (W) W (m)	kemiringan [derajat]	Scef Utara / Selatan	Scef Barat / Timur	Sc ef Ti mu	Scef Tenggara / BaratDaya
1	SE1	7,13	3,1	7,13	13,8	0	0,658	0,477	##	0,475
2	SE2	14,25	3,1	14,25	6,6	0	0,658	0,454	##	0,452
3	SE3						-	-	#	-
4	SE4						-	-	#	-
5	SE5						-	-	#	-

In calculating the OTTV value, three categories of shading devices are used. All exterior shading elements at the Banten Provincial Language Office encompass these three types, namely horizontal (SH), vertical (SV), and combination/egg-shaped (SE) shading devices. The technical parameters required as input data include the length (L), height (H), and width (W) of the shading device, as well as its angle of inclination.

3.2. Calculation of OTTV for North Orientation

Details about the north elevation are shown in Figure 7. and Table 9. The building construction on this side uses lightweight brick in accordance with the wall specifications in Table 4.

Figure 7. Detail of the north facade (source: author, 2026)

For the openings, the fenestration system uses 8 mm clear glass of types F1 and F4 (see Table 5.). The main difference between these two types of openings lies in their shading: the F1 opening uses vertical shading provided by white ACP louvers (SV1), whereas the F4 opening does not use any external shading at all.

Table 9. Identification of the North Facade
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

FASAD	Tinggi (jarak antar lantai)	Panjang	Area Fasad	Tipe Konstruksi Dinding	Kode Tipe Konstruksi Sistem Fenestrasi	Area Bukaan	Total Jumlah Lantai	Total Area Fasad	LOKASI
			[1]			[2]	[3]	= [1] x [3]	
	(m)	(m)	(m²)			(m²)		(m²)	
U 1	4,2	6,6	27,72	EW 1	F1	13,29	1	27,72	lantai 2
U 2	4,2	10,8	45,36	EW 1	F1	9,66	1	45,36	lantai 3
U 3	4,2	4,2	17,64	EW 1	F4	9,66	1	17,64	lantai 2
U 4			-					-	
U 5			-					-	

Table 10. The amount of heat transfer in the north (source: Author, 2026)

Orientation	Heat Transfer (W)		
	Wall Conduction	Opening Conduction	Radiaton Opening
North	1,030,38	929,39	4.197,63

Table 10. above shows that solar radiation through glass (radiation opening) is the largest contributor to the heat load inside the building (4,197.63), while glazing conduction contributes the least amount of heat. Glazing radiation indicates that the use of clear glass is currently the main cause of solar heat gain on the north side.

3.3. Calculation of OTTV for South Orientation

Details about the north elevation are shown in Figure 8. and Table 11. The building construction on this side uses lightweight brick in accordance with the wall specifications in Table 4.

Figure 8. Detail of the south facade (source: author, 2026)

The construction type for this side of the building uses lightweight brick material in accordance with the specifications in Table 4. For the openings, the fenestration system uses 8 mm clear glass with shading systems of types F2, F11, and F6 – F10 (see Table 5).

Table 11. Identification of the South Facade
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	FASAD	Tinggi (jarak antar lantai)	Panjang	Area Fasad	Tipe Konstruksi Dinding	Kode Tipe Konstruksi Sistem Fenestrasi	Area Bukaan	Total Jumlah Lantai	Total Area Fasad	LOKASI
				[1]			[2]	[3]	= [1] x [3]	
		(m)	(m)	(m²)			(m²)		(m²)	
1	S 1	4,2	4,25	17,85	EW 1	F6	12,75	1	17,85	Lantai 2
2	S 2	4,2	2,35	9,87	EW 1	F7	7,05	1	9,87	Lantai 2
3	S 3	1,2	2,35	2,82	EW 1	F8	2,585	1	2,82	Lantai 3
4	S 4	1,1	2,35	2,59	EW 1	F2	2,35	1	2,59	Lantai 3
5	S 5	2	14,4	28,80	EW 1	F2	12,54	1	28,80	Lantai 3
6	S 6	1,5	1,2	1,80	EW 1	F9	1,632	1	1,80	Lantai 3
7	S 7	2,1	3,3	6,93	EW 1	F10	6,21	1	6,93	Lantai 3
8	S 8	4,2	6,6	27,72	EW 1	F11	19,8	1	27,72	Lantai 2
9	S 9			-					-	
10	S 10			-					-	

Table 12. The amount of heat transfer in the south (source: author, 2026)

Orientation	Heat Transfer (W)		
	Wall Conduction	Opening Conduction	Radiaton Opening
South	341,50	1.850,13	5.319,92

Table 12. above shows that solar radiation through transparent openings (5,319.92) is the largest contributor to the heat load, while wall conduction contributes the least heat. These figures prove that lightweight brick wall materials are highly effective at blocking outdoor heat; however, the use of clear glass is currently the main cause of high solar heat gain into air-conditioned rooms on the south side.

3.4. Calculation of OTTV for West Orientation

Details about the north elevation are shown in Figure 9 and Table 13. The building construction on this side uses lightweight brick in accordance with the wall specifications in Table 4. For the openings, the glazing system uses 8 mm clear glass with F3 and F5 shading systems and an F4 system without shading (see Table 5).

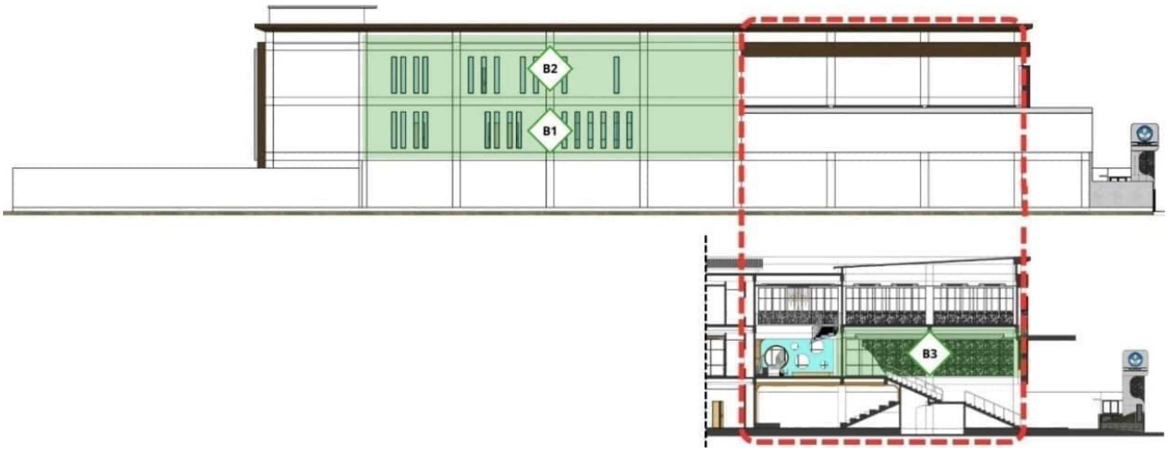

Figure 9. Detail of the west facade (source: author, 2026)

Table 13. Identification of the West Facade
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	FASAD	Tinggi (jarak antar lantai)	Panjang	Area Fasad	Tipe Konstruksi Dinding	Kode Tipe Konstruksi Sistem Fenestrasi	Area Bukaan	Total Jumlah Lantai	Total Area Fasad	LOKASI
				[1]			[2]	[3]	= [1] x [3]	
		(m)	(m)	(m²)			(m²)		(m²)	
1	B 1	4,2	21	88,20	EW 1	F4	15,68	1	88,20	Lantai 2
2	B 2	4,2	21	88,20	EW 1	F3	12,32	1	88,20	Lantai 3
3	B 3	4,2	13,8	57,96	EW 1	F5	39,6	1	57,96	Lantai 2
4	B 4			-					-	
5	B 5			-					-	
6	B 6			-					-	

The specifications for the external shading on this facade include F3 type openings that utilize the roof overhang as external shading (SH2). Meanwhile, F4 type openings do not use any external shading system at all. For F5 type openings, radiation protection is provided using a combination-type shading system (SE1) derived from the ceiling in the library/entrance area on the second floor.

Table 14. The amount of heat transfer in the west (source: Author, 2026)

Orientation	Heat Transfer (W)		
	Wall Conduction	Opening Conduction	Radiaton Opening
West	1.702,09	1.926,60	9.003,29

Table 14. above shows solar radiation through glass openings is once again the largest contributor to the heat load inside the building (9,003.29) while wall conduction contributes the least amount of heat. Although the lightweight brick walls are working hard to retain heat, the use of clear glass in the openings on the west side (which receives direct afternoon sunlight) is the main cause of the high heat levels inside the air-conditioned room.

3.5 Calculation of OTTV for East Orientation

Details about the north elevation are shown in Figure 10. and Table 15. The building construction on this side uses lightweight brick in accordance with the wall specifications in Table 4.

Figure 10. Detail of the east facade (source: author, 2026)

For the openings, the fenestration system uses 8 mm clear glass with F1-type and F12 – 16 type shading systems (see Table 5). The F1 openings use vertical shading from white ACP fins (SV1), and the F12–16 openings employ the same shading system, namely the perforated horizontal shading type (SH8 – SH12).

Table 15. Identification of the east Facade
(source: PUPR OTTV Calculator, reprocessed by the author, 2026)

No	FASAD	Tinggi (jarak antar lantai)	Panjang	Area Fasad	Tipe Konstruksi Dinding	Kode Tipe Konstruksi Sistem Fenestrasi	Area Bukaan	Total Jumlah Lantai	Total Area Fasad	LOKASI
				[1]			[2]	[3]	= [1] x [3]	
		(m)	(m)	(m^2)			(m^2)		(m^2)	
1	T 1	4,2	8,3	34,86	EW 1	F12	24,9	1	34,86	Lantai 2
2	T 2	3,5	1,2	4,20	EW 1	F13	2,556	1	4,20	Lantai 2
3	T 3	1	1,2	1,20	EW 1	F14	1,2	1	1,20	Lantai 2
4	T 4	4,2	16,28	68,38	EW 1	F15	16,8	1	68,38	Lantai 2
5	T 5	4,2	29,11	122,26	EW 1	F1	26,4	1	122,26	Lantai 2
6	T 6	1,14	30	34,20	EW 1	F16	34,2	1	34,20	Lantai 3
7	T 7	1,9	30	57,00	EW 1	F1	57	1	57,00	Lantai 3
8	T 8	2,3	28,5	65,55	EW 1	F1	49,06	1	65,55	
9	T 9			-					-	
10	T 10			-					-	

Table 16. The amount of heat transfer in the east (source: Author, 2026)

Orientation	Heat Transfer (W)		
	Wall Conduction	**Opening Conduction**	**Opening Radiaton**
East	1.791,63	6.045,31	25.151,44

Table 16. above shows solar radiation through glass openings is the largest contributor to the heat load inside the building (25,151.44). This figure indicates that the east-facing facade, which is dominated by clear glass openings (receiving direct morning sunlight), is the primary pathway for heat into the air-conditioned space.

3.6. Results of the Analysis of the Total OTTV Value Calculation

The thermal performance of the Banten Provincial Language Office building was assessed by analyzing the OTTV values for each orientation to determine the specific impact of each facade on overall heat transmission.

Quantitative calculations of the OTTV value under existing conditions were analyzed separately for each facade orientation to measure the specific thermal contribution of each building aspect. The detailed calculation results are presented in full in Table 17.

Table 17. Summary Calculation of the OTTV Value for the Banten Provincial Language Office
(source: author, 2026)

Facade Orientation	Heat Transfer (W) in Building Envelopes			Total (Watt)	Total façade area (m^2)	Total opening area (m^2)	WWR (%)	OTTV (W/m^2)
	Wall Conduction	**Opening Conduction**	**Opening Radiation**					
North	1,030,38	929,39	4.197,63	**6.157,40**	133,56	32,61	**24,42**	**46,10**
South	341,50	1.850,13	5.319,92	**7.511,55**	98,38	64,92	**65,99**	**76,36**
West	1.702,09	1.926,60	9.003,29	**12.631,98**	234,36	67,60	**28,84**	**53,90**
East	1.791,63	6.045,31	25.151,44	**32.988,37**	387,65	212,12	**54,72**	**85,10**
North	**4.865,60**	**10.751,43**	**43.672,28**	**59.289,30**	**853,94**	**377,24**	**44,18**	**69,43**

Based on the calculation of the overall OTTV value for all orientations in Table 17 above, the total OTTV value for the building envelope of the Banten Provincial Language Office is 69.43 W/m². This value is still above the maximum limit of 35 W/m², which means that this building does not yet meet the energy efficiency standards set forth in SNI 6389:2020. This high OTTV value indicates that the building envelope of the Banten Provincial Language Office is not yet capable of effectively preventing heat transfer from outside into the building.

The high value on the east-facing facade is dominated by solar radiation heat, which reaches 25,151.44 W accounting for approximately 76% of the total heat load on that side while the east facade is also the building's longest side, featuring numerous transparent openings and glass windows. An interesting phenomenon is observed when comparing the east side with the south side: although the south side has a much higher window-to-wall ratio (WWR), at 65.99%, its OTTV value (76.36 W/m²) remains lower than that of the east side, which has the highest OTTV value of 85.10 W/m². This indicates that the solar factor (SF) of 123 (see Table 2) is significantly lower on the east side.

Meanwhile, for the west and north orientations, the OTTV values were recorded at 53.90 W/m² and 46.10 W/m², respectively. For the west-facing facade, despite having a relatively low WWR (28.84%), the value still exceeds the SNI standard due to intense afternoon solar radiation exposure with a solar factor (SF) of 224 (see Table 2). Meanwhile, the north-facing facade recorded the best performance, supported by the lowest opening ratio of 24.42%. However, its value still exceeds the 35 W/m² standard.

WWR value of 44.18% indicates that the building envelope is dominated by radiative elements, particularly glass with high SHGC and U-values. This is also consistent with the principle that the higher the window-to-wall ratio, the greater the amount of heat entering the building, and vice versa. Technically, this means that nearly half of the building envelope's surface area consists of transparent elements (glass).

3.7. Modification of Glass Materials in the Façade of the Banten Provincial Language Office Building

The east-facing orientation contributed the highest OTTV value of 85.10 W/m² because it is dominated by glazed openings with high Solar Heat Gain Coefficient (SHGC) and U-values. Modifications to the glazing materials were applied to two orientation alternatives: the east and north orientations. The selection of the north orientation is based on the geographical location of Serang City, which lies south of the equator.

Table 18. Modification of the glass cladding on the Banten Provincial Language Office building (source: Author, 2026)

Orientation	Glass Type	SHGC	U – Value	OTTV Value (W/m²)
East	6mm Stopray (#2) + 12mm AS + 6mm Clear Glass	0,21	0,15	**25,55**
North	6mm Stopray (#2) + 12mm AS + 6mm Clear Glass	0,21	0,15	**17,69**

Based on Table 17. above, modifying the glass material for the east-facing orientation reduces the OTTV by 70%, resulting in an OTTV value of 25.55 W/m², while for the north orientation, it reduces the OTTV by 61%, resulting in an OTTV value of 17.69 W/m².

Table 19. OTTV Values for the Banten Provincial Language Office: Baseline (Existing) Conditions and conditions after modification (source: Author, 2026)

Orientation	Facade Area	OTTV Value (W/m²)	
		Baseline (OTTV Value)	*Double Glass* – Stopray (East + North)
Utara	133,56	**46,10**	**17,69**
Selatan	98,38	**76,36**	**76,36**
Timur	387,65	**85,10**	**25,55**
Barat	234,36	**53,90**	**53,90**
Total	**853,94**	**69,43**	**34,70**

OTTV value modified glass material	OTTV value does not meet standards	OTTV value meets standards

The modification replacing the existing glass with Stopary double-pane glass on the east and north openings resulted in a relatively good total OTTV value of 34.70 W/m², representing a 50.02% reduction from the previous OTTV value (69.43 W/m²).

4. CONCLUSION

Based on the results of the thermal performance analysis of the building envelope of the Banten Provincial Language Office, the Overall Thermal Transfer Value (OTTV) of the existing building envelope was recorded as very high, at 69.43 W/m². This value exceeds the maximum limit set by the national standard SNI 6389:2020 (35 W/m²), so the building is classified as not yet meeting the criteria for an energy-efficient building. The main component contributing the largest external heat load to the building is solar radiation through transparent openings (window glass), This high contribution from solar radiation is due to the high window-to-wall ratio (WWR) (44.18%) as well as the characteristics of the clear glass used (8 mm clear glass), which has low thermal resistance and a high solar heat gain coefficient (SHGC) of 0.81.

This analysis shows that building orientation, materials, the type and properties of the glass, and the effectiveness of shading devices are factors that influence the amount of heat transfer into the building.

Optimization through glass replacement modifications aims to examine differences in the thermal conductivity of building envelope materials (glass). Switching to a glass material with a U-value of 1.50 and an SHGC of 0.22 demonstrates the building envelope's ability to inhibit heat transfer by radiation and conduction through openings. The change in OTTV value from 69.43 W/m² to 34.70 W/m² indicates that selecting a type of glass with low thermal conductivity can reduce the OTTV value while meeting the energy efficiency standards of SNI 6389:2020 for a building.

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Can Vertical Housing Mitigate Urban Sprawl? Insights From Metropolitan Jakarta

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ABSTRACT

The transformation of Jakarta from a colonial administrative center into a modern megacity has pushed residential development outward, drove rapid conversion of green space and compounding urban problems such as traffic congestion and inefficient land use. This study evaluates vertical housing as a strategic response to mitigate urban sprawl and identifies factors influencing public interest in high-rise living across Greater Jakarta. Employing a qualitative grounded theory approach with case studies, data were collected via questionnaires distributed to Generation X, Y, and Z respondents between December 2025 and January 2026, supplemented by literature review and spatial observation using Jakarta Satu and other platforms. Findings indicate a generally positive public disposition toward vertical housing, with 58 percent of respondents expressing interest in apartment living. Primary motivators include accessibility to economic centers, proximity to public transportation, and comprehensive internal facilities, while principal barriers comprise privacy concerns, shortages of open space, and property costs. Preference clusters are concentrated in Jakarta and Greater Tangerang, where infrastructure and accessibility are strongest. The study concludes that realizing the potential of vertical housing to curb urban sprawl depends critically on coordinated action by developers and government to deliver housing that meets the United Nations' seven criteria for adequate housing, addressing both physical amenities and social needs to ensure equitable, sustainable high-density urban living.

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1. INTRODUCTION

Jakarta has undergone massive transformation since independence in 1945. The city initially served as the seat of government and a symbol of nationalism. Since then, Jakarta has rapidly developed into a major center for the economy, business, and government, attracting migrants from across Indonesia and prompting significant territorial expansion [1]. This transformation peaked in 1966 when Jakarta was designated as the "Special Capital Region," equal in status to a province, triggering exponential population growth from 500,000 people in 1930 to 6.5 million in 1980, and continuing to 8.2 million in 1990 within Jakarta itself, with an additional 9 million in the surrounding metropolitan area in the same year [2].

This population growth has continued to the present, roughly 10 million residents at night and reaching 12 million during the daytime. High commuter mobility into Jakarta has turned the capital into a megapolitan area that has developed in an unstructured way [3]. Residents are forced to seek housing on the outskirts. Development has expanded toward Bogor, Depok, Tangerang, and Bekasi. This phenomenon, known as urban sprawl, has caused a substantial increase in built-up areas into Jakarta's peri-urban and rural regions, drastically changing land use [4], [5].

A similar pattern is not unique to Jakarta but is a global phenomenon experienced by major cities such as Singapore, Tokyo, Hong Kong, and Seoul, where land constraints and population growth have driven vertical housing solutions as a mitigation strategy [6]. This approach is used because high demand for housing and limited land availability forces these cities to adopt vertical development to accommodate their growing populations [6].

This study aims to examine the potential of vertical housing in relation to the spread of development (sprawl) into the suburban areas of the *Jabodetabekjur* metropolitan region, which is currently dominated by suburban residential development.

1.1 Urban Sprawl as Significant Challenge in Large Cities

Urban sprawl is an urban phenomenon commonly associated with the uncontrolled and unplanned spread of urban areas. There is no single, universally accepted definition of urban sprawl, and relatively little effort has been made to define urban sprawl in ways that help compare regions with higher or lower levels of sprawl [7].

Land affected by urban sprawl is usually defined as land that has lost its rural character but cannot be classified as urban land, creating a certain ambiguity that leads to problems such as unplanned urban growth and land use for non-agricultural purposes. Therefore, urban sprawl can be defined as the border area between rural and urban zones [8].

Irregular city development appears in scattered and diverse settlements and an uneven population distribution. Besides affecting the environment and communities in urban and rural areas, irregular urban growth also places a significant burden on government [9]. This phenomenon can create various social and economic issues, such as economic injustice and imbalances in local administration and public finances across communities. It also affects personal life. Several studies report that urban spread reduces open space and public facilities, raises the cost of public services and taxes, causes traffic congestion, leads to urban flooding, increases the area of natural habitats, and lowers water quality [10].

There are several main **characteristics of urban sprawl** identified by Kumar Sinha [11]. He states that urban sprawl is a form of urban development generally characterized by haphazard, uncontrolled, unplanned, or poorly planned expansion.

- Low Density Development
- Excessive Consumption of Land
- Automobile Dependence
- Haphazard and Uncoordinated Development
- Aesthetics
- Separation of Land-use
- Social Segregation

The causes of urbanization are very similar to the reasons behind urban sprawl. In many situations, these similarities are difficult to separate because urban growth and spread are closely related. However, it is important to note that urbanization can occur without urban sprawl, whereas sprawl will inevitably trigger growth in urban areas. Some factors, such as population increase, can produce organized, compact urban growth or irregular, dispersed growth [12]. That growth is considered positive or negative depending on its pattern, mechanisms, and consequences.

The phenomenon of urban sprawl is a significant challenge in many large cities of developing countries. A large share of the population is forced to live in informal settlements, both in city centers and on the urban fringe, which are characterized by poverty and environmental degradation. These high-density areas suffer heavy pollution due to inadequate basic infrastructure such as clean water, sanitation systems, waste management, and road accessibility [12].

Accelerated urban growth drives massive land conversion that increases traffic congestion, exploits local resources, and reduces green open space. This expansion fundamentally alters the spatial structure and physical organization of cities. Even in developed countries, poorly integrated development patterns threaten environmental sustainability, public health, and living standards [12]. The systemic impacts of such urban expansion have become a global issue requiring serious attention in spatial planning.

1.2 The Discourse of Vertical and Adequate Housing

Population growth in large cities has caused a surge in housing needs and demand that is disproportionate to the availability of housing and urban land. This has prompted many developers in major cities to build vertically to meet the demand. Vertical housing, or high-rise residential buildings, stacks a large number of dwelling units on a limited land footprint, thereby increasing population density without expanding horizontally — a solution to uncontrolled urban sprawl that causes unplanned city dispersion [13], [14].

International human rights law recognizes every individual's right to an adequate standard of living, including access to adequate housing. The UN committee monitoring Economic, Social and Cultural Rights emphasizes that the right to adequate housing must not be understood narrowly. Instead, it should be seen as the right to live in security, peace and dignity [15].

Elements related to the right to adequate housing are elaborated in the Committee's General Comment No. 4 (1991) on the right to adequate housing and No. 7 (1997) on forced evictions. Good housing should be more than a structure with a roof and walls. Several criteria must be met for certain dwellings to be regarded as "adequate housing". For a dwelling to be considered adequate, it must at minimum satisfy the following requirements:

1) **Tenure security:** housing cannot be considered adequate if its occupants do not have secure tenure that protects them from forced eviction, intimidation, and other threats.
2) **Availability of services, materials, facilities, and infrastructure:** housing is not adequate if residents do not have access to clean water, proper sanitation, energy for cooking, heating, lighting, food storage, or waste disposal.
3) **Affordability:** living in a home cannot be considered adequate if its cost threatens or compromises the enjoyment of human rights by those who live in it.
4) **Habitability:** housing is inadequate if it does not ensure physical safety, provide sufficient space, and offer protection from cold, dampness, heat, rain, wind, other health threats, and structural hazards.
5) **Accessibility:** housing cannot be considered adequate if the needs of marginalized groups are not taken into account.
6) **Location:** housing is also inadequate if it is separated from employment opportunities, health services, schools, childcare centers, and other social facilities, or if it is located in dangerous or polluted areas.
7) **Cultural adequacy:** a dwelling is not considered adequate if it does not respect and take into account the cultural identity and cultural expression of its occupants.

2. METHOD

In conducting the research, For the study on the Paradigm of Vertical Housing in the Context of Urban Sprawling in *Jabodetabekjur*, a qualitative method with a Grounded Theory approach was chosen as an exploratory option to develop theory based on data collected systematically. According to John W. Creswell, qualitative research is an approach to understanding human and social phenomena through in-depth exploration of experiences and meanings [16].

The Grounded Theory approach is a research methodology that derives generalizations from participants' observations about one or more phenomena, focusing on exploration of the data to identify patterns and key concepts [17]. In the context of this study, Grounded Theory will be used to construct theory from events, procedures, and relationships among respondents related to vertical housing amid urban sprawl in the *Jabodetabekjur* agglomeration.

The research will focus on the ***Jabodetabekjur* Metropolitan** area as the study object. The scope includes Bogor, Depok, Tangerang, Bekasi, and Cianjur—Jakarta's surrounding buffer regions—where urban sprawl and the growth of vertical housing are especially significant. The observation period for this study lasted four months, from October 2024 to January 2025, during which the distribution of urban sprawl was analyzed for the years 2000–2022 and the current state of vertical housing in the *Jabodetabekjur* area. The author distributed questionnaires from 11 December 2025 to 7 January 2026 among the communities around *Jabodetabekjur*.

The questionnaire items referred to the UN Habitat housing adequacy standards. The researcher also explored respondents' interest, suggested locations, and essential aspects of vertical housing.

2.1 Data Collection Method

A total of 72 respondents participated, with varied geographic and demographic distribution. Respondents from Tangerang Raya made up 27% of the sample. Jakarta contributed 25% of respondents. Depok accounted for 18% and Bogor 15%. Bekasi recorded 6% and Cianjur 1%. Respondents from outside the *Jabodetabekjur* area numbered 8%. The data show a dominance of Gen Z at 74%, while Gen Y represented 26% of respondents. The study obtained no respondents from the Gen X category, which is suspected to reflect limited interest in vertical housing among that generation.

Table 1. List of questions used in the questionnaire (source: author, 2026)

SECTIONS	QUESTIONS
RESPONDENT PROFILE	Name
	Year of Birth
	City of Origin
REFLECTION ON CURRENT HOUSING	Tenure security
	Availability of services, materials, facilities, and infrastructure
	Affordability
	Habitability
	Inclusiveness
	Accessibilty
	Location
	Cultural adequacy
PERCEPTIONS OF VERTICAL HOUSING	Interest in Vertical Housing and Reasons
	Suitability of the Location and Reasons
	Key Considerations in Vertical Housing

The questionnaire also included instruments capturing respondent biodata, namely name, year of birth, and city of origin. Next were questions about respondents' current housing adequacy based on the seven adequate housing points agreed by the UN. These questions served as a reflection of respondents' current housing before they gave opinions on vertical housing.

Part 3 served as the main instrument of the questionnaire. It contained three questions about respondents' interest in vertical housing and their reasons, respondents' recommended locations for vertical housing and their reasons, and, finally, respondents' views on whether vertical housing would be suitable for them.

Secondary data were obtained indirectly through a literature study sourced from academic journals, previous research reports, and relevant official government documents.

2.2 Data Analysis Method

The data analysis method is the process of organizing, categorizing, and interpreting data to find patterns, themes, and significant relationships in order to answer the research questions [18]. In this study, two types of data were obtained: image data from satellite imagery and land cover maps of the *Jabodetabekjur* area, and textual data from the questionnaires. These data will then be analyzed qualitatively to identify the main categories and the relationships between categories that emerge from residents' perceptions and the dynamics of urban sprawl.

Table 2. Open coding table used (source: author, 2026)

NO	RESPONDENT ID	QUESTIONS	SEGMENT	CODE	CATEGORY	THEME
1	1	Answer	1	...	...	...
2			2	...	...	...
3	2	Answer	1	...	...	...
...	...	...	...	...	...	...

This approach iteratively involves open coding to identify key concepts from the data, followed by axial coding to connect those concepts into broader categories, and concludes with selective coding to develop a core theory that explains the studied phenomenon [19].

3. RESULTS AND DISCUSSION

On April 25, 2024, Law Number 2 of 2024 concerning the Special Capital Region Province of Jakarta was approved, stipulating an expansion of the agglomeration area. This regulation changes the nomenclature from Jabodetabek to *Jabodetabekjur*. The acronym, which initially comprised Jakarta, Bogor, Depok, Tangerang, and Bekasi, officially now includes Cianjur Regency within the scope of that strategic coordination.

Indonesia started pioneering vertical housing projects in the 1970s. However, only in the 1990s did this housing type begin to be built on a large scale, with a focus on luxury apartments targeted at financially well-off groups. Vertical housing for low-income residents in Indonesia began to be piloted in the mid-1990s in several locations in Jakarta, in the form of multi-storey apartment housing [20].

This housing development was driven by a population surge from the 1970s through 2000 in Jakarta. BPS data show Jakarta's population in 1971 was 4,579,303. By 2000—just three decades later—Jakarta's population had reached 9,588,194. This drastic increase directly correlates with the limited land available in Jakarta because of irregular, horizontal expansion. Built-up area in Jakarta covers about 85.29% of its total land, leaving only a small portion as green or undeveloped land [21]. Specifically, the built urban area increased from 483 km² in 2000 to 574 km² of the total 661 km² of Jakarta in 2020, representing a 19% increase, with remaining green open space less than 9% of Jakarta's total area (Sarker et al., 2024).

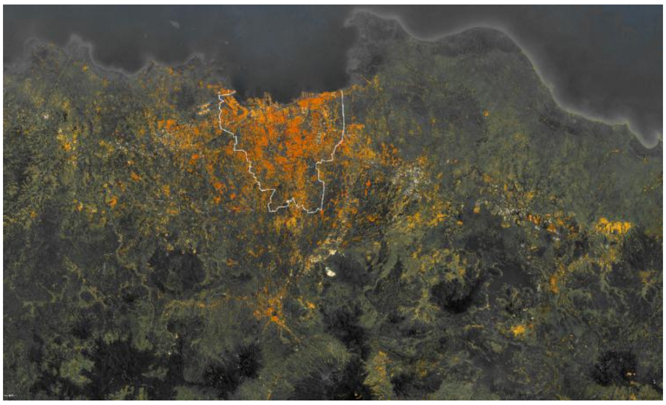

Figure 1. Satellite image of Jakarta in 2000 (source: Google Earth, 2026)

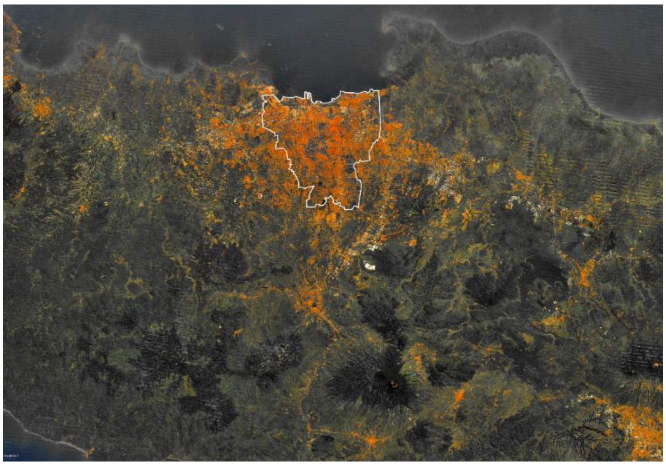

Figure 2. Satellite image of Jakarta in 2010 (source: Google Earth, 2026)

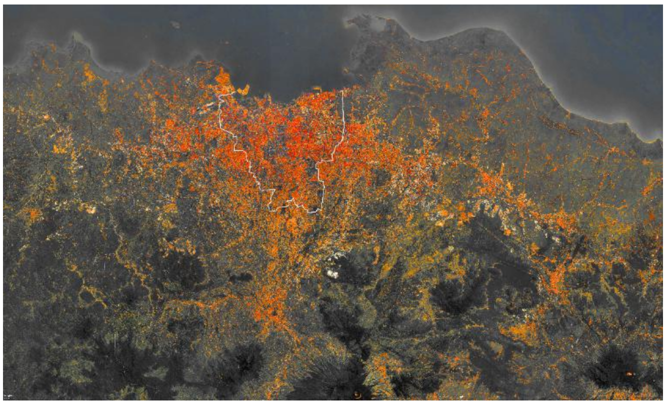

Figure 3. Satellite image of Jakarta in 2020 (source Google Earth, 2020)

This situation caused population growth trends to shift toward neighboring cities such as Bogor, Depok, Tangerang, and Bekasi. The population shift can be seen in BPS data: Jakarta's growth rate was 0.31 in 2024, compared with Bogor (1.23), Bogor City (0.89), Depok City (1.37), Tangerang (0.79), South Tangerang (1.05), Bekasi (1.35) and Bekasi City (1.04) in the same year.

This comparison indicates an urban sprawl phenomenon in the *Jabodetabekjur* Metropolitan area, where population growth in the agglomeration cities is higher than in Jakarta.

Spatially, the distribution of vertical housing in *Jabodetabekjur* shows concentric and corridor patterns. Jakarta remains the highest concentration center, especially Central, South, and West Jakarta, which are close to economic, service, and government activity centers. The density of vertical housing in these areas correlates strongly with high land values and the availability of relatively mature urban infrastructure.

Outside Jakarta, *Bodetabek* areas—such as Bekasi, Tangerang, and Depok—have experienced rapid vertical housing growth, especially along major transport corridors like toll roads, commuter train lines, and transit-oriented development (TOD) zones. Vertical housing in these areas functions as a buffer for Jakarta, accommodating housing needs for people who work in the city center but seek more affordable living options.

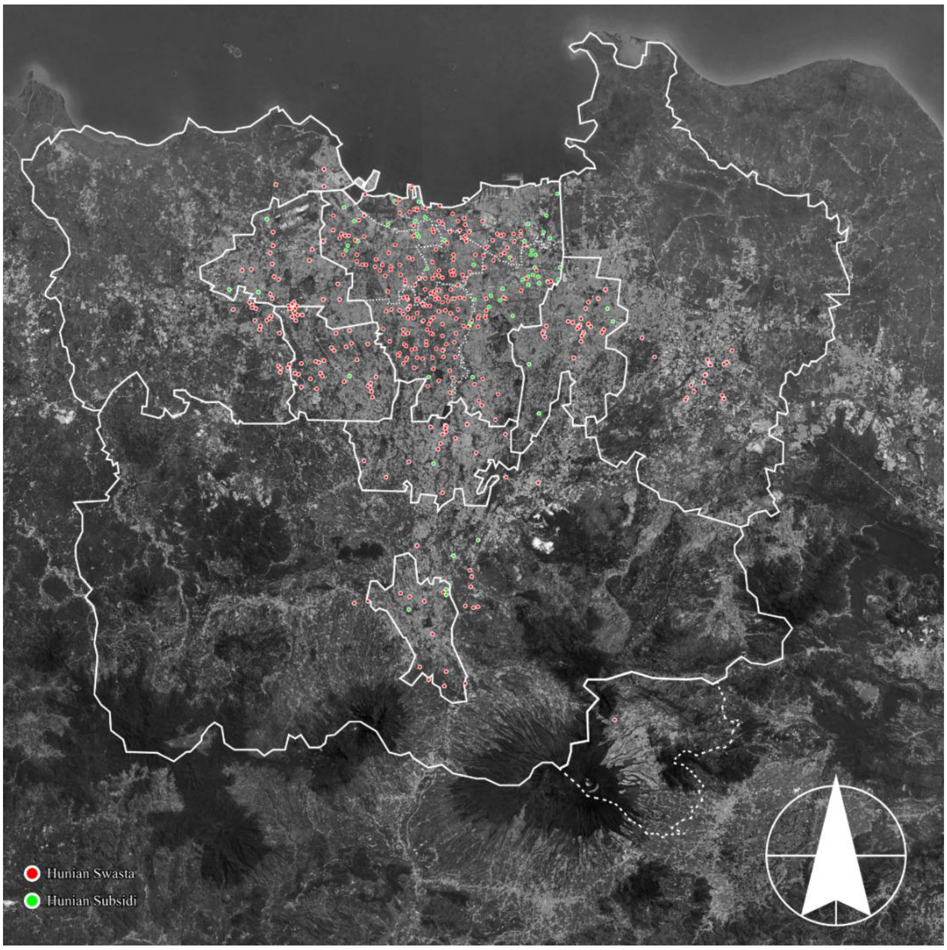

Figure 4. Distribution points of vertical housing in Jabodetabekjur (source: author, 2026)

Meanwhile, Cianjur, as the outermost part of *Jabodetabekjur*, still shows relatively low intensity of vertical housing. This distribution indicates that proximity to activity centers and connectivity to regional transport networks are primary factors determining the location and intensity of vertical housing development.

Table 3. The number of vertical housings in each city (source: author, 2026)

TYPE	JAKARTA	BOGOR	DEPOK	TANGERANG	BEKASI	CIANJUR
Private	217	21	16	73	40	1
Subsidy	44	5	1	4	4	-
TOTAL	261	26	17	77	44	1

3.1 Reflection of Housing Suitability Based on Respondents' Perceptions

As noted by the UN committee overseeing Economic, Social and Cultural Rights, there are seven main indicators of adequate housing: security of tenure, availability of services, affordability, physical adequacy, accessibility, location, and cultural appropriateness. In the questionnaire that was distributed, these indicators were used to capture respondents' reflections on their current housing. Based on the collected data, the resulting evaluation will provide a comprehensive picture of perceptions regarding the adequacy standards of their housing.

Table 4. Likert table of respondents' housing adequacy (source: author, 2026)

CATEGORY	AVERAGE PERCENTATION (%)	CRITERIA
Tenure security	80,69%	Baik
Availability of services, materials, facilities, and infrastructure	81,39%	Sangat Baik
Affordability	77,64%	Baik
Habitability	77,50%	Baik
Inclusiveness	68,33%	Baik
Accessibilty	77,36%	Baik
Location	76,11%	Baik

On the first indicator, security of tenure, respondents tended to feel reasonably secure in their homes, but some still reported problems with housing security. A similar pattern appeared for the availability of basic services: most respondents felt that public and social facilities around their homes were adequate, but a portion still felt their needs were unmet.

The affordability indicator shows that although rent or mortgage payments were perceived as fairly affordable by the majority, a substantial share of respondents still felt they were not fully affordable. Likewise, for physical adequacy, responses clustered around a score of eight, indicating that the physical condition of housing was generally considered adequate, but some aspects still require improvement.

The same pattern appears for the location and cultural appropriateness indicators: most respondents felt their housing locations were strategic and aligned with their social and cultural needs, yet a small portion still perceived mismatch.

Unlike the other indicators, inclusivity showed a diversification of perceptions: some respondents stated that their residential environment is welcoming to different groups, while others felt there remain challenges in accommodating the needs of diverse residents.

3.2 Interest in Living in Vertical Housing

Overall, respondents' interest in vertical housing is generally positive. Survey results show 58 percent of respondents are interested in living in vertical housing, with another 13 percent expressing conditional or mild interest. Meanwhile, 25 percent said they were not interested, and the remainder did not respond.

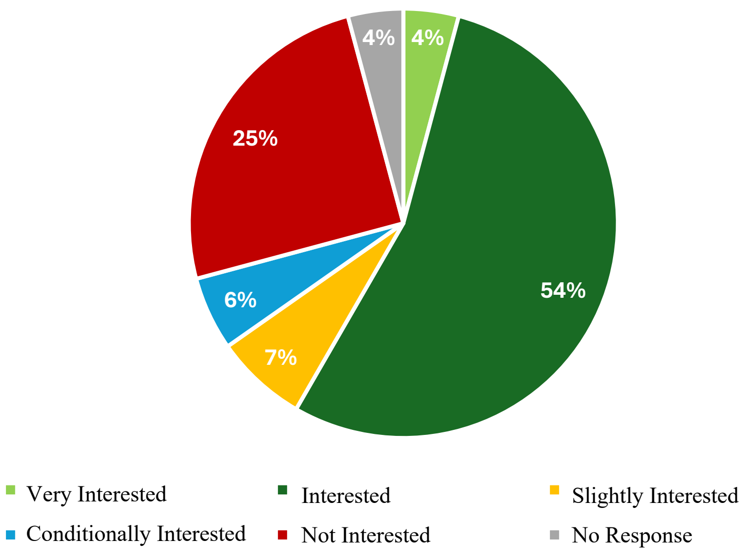

Figure 5. Pie chart of respondents' interest in vertical housing (source: author, 2026)

According to the survey data, interest in living in vertical housing does not appear to be strongly influenced by generational group. Instead, preference for vertical housing is more affected by factors such as accessibility, proximity to activity centers, privacy, and private open space. For example, only 3 of 19

Generation Y respondents expressed disinterest in vertical housing, whereas 15 respondents in Generation X were not interested.

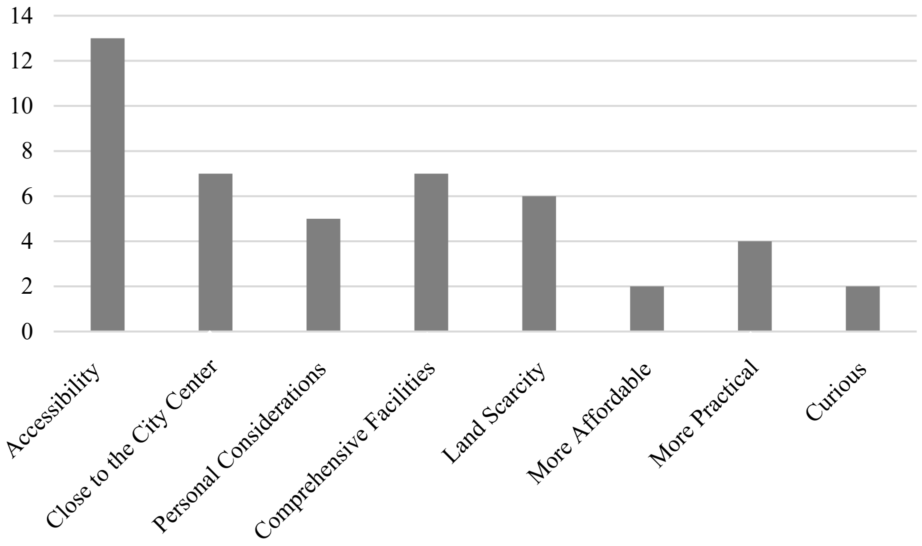

Figure 6. Reasons for interest in vertical housing (source: author, 2026)

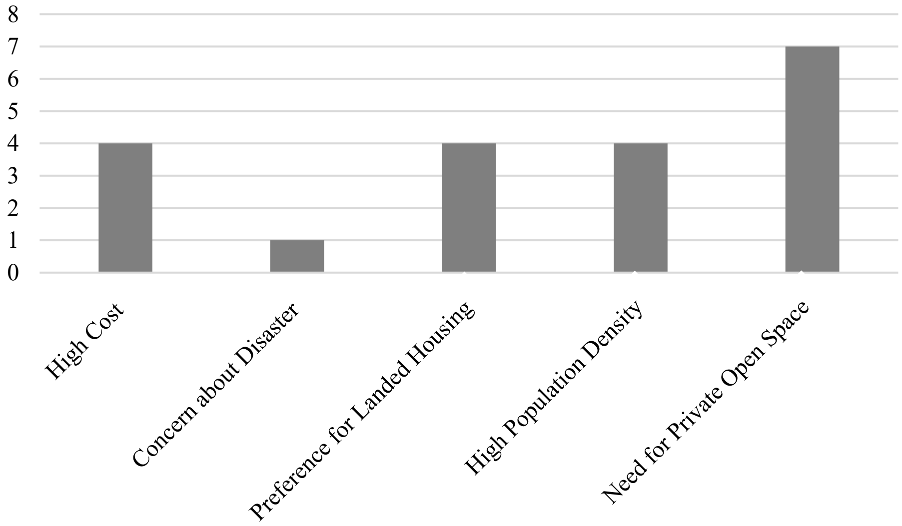

Figure 7. Reasons for not being interested in vertical housing (source: author, 2026)

This confirms that preferences for vertical housing are more complex than simple generational demographics and are influenced by pragmatic considerations like proximity to workplaces and public facilities, as well as the quality of the residential environment. These findings are also consistent with respondents' current housing experiences, particularly their perceptions of accessibility, privacy and security, availability of services, and inclusivity.

3.3 Preference for vertical Residential Locations According to Respondents

Respondents' location preferences for vertical housing show a strong tendency toward city-center areas close to public facilities, public transportation, and centers of socio-economic activity. This tendency is reflected in the survey results, which show that most respondents chose Jakarta as their preferred location for vertical living. The preference supports the idea that millennials and Gen Z want to live in downtown or metropolitan areas that offer easy access to workplaces and a range of urban amenities, although there is also a tendency among some to move to suburban areas.

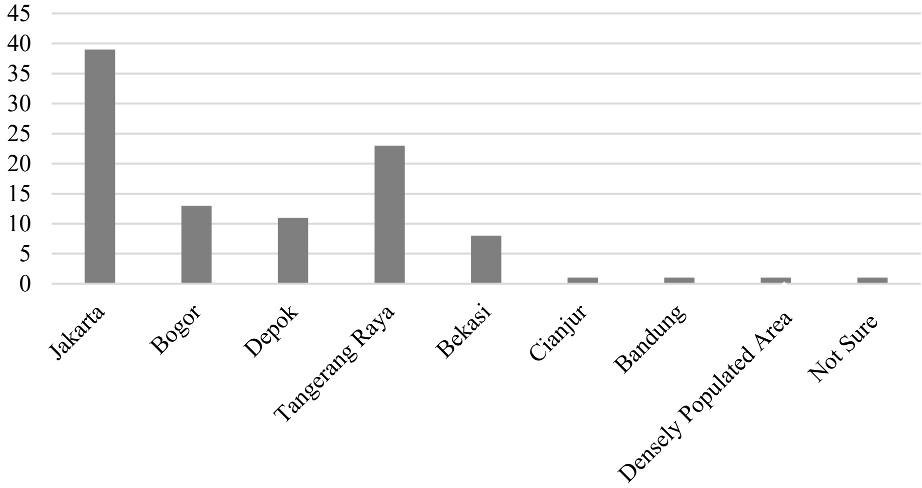

Figure 8. Respondents' location preferences for vertical housing (source: author, 2026)

Population density and limited land are also reasons behind respondents' location preferences for vertical housing, since vertical housing is often an efficient solution to land scarcity in densely populated urban areas.

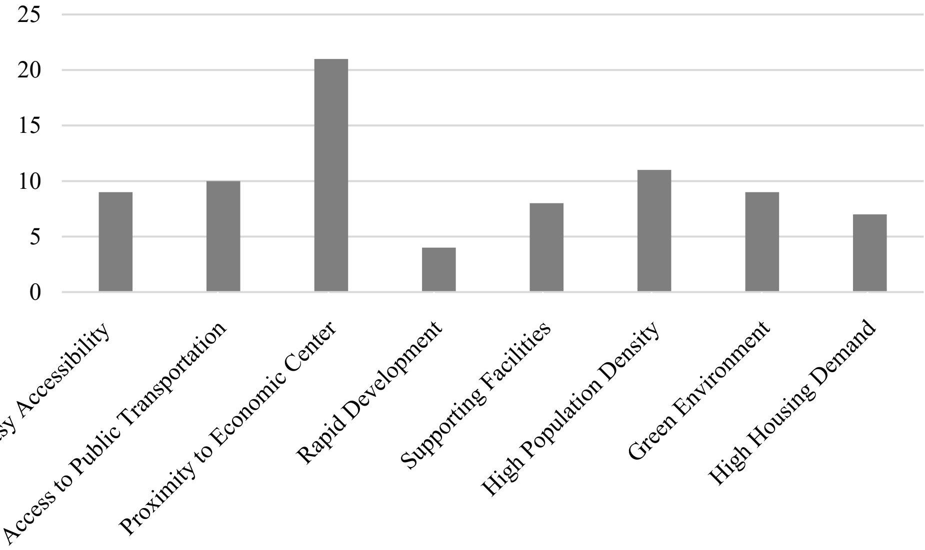

Figure 9. Reasons for location preference for vertical housing (source: author, 2026)

Furthermore, location preferences reflect the spatial distribution of vertical housing in the *Jabodetabekjur* area, which shows high concentrations in Jakarta and the greater Tangerang area. This indicates that the availability of infrastructure and ease of accessibility are the main drivers of vertical housing preferences in these two regions, in line with the economic prospects and quality of life they offer.

3.4 Factors that Influence Interest in living in Vertical Housing

The survey data show that accessibility is the single most important determinant of interest in living in vertical housing. This aligns with respondents stated reasons and location preferences: ease of access to economic centers and public facilities is the main consideration when deciding whether to live in vertical housing. Accessibility aspects include ease of reaching transport systems, proximity to major roads and tollways, and access to stations or other public transit.

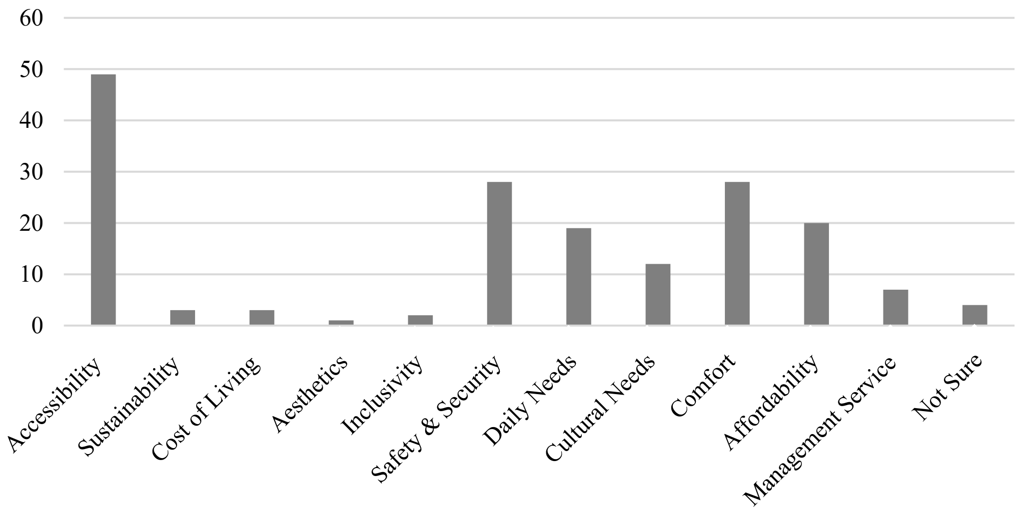

Figure 10. Key aspects in determining vertical housing (source: author, 2026)

Other important factors respondents identified for adequate vertical housing include security and comfort, which are the second most important considerations after accessibility. Housing security and comfort cover aspects such as privacy protection, tenure rights, safety from natural hazards, and the quality of the environment both inside and outside the dwelling. In addition, affordability and everyday cost of living are important considerations, since strategic locations close to city centers and public facilities often correlate with higher property values—highlighting the need to balance accessibility with affordability.

3.5 Synthesis of Analytical Findings

Based on the analysis, this study used spatial distribution and characteristics of vertical housing in the *Jabodetabekjur* area, together with patterns of sprawl identified via spatial analysis on the Jakarta Satu portal, Rukamen, and Google open data. Survey questionnaire data on public perceptions of the adequacy of vertical housing were also used to understand location preferences and factors influencing the desire to live in such housing.

When integrated, the findings indicate that sprawl in *Jabodetabekjur* occurs as a response to limited land and high property prices in city centers, which push people to seek landed housing in peripheral areas in hopes of getting more space at lower cost. Individually, many people also perceive vertical housing as offering limited privacy, higher density, and relatively high costs, which encourages a preference for suburban landed housing.

These findings align with key drivers of urban sprawl: demand for larger living spaces and more affordable housing in suburban areas. This continuity suggests that structural urban factors and individual preferences interact to shape settlement patterns across *Jabodetabekjur*.

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However, this phenomenon contradicts the high interest in living in vertical housing. That interest is driven by a desire for good accessibility to urban amenities and economic activity centers, and it corresponds to elements of adequate housing as defined by the UN.

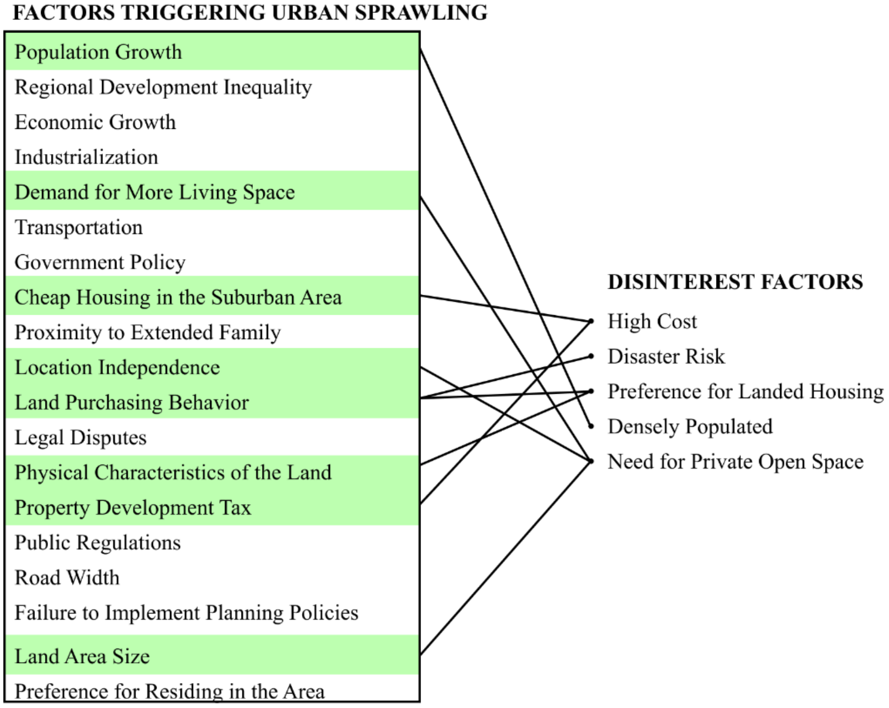

Figure 11. Data correspondence with urban sprawling (source: author, 2026)

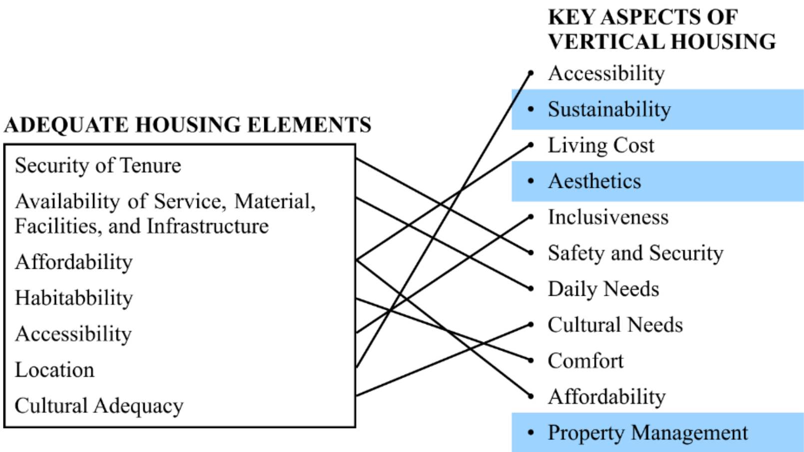

Figure 12. Data correspondence with elements of adequate housing (source: author, 2026)

The contradiction between sprawl drivers and interest in vertical living highlights a gap between an ideal preference for central accessibility and the economic reality that forces compromises toward affordable housing in the suburbs. This creates a complex dilemma for urban residents choosing an optimal place to live—balancing proximity and accessibility against financial capacity.

Therefore, the need for affordable housing in city centers becomes a crucial challenge that local governments must address to mitigate urban sprawl. Local authorities should design incentive policies and zoning regulations that encourage development of affordable vertical housing in transit-integrated areas. Still, housing planning cannot consider only the adequacy criteria agreed by the UN; public preferences for other factors—such as aesthetics, investment value, and neighborhood safety—must also be taken into account.

4. CONCLUSION

The development of urban sprawl in the peri-urban areas of *Jabodetabekjur* has created several challenges, including environmental degradation, increased traffic congestion, and high commuting costs. These issues affect people's quality of life and have the potential to create socio-economic disparities between urban cores and their peripheries.

This urban sprawl phenomenon is not unique to *Jabodetabekjur* but is a global issue faced by many metropolitan areas in developing countries. Rapid population growth and uncontrolled urbanization are the triggers. Vertical housing development has been proposed as a solution to mitigate the impacts of urban sprawl and to meet the rising housing demand in urban areas.

Within *Jabodetabekjur* itself, the implementation and distribution of vertical housing are still uneven. Spatial distribution data obtained from analysis on the Jakarta Satu portal and Rukamen show that vertical housing remains concentrated in Jakarta city. However, the spread of vertical housing in supporting areas such as Depok, Tangerang, and Bekasi shows a significant upward trend. In practice, vertical housing development in these areas still tends to focus on upper-middle segments in the form of privately managed apartment units.

Nevertheless, survey data on public perceptions of the suitability of vertical housing—collected through questionnaires to understand location preferences and factors influencing interest in living in such housing—show positive responses. More than 50 percent of respondents expressed interest in living in vertical housing, especially if it is integrated with public transport and adequate public facilities, and offers competitive prices compared with detached housing.

These findings indicate that vertical housing has strategic potential to be a solution for addressing sprawl and limited urban land. With proper planning and supportive policies, vertical housing can be an effective instrument to optimize the use of limited land in metropolitan areas.

In the analysis of preferences for vertical housing, most respondents preferred housing in strategic locations, followed by other factors that correspond to elements of adequate housing as defined by the UN. However, these preferences represent respondents' ideal standards, which contradict the availability of affordably priced housing. Economic reality often forces people to compromise by choosing housing in less strategic locations.

This condition underscores the need for policy interventions that can bridge the gap between preferences for strategic locations and people's financial capabilities by providing affordable vertical housing in strategic areas. Synergy between government and the private sector is required to promote the development of affordable vertical housing integrated with supporting facilities such as public transport systems and economic activity centers. In addition, respondents also showed preferences for housing aesthetics, sustainability, and good investment value.

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Grown, Not Mined:
Hybrid Bamboo Construction as a Low-Carbon Alternative to Concrete and Steel in a Tropical Restaurant

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ABSTRACT

The construction sector is a major source of global carbon emissions, driven largely by cement, whose manufacture accounts for roughly 7–8% of worldwide CO_2. Heavy reliance on energy-intensive, non-renewable concrete and steel intensifies this burden, prompting a search for renewable structural alternatives such as bamboo: fast-growing, renewable, and an active carbon sink. This study evaluates how bamboo performs as an alternative structural material in an in-service commercial building, and how its known limitations are managed. Using a qualitative single-case design at Kampung Kecil Cinere Restaurant, Depok, data were gathered through field observation of 38 dining units (saung), visual documentation of structural details, a management interview, and a literature-based comparison with concrete and steel. The building relies on two local species used by function: black bamboo (Gigantochloa atroviolacea, "Wulung") as load-bearing columns, and rope bamboo (Gigantochloa apus, "Apus") for curved members, joined by traditional ijuk and rattan lashings. Durability, bamboo's main weakness in a hot-humid climate, is managed through a hybrid strategy: ceramic clad concrete plinths isolate columns from moisture, and a metal roof replaced the original thatch while a woven bamboo ceiling preserves the interior. The study's contribution is to reframe bamboo's feasibility as a matter of configuration: species selection, hybrid detailing, and moisture management; rather than of the raw material, offering transferable guidance for low carbon tropical commercial architecture; it did not include load testing or quantitative life cycle carbon assessment.

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1. INTRODUCTION

The intensification of human activity since the mid-twentieth century has accelerated the accumulation of atmospheric greenhouse gases and, with it, global warming [1]. The built environment is deeply implicated in this trend. Conventional structural materials, principally concrete and steel, are non-renewable resources whose extraction, processing, and assembly are highly energy intensive, so that their continued, large scale use both depletes finite mineral reserves and adds substantially to carbon emissions [2], [3]. Cement, the binder in concrete, is the single most consequential case: its manufacture accounts for roughly 7–8% of global CO_2 emissions, on the order of three times the emissions of the entire commercial aviation industry, because heating limestone clinker releases CO_2 chemically as well as through fuel combustion [4]. With the Global Cement and Concrete Association reporting on the order of fourteen billion cubic metres of concrete cast each year, the scale of this dependence is itself the problem [4].

This pressure has pushed architects toward renewable, lower-impact materials, and bamboo recurs as a leading candidate [5], [6]. Several properties explain its appeal. Bamboo matures in three to five years rather than the decades required by timber, allowing repeated harvest from the same clump and making it genuinely renewable even at volume [7], [8]. As a living stand it is an effective carbon sink, on the order of twelve tonnes of CO_2 sequestered per hectare per year during growth [9], and its extensive root system stabilises soil and conserves water, making it valuable for reforestation and land rehabilitation [10]. Mechanically, bamboo combines a high strength-to-weight ratio with flexibility, and life-cycle studies generally credit it with a markedly lower Global Warming Potential than steel or concrete [11], [12]. Yet wider adoption in modern construction still depends on resolving practical pre-conditions: material standardisation, reliable connection systems, durability treatment, and clear regulation [7].

It is precisely on these practical pre-conditions that the gap in knowledge lies. Much of the Indonesian literature establishes bamboo's ecological promise and its laboratory mechanical properties, but comparatively little examines how an actual, occupied commercial building resolves the material's well-known weaknesses, its susceptibility to moisture, fungi, and powder-post beetles, and the difficulty of detailing joints in a member that is strong in tension but weak in shear [13], [14]. This is the problem the study addresses: whether, and how, bamboo can serve as a durable primary structure in an occupied tropical commercial building rather than in laboratory or rural conditions alone. A working restaurant that has used bamboo as its primary structure for several years offers a rare opportunity to read these resolutions directly: which species are chosen for which task, how joints are made, how the structure is kept dry, and what has had to change over time.

This study takes that opportunity through a single case, the Kampung Kecil Cinere Restaurant, a semi-open, naturally themed eating place in a dense peri-urban buffer zone immediately south of Jakarta. The research is guided by two questions: (1) How does bamboo function as an alternative to conventional materials in the structure of this building, and through what configuration of species, jointing, and moisture management is it made durable? (2) What are the comparative advantages and limitations of bamboo relative to concrete and steel for this building type, as evidenced by the case and the literature? The objective is to produce an evidence-based account of in-service bamboo construction: its technical strengths, its environmental rationale, and the adaptive strategies that close the gap between bamboo's promise and its practical durability; and from it to derive transferable design guidance for low-carbon commercial architecture in the humid tropics. The contribution is twofold: empirically, the study links species-by-function selection and hybrid detailing to observed in-service performance in a building rarely documented in this depth; conceptually, it reframes bamboo's feasibility as a property of *configuration* (material, detail, and microclimate together) rather than of the raw material alone.

1.1. Literature Review

1.1.1. Sustainable Architecture and the Carbon Logic of Material Choice

Sustainable architecture is the design approach that seeks to minimise a building's negative environmental impact through moderation and efficiency in the use of material, energy, and space, without lowering occupants' quality of life [15]. In the face of escalating climate pressure, the construction sector is expected to shift from energy-profligate conventional practice toward more ecologically responsible methods, integrating passive design (daylight optimisation, cross-ventilation) with materially responsible specification [1], [7]. Two analytical lenses discipline this ambition. Life Cycle Assessment (LCA) evaluates environmental impact across all stages of a material's life, from raw-material extraction to end-of-life; under LCA, bio-based materials such as bamboo can reduce greenhouse-gas emissions substantially because of the carbon captured during growth, yielding a lower carbon footprint than cement and concrete [12]. The complementary lens, the strength-of-materials tradition, ensures that ecological gains are not bought at the cost of safety: parameters such as bending, tensile, and compressive strength confirm whether an alternative material can in fact carry the loads imposed on columns and beams [14]. This study is positioned at the intersection of the two, treating bamboo at Kampung Kecil Cinere not as a nostalgic aesthetic choice but as an environmentally measurable and technically testable proposition.

1.1.2. Green Materials and Embodied Carbon

A green material is one whose procurement, use, and disposal carry a low ecological footprint and pose no health hazard, the aim being to reduce the *embodied energy* locked into a material by intensive extraction and manufacture [15]. Embodied (as opposed to operational) carbon is the share of a building's emissions attributable to its materials; because cement and steel are produced at high temperature, they carry high embodied carbon, and substituting bio-based materials such as bamboo is an effective mitigation strategy that can sharply lower emissions per square metre relative to brick or concrete walls [11], [4]. Bamboo qualifies as one of the most promising green materials in Indonesia by virtue of its renewability and abundance, and being a poor heat store, it tends to produce a cooler indoor microclimate than concrete or metal [6], [7].

1.1.3. Bamboo: Botany, Morphology, and Mechanical Behaviour

Bamboo is a woody member of the grass family (Poaceae, subfamily Bambusoideae), distinguished by a hollow, segmented culm and exceptionally fast growth [16], [17]. Worldwide there are more than 1,640 species across roughly 100 genera; Indonesia hosts an estimated 176 species, about 12% of the global total, of which only a handful are economically significant for construction [18], [19]. Morphologically, the culm is a cylinder partitioned by a diaphragm at each node, which stiffens it against buckling; fibres run parallel to the axis and are denser toward the outer skin, giving the surface hardness and the member as a whole an efficient strength-to-weight ratio and good flexibility under dynamic load [14], [15].

Mechanically, bamboo is best harvested at biological maturity (about 3–5 years), when fibre strength peaks [20]. It is exceptionally strong in tension, often called “natural steel,” with some specimens exceeding the yield stress of medium-grade steel, and certain species (notably Petung) show high compressive strength parallel to the grain, qualifying them as primary structural elements [21], [22]. Its critical weakness is low shear strength, which makes the design of connections the decisive factor in structural safety [14]. Ecologically, bamboo releases up to 35% more oxygen than comparable trees and, as noted, sequesters carbon vigorously while growing [7]. Its principal vulnerability in service is biological: a high starch content invites powder-post beetles and fungi, so that untreated bamboo may last only 2–5 years, making preservation a precondition for durability [13], [22].

Among Indonesian construction species, six recur in the literature; Table 1 summarises those most relevant to this case.

Table 1. Indonesian bamboo species commonly used in construction (source: compiled by the authors from Kusuma Bhudi & Studi Arsitektur (2024) and species references cited therein)

Species (local name)	Height/Diameter	Distinguishing Features	Typical Structure Use
Wulung — *Gigantochloa atroviolacea*	≈15 m / 6–8 cm	Deep black culm; strong visual character	Roof frames; exposed columns where aesthetics matter
Legi — *Gigantochloa atter*	≈16 m / 6–8 cm	Similar dimensions to Wulung	Structural frames, wall frames, fencing
Petung — *Dendrocalamus asper*	≈20 m / 20–25 cm	Massive section; green culm with lichen flecks	Heavy structure: bridges, houses, primary columns
Ampel — *Bambusa vulgaris*	≈20 m / ≤10 cm	Yellow/ivory sub-species used ornamentally	Posts and uprights; urban ornamental planting
Gombong — *Gigantochloa pseudoarundinacea*	≤15 m / 2–10 cm	Green culm with yellow striping	General framing
Apus — *Gigantochloa apus*	≈22 m / 4–15 cm	Straight green culm; flexible	Bent/curved members; lashings and ties

1.1.4. Conventional Materials: Concrete and Steel

Conventional materials are those long established by industry convention: cement, sand, brick, and, pre-eminently, concrete and steel [23], [24]. Concrete, a hydrated mixture of Portland cement, aggregate, and water, offers massive compressive strength and formability and reaches design strength at about 28 days; steel, an iron carbon alloy, offers superior tensile strength, ductility, and predictable behaviour under load [25], [26]. Reinforced concrete, combining the two, has been the backbone of urban infrastructure for over a century. From a sustainability standpoint, however, both are non-renewable: their feedstocks: limestone, silica, iron ore; are mined, slowly exhausting finite reserves [7]. The environmental cost is concentrated in cement: globally about 7–8% of CO_2 emissions, sourced both from clinker calcination and from the energy intensity of production, with extraction adding land degradation and ecosystem loss [4], [15]. These figures supply the comparative baseline against which bamboo is assessed in Results and Discussion section.

1.1.5. Naturally Themed Restaurants and Vernacular Commercial Architecture

Naturally themed restaurants integrate ecological principles and natural elements into both design and the visitor experience, pursuing a synergy between dining and landscape that goes beyond visual styling to the substantive use of natural components [27]. This reflects an organic-architecture philosophy of harmony between the built and the natural [28]. In commercial buildings, modern vernacular approaches increasingly fold local materials (bamboo, timber, natural stone) into contemporary design to build a visual and psychological connection with nature, in line with green architecture principles [29]. For restaurants on a "village" (*kampung*) or rural theme in particular, bamboo offers a double advantage: a warm, unique texture that factory products cannot imitate, and thermal comfort in semi-open settings because the material does not store heat, well suited to the tropical open air typology [30].

1.1.5.1. Design Criteria for Bamboo Structure in Public Buildings

As a public building, a restaurant demands a high standard of structural safety under dynamic live loads. Following Gaffar Bakri [21], bamboo structures in public use should satisfy: (i) *structural safety* under combined dead and dynamic live loads; (ii) *super-structure capacity*, with tensile and compressive strength sufficient for columns and roof frames to substitute for steel or concrete over wide spans; (iii) *appropriate jointing*, since the joint is the weakest point, using sound traditional or mechanical connections (bolts, pegs) to distribute load stably; (iv) *weather protection* against UV and direct rain through wide eaves or coatings, to match the durability of conventional materials; (v) *function-led species selection*: large, thick-walled species such as Petung for primary columns, Wulung or black bamboo where exposed aesthetics matter; and (vi) *integration of structure and aesthetics*, exposing structure as an experiential feature rather than concealing it.

1.1.6. Precedents: Commercial and Institutional Bamboo Buildings

Two precedents bracket the range of contemporary bamboo practice relevant to this case. **Guha**, by Realrich Sjarief (Realrich Architecture Workshop), is a renovation and extension of a residence and architecture studio set within a dense urban neighbourhood. Its significance lies in demonstrating that bamboo can coexist harmoniously with concrete, steel, and red brick in a hybrid structural system, and that—through neat, inventive joinery using bolts, pegs, and modern ties, bamboo can be worked to factory-like precision in a metropolitan context. Guha also exploits bamboo's thermal behaviour, using it to admit natural ventilation and passive light and so reduce reliance on mechanical systems. **Bamboo U/Kul Kul Farm** in Bali, founded within the Green School ecosystem, pairs traditional bamboo craft with modern engineering: bolted steel connections, precise 1:10 structural models, and *bundled-bamboo* techniques that achieve stable organic curves, all preceded by standardised borax preservation to secure long-term durability. Together the precedents establish that bamboo is neither a "second-class" nor a merely rural material when species selection, preservation, and connection design are handled rigorously, the same triad this study reads at Kampung Kecil Cinere.

2. METHOD

2.1. Research Design

The study adopts a qualitative single-case design, appropriate for an in-depth, contextual reading of a phenomenon in its natural setting rather than for statistical generalisation [31], [32]. The case study structures the choice of subject, site, and data techniques and supports systematic interpretation toward valid conclusions [32]. The design combines three complementary strands: field observation, visual documentation, and a management interview; triangulated against a literature-based material comparison, so that what is built, what is reported, and what is known from prior research can be read together.

2.2. Case and Setting

The case is Kampung Kecil Cinere Restaurant, at Jl. Telaga Warna, RT.07/RW.05, Pangkalan Jati, Cinere District, Depok, West Java (approx. 6°19′23″S, 106°46′53″E), on a 4,392 m² site. Cinere is an active buffer zone immediately south of Jakarta, marked by dense, rapidly growing urban and commercial development; the restaurant's use of natural materials there represents a deliberate counter-move to the concrete-dominated peri-urban norm. The building is a semi-open, naturally themed restaurant of about 120-person capacity, organised as a themed "village" of named lanes and units, with three dining typologies: a central non-*saung* area, 16 land-based seated *saung* (non-pond), and 22 seated *saung* over a fish pond.

2.3. Data Collection

Fieldwork ran over four months (October 2025–January 2026), with two scheduled observation visits (December 2025 and January 2026; Table 2). Three primary techniques and one secondary technique were used.

2.3.1. Field Observation

Systematic direct observation and recording of the physical object [33]. All 38 *saung* (16 non-pond, 22 over-pond) were mapped for species use, member function, connection type, and moisture-management detailing. Particular attention was paid to where Wulung versus Apus was used, and to the ceramic-clad concrete plinths beneath over-pond seating. Findings were recorded as schematic diagrams and an existing-condition plan.

2.3.2. Visual Documentation

Detailed photographic recording of structural and connection details, lashed (*ijuk*, rattan) and any mechanical joints, and of the roof system's evolution from thatch (*ijuk*/*ilalang*) to metal, including the retained woven-bamboo ceiling beneath the new roof [34]. Photographs serve as authentic evidence of conditions and details that narrative alone cannot convey.

2.3.3. Semi-structured Interview

An in-depth interview with the restaurant's supervisor/management [35], covering operations since 2023 and focused on three themes: the rationale for choosing bamboo in this urban setting; the technical problem of thatch weathering that prompted the switch to metal roofing; and experience of biological degradation (pest/fungal attack) and its maintenance implications. Participation was voluntary; the interviewee was informed of the study's purpose and consented, and no personally identifying information is reported.

2.3.4. Literature Study (secondary)

A structured review of journals, texts, and reports on the physical-mechanical properties of bamboo, sustainable-architecture theory, and carbon-footprint parameters, providing the comparative benchmarks used in analysis [36].

Table 2. Observation schedule (source: authors)

Visit	Period	Focus
Observation 1	December 2025	Building layout and zoning; species-by-function mapping across all 38 *saung*; column and beam survey
Observation 2	January 2026	Connection details; roof and ceiling system; moisture-management detailing (*umpak*, pond-edge seating); management interview

2.4. Data Analysis

Analysis proceeded in three steps. First, observation and interview data were related to sustainability criteria drawn from the literature. Second, a *comparative analysis* set bamboo against conventional materials (concrete and steel) on technical and environmental parameters, drawing the quantitative benchmarks from prior studies rather than from on-site testing. Third, the strands were combined in a *synthesis* that assesses the feasibility of bamboo as a sustainable substitute and distils transferable design guidance. Manual sketching (used during fieldwork to dissect the structural and connection systems and to trace air-flow and circulation) and photographic documentation supported interpretation. Triangulation across observation, interview, and literature was used to limit the subjectivity of any single source.

2.5. Limitations

Four boundaries frame the claims that follow. First, the study is observation- and perception-based: it did not include in-situ structural load testing, so statements about structural adequacy rest on *observed in-service performance* combined with mechanical properties reported in the literature, not on measurements taken at the site. Second, no quantitative life-cycle assessment or site carbon accounting was performed; the carbon and emissions figures cited (e.g., ~12 t CO_2/ha/yr sequestration; cement's 7–8% share of global CO_2) are literature values used as comparative indicators, and the sequestration figure refers to living bamboo stands during growth rather than to carbon dynamics of the harvested members in this building. Third, as a single case the findings are analytically, not statistically, generalisable. Fourth, the durability assessment reflects the building's history to date as reported by management and observed on site, not a controlled longitudinal measurement. These limitations point to the value of pairing this reading with load testing and quantitative LCA in future work.

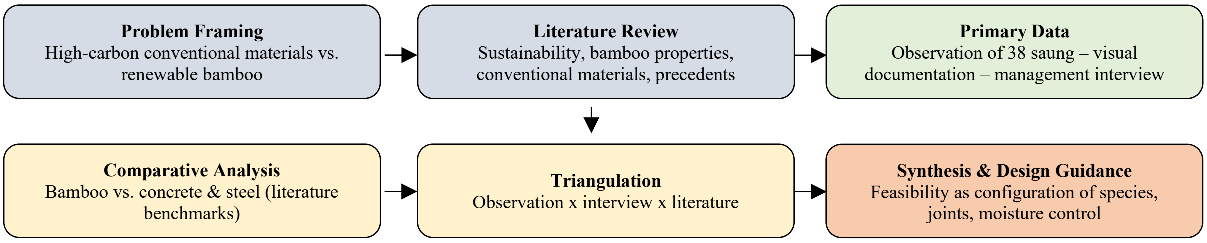


Figure 1. Research flow (source: authors, 2026)

3. RESULTS AND DISCUSSION

3.1. Site and Building Context

Depok comprises eleven districts; Cinere lies on the city's northern edge, bordering South Jakarta, and functions as an active buffer zone for the capital. In this densely built, commercially intensifying setting, the carbon cost of conventional concrete-and-cement construction is a pressing concern, and Kampung Kecil Cinere reads as a deliberate demonstration of natural-material building amid that norm. The 4,392 m² site is organised along a north-running axis with clearly zoned circulation: a one-way vehicle system (entry and exit), separated car and motorcycle parking, a main pedestrian entrance leading to the cashier and a bamboo architecture focal point, a kitchen placed to the side for service efficiency, and edge-placed support facilities (prayer room, toilets, open garden). The three dining typologies: central non-*saung* seating, 16 land *saung*, and 22 over-pond *saung*; are arranged around a large fish pond that doubles as an aesthetic centrepiece and a passive microclimatic device, cooling the semi-open dining areas. The vernacular modern framing: local bamboo, water, and a themed "village" of named lanes; builds the visual and psychological connection to nature that the typology depends on.

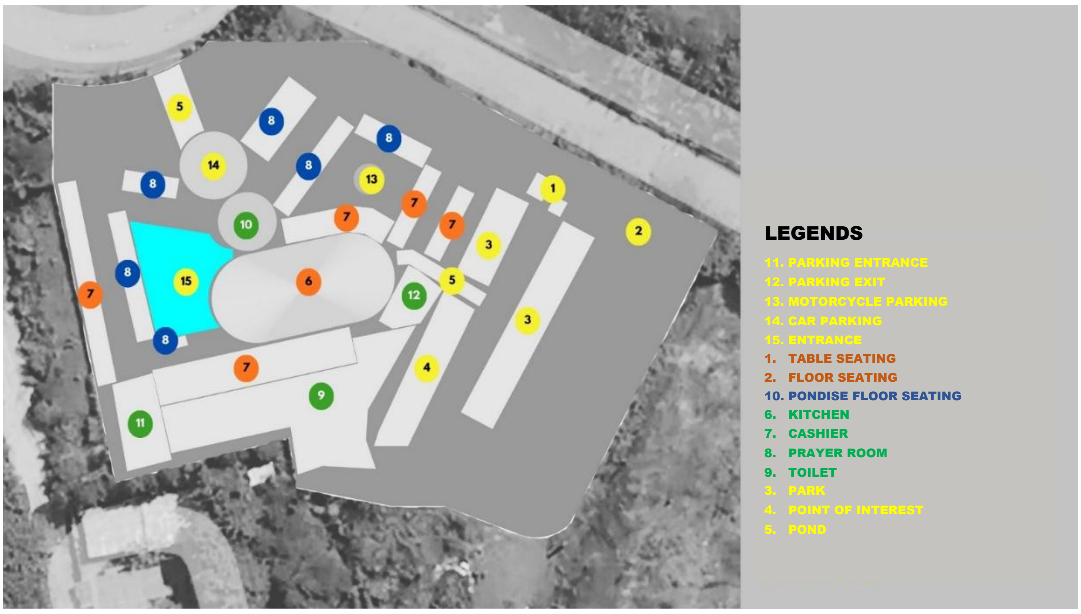


Figure 2. Site location and zoning of Kampung Kecil Cinere (Source: Google Earth, processed by the authors, 2026)

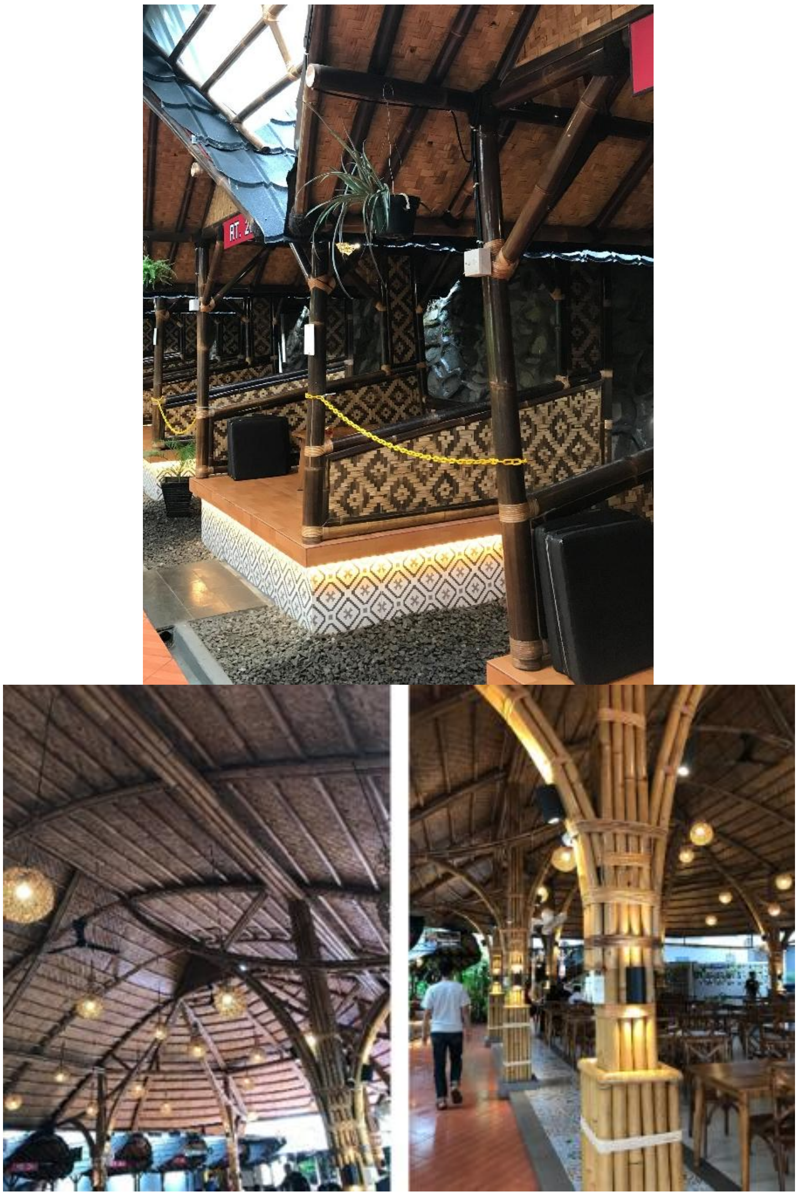
3.2. Structural Application of Bamboo: Species by Function

The building's primary structure relies entirely on bamboo for columns and beams, with species assigned by mechanical character and intended effect:

- **Black bamboo (Wulung, *Gigantochloa atroviolacea*)** serves as the main columns in the seated (*lesehan*) areas, where its deep black culm provides a strong visual identity and the section gives a robust, legible structural presence.

- **Rope bamboo (Apus, *Gigantochloa apus*)** is used in the non-seated dining area, where its flexibility allows members to be formed by bending—producing the curved geometry that would be awkward and costly in rigid conventional materials.

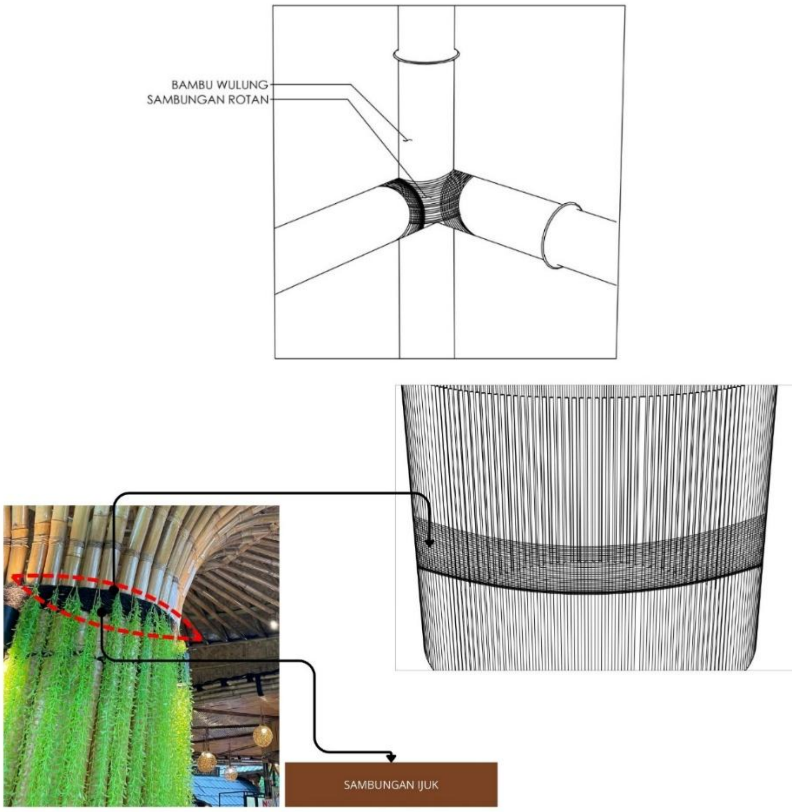
This division illustrates the function-led selection principle from Section 1.1.5.1. in practice: a stiff, visually dominant species for vertical load paths, a flexible species for shaped members. It is worth noting a point of nuance against the general literature, which often nominates the large-section Petung for primary columns [22]. At Kampung Kecil Cinere the primary columns are Wulung rather than Petung, a choice that trades Petung's greater section for Wulung's aesthetic value and adequacy at this building's spans and loads. The case therefore confirms the *principle* of matching species to task while showing that, for a single storey, wide-roof commercial pavilion, a medium section species can be sufficient when paired with appropriate jointing and moisture control. (Petung remains the literature's recommendation for heavier or longer-span primary structure and is not used here).



Wulung columns in a seated saung (Above)
Bundled/curved Apus structure in the non-seated area (Below)
Figure 3. Species by function use of bamboo: Wulung columns and bent Apus members (Source: authors' documentation, 2026)

3.3. Connections

Members are joined with traditional lashings of *ijuk* (black palm fibre) and rattan rather than mechanical fasteners. Because bamboo's structural Achilles' heel is shear at the connection [14], the joint detail is the critical determinant of safety; here, lashed joints allow a degree of flexible load distribution consistent with the dynamic behaviour of a natural material and with the building's low-rise, lightweight roof. The reliance on lashings rather than bolts also distinguishes this case from the precedents (Guha and Bamboo U), which adopt bolted/mechanical connections for greater span and predictability. The trade-off is clear: traditional lashings reinforce the vernacular character and are well matched to modest spans, but mechanical connections, identified in both precedents and in the public-building criteria [21], would be the route to larger spans, higher live loads, or multi-storey use. This is a concrete design lever for practitioners scaling the approach.



(a) Rattan-lashed joint detail
(b) Ijuk-lashed connection

Figure 4. Traditional lashed connections in *ijuk* and rattan (Source: authors' documentation, 2026)

3.4. Durability and the Hybrid Strategy

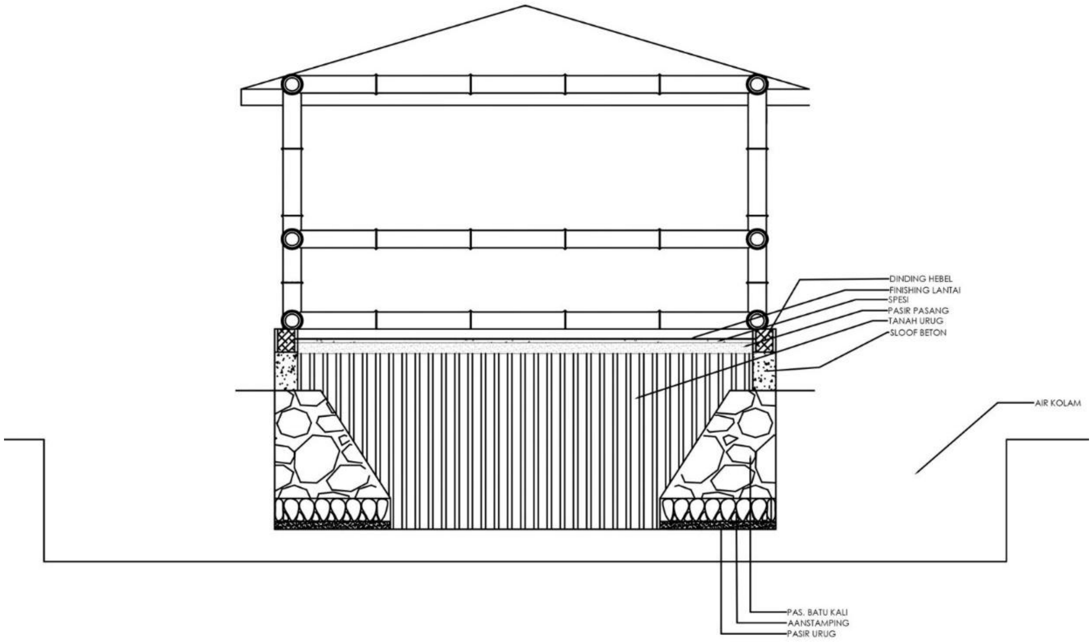
The most instructive findings concern durability, the gap between bamboo's ecological promise and its service life in a hot-humid climate. The restaurant manages this gap not by abandoning bamboo but by combining it selectively with conventional materials, a hybrid strategy with three observed moves:

- **Moisture isolation by concrete plinth (*umpak*).** Over-pond *saung* seating sits on ceramic-clad concrete plinths, preventing bamboo columns and the seating base from direct contact with pond water and ground moisture, and so cutting off the principal pathway to rot and biological degradation. This is the single most important durability device in the building: it preserves the visible bamboo structure while delegating the wet, vulnerable interface to an inert material.
- **Roof evolution from thatch to metal.** The roof was originally thatch (*ijuk*/*ilalang*) but, after about two years of weathering, was replaced with metal sheeting for weather resistance and longer service life. Crucially, a woven-bamboo ceiling was retained beneath the metal, preserving the warm interior character and thermal feel when seen from within the dining area. This is a candid, real-world record of adaptive maintenance rather than an idealised design narrative.

- **Permanent wet-zone construction.** The cashier area uses permanent ceramic-clad walls, giving a functional, easily cleaned, durable surface that contrasts deliberately with the bamboo-dominated dining areas.

Read together, these moves embody the public-building criterion of *weather protection* (Section 1.1.5.1.) and align with the hybrid logic of the Guha precedent, where bamboo is combined structurally with concrete, brick, and steel for optimal performance. The lesson is general: in the humid tropics, exposed structural bamboo is best treated as part of a system in which inert materials guard the moisture-critical interfaces (footings, wet zones, the weather face of the roof) while bamboo carries load and defines character. Notably, the case relies on physical isolation rather than chemical preservation (e.g., the borax treatment standardised at Bamboo U); combining the two would be a logical durability upgrade, and the absence of systematic chemical preservation is a maintenance risk the management itself associates with periodic pest concerns.

(a) Metal roof over a Wulung frame with retained woven-bamboo ceiling
(b) Over-pond saung on a ceramic clad concrete plinth



(c) Section through an over-pond saung: bamboo isolated from pond water by a concrete/stone footing (Indonesian labels retained)

Figure 5. Hybrid moisture-management detailing at the roof and pond edge (source: authors' documentation, 2026)

3.5. Comparative Parameters: Bamboo versus Conventional Materials

Table 3 consolidates the comparison drawn from the case and the literature. The values for strength, carbon, and durability are literature-based comparative indicators (cited), not site measurements; they are presented to position bamboo relative to the conventional baseline established in Section 1.1.4., not to certify the structural capacity of this specific building.

Table 3. Comparative parameters: bamboo versus conventional materials (concrete, steel) (source: authors, from the cited literature and field observation. Numerical values are indicative comparative benchmarks, not measurements of the case building)

Parameter	Bamboo	Concrete/Steel	Source Basis
Renewability	Renewable; harvest cycle 3–5 years; repeated harvest from one clump	Non-renewable; mined feedstock (limestone, silica, iron ore)	[7]; [20]
Tensile strength	Very high ("natural steel"); some specimens exceed mild-steel yield	Steel high in tension; concrete weak in tension (needs reinforcement)	[21]
Compressive strength	Good parallel to grain (esp. Petung)	Concrete very high in compression	[22]
Critical weakness	Low shear → joints govern; biological decay if untreated	High self-weight; brittle failure (concrete); corrosion (steel)	[14]; [13]
Embodied carbon/GWP	Low; lower GWP than steel/concrete; potential net-negative over life cycle when sequestration is counted	High; cement ≈ 7–8% of global CO_2	[11]; [12]; [4]
Carbon Sequestraction (growth)	≈ 12 t CO_2 / ha / yr by living stands; ~35% more O_2 than comparable trees	None	[9]; [7]
Thermal behaviour	Poor heat store → cooler microclimate; suits semi-open tropical use	High heat capacity; stores/re-radiates heat	[7]; [30]
Durability (untreated)	2–5 years untreated; greatly extended by preservation + moisture isolation	Decades; established standards and predictability	[13]; case observation
Operating-cost implication	Semi-open bamboo design avoids mechanical cooling (no AC) in this case	Sealed concrete/steel buildings typically need active cooling	Case observation

3.6. Interpreting the Environmental Case Honestly

Bamboo's environmental advantage in this comparison is real but must be stated precisely. The ~12 t CO_2/ha/yr figure describes sequestration by *living* bamboo stands during growth; it is not a property of the harvested culms in this building, which instead *store* previously captured carbon and carry a low embodied carbon relative to cement and steel [12]. [11]. The often cited "negative carbon footprint" is therefore best understood as a life cycle potential—plausible when low embodied carbon, biogenic carbon storage, durable service life, and responsible end of life are all achieve, rather than an automatic attribute of any bamboo building. Likewise, cement's 7–8% share of global CO_2 is the macro-scale justification for substitution, not a measured saving at this site. Within these bounds, the case still makes a clear environmental argument: by substituting a renewable, low-embodied-carbon, locally sourced material for concrete and steel in its primary structure, and by avoiding mechanical cooling through a semi-open, heat shedding design, Kampung Kecil Cinere reduces both embodied and operational carbon relative to a conventional equivalent, while the surrounding planted bamboo contributes sequestration at the landscape scale.

3.7. Synthesis: Bamboo Feasibility as a Matter of Configuration

The central finding is that bamboo's success here is a property of *configuration* rather than of the raw material. Three design decisions, working together, convert bamboo's theoretical promise into in-service reality: (1) *species by function*: Wulung for visible load bearing columns, Apus for bent members; (2) *connection logic* matched to scale: traditional lashings for this low rise, modest-span pavilion, with mechanical joints the identified route to larger spans; and (3) *moisture management through hybridity*: ceramic-clad concrete plinths, a metal weather-roof over a retained bamboo ceiling, and permanent construction in wet zones. This configuration directly answers the two research questions: bamboo functions as a credible primary structural alternative in this building type (RQ1), and its comparative profile: renewable, low carbon, thermally benign, but shear limited and decay-prone unless detailed and isolated; defines both why it is attractive and where it must be supported (RQ2). The result reframes the standard "bamboo versus concrete" debate as a question of how to combine them: bamboo for load and character, conventional materials for the moisture critical and high demand interfaces.

4. CONCLUSION

This study examined how bamboo performs as an alternative to conventional materials in an occupied tropical restaurant, using a qualitative single-case design at Kampung Kecil Cinere, Depok. The evidence shows that bamboo can serve as a building's primary structure when it is configured correctly: black bamboo (Wulung) carries the load and defines the architectural character of the seated areas, rope bamboo (Apus) supplies the curved geometry of the non-seated area, and traditional *ijuk* and rattan lashings connect members at a scale suited to a low rise pavilion. The material's decisive weaknesses, shear at the joint and biological decay in a humid climate, are managed through a hybrid strategy in which inert materials guard the vulnerable interfaces: ceramic-clad concrete plinths isolate columns from water, and a metal roof installed after two years of thatch weathering protects the structure while a woven bamboo ceiling preserves the interior.

Environmentally, bamboo offers a renewable, low embodied carbon, thermally benign alternative to concrete and steel, with sequestration benefits at the landscape scale, provided that carbon claims are read as life-cycle potentials rather than automatic attributes. The transferable lesson for low carbon commercial architecture in the humid tropics is to treat bamboo not as a substitute material to be used in isolation but as the load bearing and expressive core of a hybrid system, with species, joints, and moisture detailing designed together. For practice, two recommendations follow directly: place every moisture exposed bamboo member on a permanent plinth or concrete footing, and add systematic chemical preservation (e.g., borax) and periodic protective coating to the physical isolation strategy already in use. For research, the priorities are in-situ load testing of the as-built connections and a quantitative life cycle carbon assessment, together with standardised guidance for mechanical joints in curved bamboo, so that the configuration demonstrated here can be scaled with confidence.

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Construction Risk Management Under Pandemic Conditions: An Activity-Level Assessment of Construction Activities in Indonesia

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ABSTRACT

The COVID-19 pandemic significantly disrupted construction projects worldwide by introducing risks related to occupational health and safety (OHS), workforce availability, and material supply. While previous studies have largely focused on project- and organizational-level impacts, limited empirical research has examined how pandemic-related risks affect individual construction activities. This study investigates pandemic-related risks from an activity-level perspective and proposes mitigation strategies based on evidence from a developing-country context. A descriptive quantitative approach was employed using a questionnaire survey of 112 construction practitioners involved in active projects during the pandemic. Data were analyzed using Mean Score Analysis and the Relative Importance Index (RII) to evaluate the severity of risks affecting construction stakeholders and specific construction activities. The results show that OHS was the most critical risk category (mean = 3.82), followed by labor availability (3.71) and material procurement (3.58). At the activity level, masonry work was the most affected (mean = 3.79), followed by earthwork (3.63) and concrete work (3.49). These findings indicate that pandemic-related risks are unevenly distributed across construction activities, with labor-intensive activities being particularly vulnerable to health restrictions and workforce disruptions. This study extends construction risk management literature by introducing an activity-level assessment perspective and emphasizes the need to integrate health-related risks into conventional risk management frameworks while adopting activity-specific mitigation strategies to improve resilience against future public health emergencies and other large-scale disruptions.

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1. INTRODUCTION

The construction industry plays a vital role in economic development by supporting infrastructure provision, generating employment opportunities, and stimulating investment. Despite its significant contribution, construction projects are inherently exposed to numerous uncertainties due to their complexity, dynamic working environments, resource constraints, and the involvement of multiple stakeholders [7] [9]. These uncertainties may adversely affect project performance in terms of cost, schedule, quality, and safety, making effective risk management an essential component of successful project delivery.

The COVID-19 pandemic created an unprecedented global disruption that fundamentally altered construction project execution. Government-imposed mobility restrictions, mandatory health protocols, workforce limitations, and supply chain interruptions significantly affected construction productivity, project scheduling, and operational efficiency [13] [5]. Unlike conventional construction risks, pandemic-related risks simultaneously impacted multiple aspects of project performance, requiring contractors to address not only technical and financial challenges but also public health concerns. Consequently, occupational health and safety (OHS), labor availability, and material procurement emerged as critical risk factors during the pandemic [2].

Although a growing body of literature has examined the effects of the COVID-19 pandemic on construction projects, most studies have focused on project-level and organizational-level impacts, including schedule delays, productivity losses, cost escalation, and supply chain disruptions [3] [1] [8]. However, empirical evidence remains limited regarding how pandemic-related risks affect individual construction activities. This gap is particularly important in labor-intensive construction environments such as Indonesia, where different activities vary considerably in their dependence on manual labor, worker interaction, equipment, and material availability. As a result, the severity of pandemic-related risks is likely to differ across construction activities.

Therefore, this study investigates pandemic-related risks from an activity-level perspective by assessing the relative impact of major risk categories on selected construction activities. By identifying the activities most vulnerable to pandemic-induced disruptions, this study provides a more granular understanding of construction risk management and offers practical insights for developing activity-specific mitigation strategies to enhance project resilience against future public health emergencies and other large-scale disruptions.

1.1 Construction Risk Management

Construction risk management is a systematic process of identifying, assessing, responding to, and monitoring uncertainties that may influence project objectives, including cost, schedule, quality, safety, and overall project performance [6] [9]. Due to the fragmented nature of the construction industry and the involvement of multiple stakeholders, construction projects are inherently exposed to diverse sources of risk throughout the project lifecycle. These risks originate from technical complexity, financial uncertainty, contractual disputes, regulatory changes, environmental conditions, and social factors [10].

Effective risk management enables project stakeholders to anticipate potential disruptions, allocate resources efficiently, and implement preventive or corrective measures before risks escalate into project failures. Traditional construction risk management frameworks generally categorize risks into internal risks, which are associated with project execution and management, and external risks, which arise from economic, political, environmental, or legal conditions. However, these frameworks have largely been developed under relatively stable operating environments and primarily focus on predictable project uncertainties.

The COVID-19 pandemic exposed a significant limitation of conventional construction risk management practices by demonstrating that large-scale public health emergencies can simultaneously affect multiple dimensions of project performance. Unlike conventional risks that are often localized or project-specific, pandemic-related risks are systemic, dynamic, and highly interconnected, influencing workforce availability, material procurement, project financing, contractual obligations, and occupational safety simultaneously [11]. Consequently, construction risk management frameworks need to evolve by incorporating health-related risks and enhancing project resilience against future large-scale disruptions.

1.2. Occupational Health and Safety Risks During COVID-19

Occupational health and safety (OHS) became one of the most critical concerns for the construction industry during the COVID-19 pandemic. Construction activities typically require close physical interaction among workers, frequent equipment sharing, collaborative teamwork, and continuous movement across dynamic work environments, making construction sites particularly vulnerable to infectious disease transmission [2]. Unlike many office-based industries, construction work cannot be fully performed remotely, increasing workers' exposure to health risks while maintaining project continuity.

To minimize virus transmission, governments and construction authorities introduced various preventive measures, including mandatory use of personal protective equipment (PPE), physical distancing, routine health screening, temperature monitoring, site sanitization, staggered work schedules, and limitations on workforce density. While these measures successfully reduced infection risks, they also altered normal construction operations by reducing labor productivity, increasing operational costs, and creating additional management complexity.

Previous studies consistently reported that COVID-19-related OHS measures negatively affected project performance. Reduced workforce capacity, temporary site closures following confirmed infections, quarantine requirements, and stricter health protocols resulted in schedule delays, increased labor costs, and decreased construction productivity. These findings demonstrate that occupational health risks during a pandemic should no longer be treated solely as safety issues but also as strategic project risks that significantly influence construction performance.

1.3. Pandemic-Induced Risks in Construction Project

Beyond occupational health risks, the COVID-19 pandemic generated a wide range of interconnected risks affecting nearly every aspect of construction project delivery. One of the most significant challenges was labor availability. Government-imposed mobility restrictions, regional lockdowns, quarantine regulations, and workers' health concerns reduced workforce availability and disrupted labor allocation across construction sites. Many projects experienced labor shortages due to travel restrictions affecting migrant workers and limitations on workforce density implemented to comply with health regulations.

The pandemic also severely disrupted global and domestic construction supply chains. Manufacturing slowdowns, transportation restrictions, border closures, and fluctuating market demand contributed to shortages of construction materials and substantial increases in material prices [8]. Delays in material procurement subsequently disrupted project schedules, increased project costs, and reduced overall productivity.

In addition, the pandemic created financial and contractual uncertainties. Project owners experienced budget constraints, contractors faced cash flow problems, and contract execution became increasingly complicated due to force majeure conditions and changing government regulations. These interconnected risks demonstrate that pandemic-related disruptions extend beyond traditional project risks by simultaneously affecting human resources, logistics, financial management, and operational decision-making [3]. Therefore, pandemic-induced risks should be recognized as an integral component of modern construction risk management frameworks.

1.4. Research Gap

Existing literature has extensively examined the impacts of the COVID-19 pandemic on construction projects from project-level and organizational perspectives. Previous studies primarily focused on project delays, cost overruns, workforce productivity, supply chain disruptions, contractual issues, and organizational resilience [1] [3] [8]. These studies have substantially improved understanding of the macro-level consequences of the pandemic on construction project performance.

However, relatively little attention has been given to how pandemic-related risks influence individual construction activities. Construction projects consist of multiple activities with varying levels of labor intensity, equipment dependency, material requirements, and operational characteristics. Consequently, the vulnerability of each activity to pandemic-related disruptions is unlikely to be uniform. Labor-intensive activities requiring close worker interaction, such as masonry or concrete work, may experience greater disruption than equipment-intensive activities.

This knowledge gap is particularly evident in developing countries such as Indonesia, where construction projects often rely heavily on manual labor and face additional challenges related to resource availability and health protocol implementation. Understanding risk at the activity level can provide more precise information for prioritizing mitigation strategies, optimizing resource allocation, and improving project resilience during future public health emergencies. Therefore, this study investigates pandemic-related risks from an activity-level perspective by identifying the most affected construction activities and evaluating the relative importance of different risk categories. This approach complements existing project-level studies and contributes a more granular understanding of construction risk management under pandemic conditions.

2. METHOD

This study used a descriptive quantitative research design to examine risks arising due to the pandemic at the activity level in the construction industry in Indonesia. Questionnaire data was collected by administering it to construction professionals who were working on construction projects amid the coronavirus outbreak.

A total of 112 valid questionnaires was completed by project managers, site engineers, contractors, and site supervisors using the purposive sampling method. These participants had to meet the criteria of at least three years of work experience in construction project management and participation in executing projects under the pandemic condition.

Two parts constituted the structure of the questionnaire: (1) impact of pandemic-related risks on stakeholders and resources of the construction project, and (2) impact of pandemic conditions on specific construction activities. Respondents gave answers based on a four-point Likert scale with options 1 – no impact and 4 – very significant impact.

Questionnaire tool was validated and checked for reliability before analyzing the data. All items in the questionnaire proved their validity with $r > 0.30$ while Cronbach's Alpha score was found equal to 0.846. The collected data were then analyzed with the help of Mean Score Analysis.

3. RESULTS

3.1. Impact of Pandemic-Related Risks on Construction Projects

Table 1. Ranking of Pandemic-Related Risks

Risk factor	Mean Score	Rank
Occupational Health and Safety	3.82	1
Labor Availability	3.71	2
Material Procurement	3.58	3
Equipment Availability	3.22	4
Financial Risk	3.11	5

The results indicate that occupational health and safety (OHS) was perceived as the most significant risk during the COVID-19 pandemic, with the highest mean score of 3.82. This finding reflects the substantial challenges faced by construction projects in maintaining worker safety while ensuring project continuity under strict public health regulations. Construction sites involve frequent physical interaction, shared equipment, and labor-intensive operations, making compliance with health protocols such as physical distancing, routine health screening, mandatory use of personal protective equipment (PPE), and site sanitization particularly challenging. Consequently, OHS risks extended beyond worker protection and directly influenced project productivity, scheduling, and operational efficiency.

The availability of labor ranked as the second most critical risk, with a mean score of 3.71. Workforce shortages were primarily driven by government-imposed mobility restrictions, quarantine requirements, illness among workers, and limitations on the number of personnel permitted on construction sites. These conditions reduced workforce capacity, disrupted work sequences, and delayed project completion, particularly for labor-intensive construction activities.

Material procurement was identified as the third highest risk, with a mean score of 3.58. The pandemic disrupted both domestic and international supply chains through manufacturing slowdowns, transportation restrictions, and fluctuating market demand. These disruptions resulted in delayed material deliveries, shortages of essential construction materials, and increased material prices, all of which adversely affected project schedules, construction costs, and overall project performance.

Overall, the findings demonstrate that pandemic-related risks were multidimensional and interconnected. Health-related risks triggered labor shortages, while supply chain disruptions further constrained project execution. This highlights the need for construction risk management frameworks that integrate occupational health, workforce planning, and supply chain resilience to improve preparedness for future large-scale disruptions.

3.2. Activity Level Analisys of Pandemic Risks

Table 2. Activity Level Impact Assement

Construction Activity	Mean Score	Rank
Mansory Work	3.79	1
Earthwork	3.63	2
Concrete Work	3.49	3
Mechanical and Electrikal Work	3.32	4
Finishing Work	3.18	5

The results reveal that the effects of the COVID-19 pandemic were not uniformly distributed across construction activities, indicating that each activity exhibited different levels of vulnerability depending on its operational characteristics, labor requirements, and work environment.

Masonry work recorded the highest mean score (3.79), indicating that it was the construction activity most severely affected during the pandemic. Masonry operations typically require close collaboration among workers for material handling, bricklaying, plastering, and alignment tasks, making compliance with physical distancing measures particularly difficult. In addition, the labor-intensive nature of masonry work increased its susceptibility to workforce shortages resulting from illness, quarantine requirements, and mobility restrictions. These factors collectively reduced productivity and contributed to project delays.

Earthwork ranked second with a mean score of 3.63. Although earthwork often relies heavily on construction equipment, its execution still requires coordinated interaction among machine operators, surveyors, supervisors, and supporting labor. Pandemic-related labor shortages, restrictions on site occupancy, and interruptions in equipment mobilization reduced operational efficiency and affected work scheduling.

Concrete work ranked third with a mean score of 3.49. Concrete construction involves time-sensitive operations, including reinforcement installation, formwork preparation, concrete pouring, and curing. Delays in labor availability or material delivery can interrupt these sequential processes, potentially compromising construction quality and extending project duration.

Mechanical and electrical work recorded a moderate impact (mean = 3.32). These activities generally involve smaller specialized teams and can be scheduled more flexibly than structural works, reducing their exposure to pandemic-related disruptions.

Finishing work exhibited the lowest mean score (3.18), suggesting that it was relatively less affected by the pandemic. Finishing activities are commonly performed during the later stages of construction, often by smaller work crews operating in separated areas. Their greater scheduling flexibility and lower dependence on large numbers of workers enabled contractors to better adapt to health protocols and workforce limitations.

Overall, these findings demonstrate that labor-intensive construction activities were considerably more vulnerable to pandemic-related risks than activities requiring smaller or more specialized workforces. This variation highlights the importance of adopting activity-specific risk management strategies rather than relying solely on project-level approaches, enabling contractors to prioritize mitigation measures for the activities most susceptible to large-scale public health disruptions.

4. DISCUSSION

The results show that pandemic-induced risks have made notable changes to the construction risk profile by adding health-related risks as a primary factor that causes project uncertainties. Occupational health and safety have been found to be the most important risk factor in the present research, which aligns well with the findings of [2] and Kermanshachi et al. (2021) who have found that construction projects are highly susceptible to the spread of diseases because of extensive worker interactions and constantly changing nature of the construction sites.

Labor availability has been determined to be the second most important risk factor. The present research supports the conclusions reached by [8] according to whom mobility and quarantine restrictions imposed on workers decreased labor productivity.

One of the novel findings in the current research is the assessment of pandemic-induced risks at the level of activities. Previous researches considered pandemic-induced risks at the level of construction projects and identified project delays, lower productivity and increased cost as the outcomes [3] [1].

Masonry work was found to be the most vulnerable activity because it relies heavily on labor-intensive processes and close physical interaction among workers. Similar observations were reported by Kabir et al. (2022), who identified labor-intensive construction activities as particularly susceptible to pandemic-related disruptions. In contrast, finishing activities were less affected because they generally require fewer workers and offer greater flexibility in task scheduling. These findings suggest that project-level risk assessments alone may not adequately capture operational vulnerabilities during crisis situations. Therefore, activity-level risk assessment should be integrated into construction risk management frameworks to support more targeted mitigation strategies and improve project resilience against future disruptions.

Regarding this, there are several contributions that the present research makes to the existing knowledge base on construction risk management. Firstly, the current research involves health-related risks of the pandemic into the existing construction risk management framework. Secondly, this research uses a task-based risk assessment methodology. Finally, empirical data are generated in the case of Indonesia where manual labor is still widespread in construction.

The findings of this research increase the scientific knowledge of the construction risk management area by revealing an uneven distribution of the pandemic-related risks among the various construction activities. In accordance with the findings of this research, the most important risk factors during the pandemic period were occupational health and safety (mean = 3.82), labor availability (mean = 3.71), and material procurement (mean = 3.58).

In addition, the masonry activity received the highest average score of vulnerability (mean = 3.79), the earthworks activity got the second-highest average score (mean = 3.63), while the third place was taken by the concrete work activity (mean = 3.49). Thus, the findings of the research prove the need to incorporate the concept of health risks into the current models of construction risk management and analyze risks on the level of activities rather than projects.

6.2. Practical Implications

The findings from this research will be beneficial to construction practitioners in mitigating crisis situations during their future projects. Since those construction processes, which are labor dependent, for example, bricklaying process and earthwork, have been identified to be very susceptible to disruptions due to pandemic, then such activities should be prioritized while addressing such risks.

Some of the approaches are employee scheduling in shifts, health check-up of employees, contingency plan for employees, and material inventory management. Additionally, carrying out risk assessments in relation to activities will enable the stakeholders of the construction project to manage their resources without disturbing the schedules of the project.

On the other hand, the current research is associated with some limitations. First, the current research is based on questionnaire data, and therefore it can be biased by the perceptions of respondents. Second, the current research deals only with construction projects in Indonesia. It is recommended that further studies should be carried out using large samples and employing advanced techniques of data analysis such as SEM or multivariate analysis for the purposes of examining risk factors in connection with the pandemic. Further studies might take into account the use of digital technologies including BIM, AI, and digital monitoring.

5. CONCLUSION

This study examined the impact of pandemic-related risks on construction projects through an activity-level risk assessment. The findings indicate that occupational health and safety (OHS), labor availability, and material procurement were the most significant risk factors affecting construction project performance during the COVID-19 pandemic. Among the construction activities analyzed, masonry work was identified as the most vulnerable, followed by earthwork and concrete work, reflecting the greater susceptibility of labor-intensive activities to workforce shortages, health restrictions, and operational disruptions.

The results demonstrate that pandemic-related risks are not uniformly distributed across construction activities. Instead, the level of risk exposure varies according to the operational characteristics, labor intensity, and resource dependency of each activity. This finding highlights the limitations of conventional project-level risk assessments and underscores the importance of incorporating activity-level analysis into construction risk management.

The primary contribution of this study is the introduction of an activity-based perspective for assessing construction risks during large-scale public health emergencies. From a practical standpoint, the findings suggest that contractors and project managers should adopt activity-specific mitigation strategies, prioritizing labor-intensive activities through enhanced health protocols, workforce contingency planning, and more resilient material procurement practices. Such targeted approaches can improve project resilience and minimize disruptions during future crises.

From a theoretical perspective, this study extends construction risk management literature by integrating health-related risks into traditional risk assessment frameworks and demonstrating the value of activity-level analysis in supporting more informed risk prioritization and decision-making under crisis conditions. Future research may further validate this framework across different project types, procurement methods, and geographical contexts to enhance its broader applicability

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Bioclimatic Design Strategies for a Public Plaza in Pekanbaru, Indonesia

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ABSTRACT

The development of commercial areas in major cities such as Pekanbaru continues to grow rapidly in line with increasing economic activity and the rising demand for multifunctional public spaces. However, most commercial buildings in Indonesia remain focused on visual image-making and modern aesthetics, with limited consideration for energy efficiency and thermal comfort. This design study examines the application of bioclimatic architectural principles to a three-story commercial plaza whose primary functions include a culinary center, coworking space, and retail area. The aim of this design is to create a climate-responsive and energy-efficient building that ensures optimal thermal comfort for its users. The design method employs a bioclimatic approach through analysis of building orientation, spatial layout, facade treatment, and the integration of passive elements such as vegetated balconies, secondary skin, and overhangs. The design results indicate that the façade strategy using a secondary skin effectively reduces direct heat exposure from the west, while the addition of vegetation on balconies and the roof provides natural shading and enhances the building's visual quality. Furthermore, the spatial orientation based on sun path and wind flow improves the efficiency of natural lighting and ventilation. Overall, this design demonstrates that the integration of passive architectural elements can create sustainable commercial buildings that are adaptive to tropical climatic conditions.

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1. INTRODUCTION

The rapid growth of commercial developments in Indonesian cities has increased the demand for multifunctional buildings that combine retail, dining, and public activities. In cities such as Pekanbaru, commercial plazas have become important urban destinations that accommodate various social and economic activities. As these buildings are designed for intensive daily use, providing a comfortable indoor environment has become one of the main challenges. However, many commercial buildings in Indonesia continue to prioritize contemporary appearance and commercial appeal while giving limited attention to climate-responsive design. As a result, thermal comfort is often achieved through extensive use of air-conditioning systems, leading to high operational energy consumption.

The analysis of land surface temperature and the *Urban Heat Island* (UHI) phenomenon in Pekanbaru indicates a significant increase in the 25–28°C temperature class, which covers approximately 61.34% of the city's total area. The dominance of this temperature range suggests a considerable rise in land surface temperatures, reflecting the expansion of urbanized areas and changes in land cover. This finding indicates that the *Urban Heat Island* effect has become increasingly pronounced in Pekanbaru, with potential implications for outdoor thermal comfort, environmental quality, and the cooling energy demand of buildings [1].

Previous studies have shown that buildings are among the largest consumers of energy because of their dependence on mechanical cooling systems. According to [2], [3], [4], the excessive use of air conditioners contributes significantly to building energy consumption. Many modern buildings fail to provide adequate thermal comfort through passive design strategies, making mechanical cooling the primary solution [3]. This issue is particularly important in humid tropical cities such as Pekanbaru, where high temperatures and humidity create continuous cooling demands throughout the year.

One approach that addresses this challenge is bioclimatic architecture. Rather than relying mainly on mechanical systems, bioclimatic design responds to local climatic conditions by optimizing natural environmental resources [5], [6], [7]. Passive strategies such as appropriate building orientation, natural ventilation, solar shading, daylight utilization, vegetation, and climate-responsive materials can improve thermal comfort while reducing cooling demand. Buildings should be designed according to local climatic conditions to create comfortable environments [8], [9]. Similarly, [10] argued that architecture in tropical regions should utilize natural environmental potentials to reduce energy consumption while maintaining occupant comfort.

Although bioclimatic architecture has been widely discussed in residential [5], [11], [12], market [13], office [6], [7], [8], and educational buildings [14], [15], [16] its application in the design of contemporary commercial plazas has received less attention, particularly in the context of humid tropical cities such as Pekanbaru. Commercial plazas generally require large enclosed spaces, accommodate various public activities, and operate for long hours, resulting in considerable cooling demands. These characteristics make them an appropriate building type for exploring passive environmental design strategies. Integrating bioclimatic principles into contemporary commercial architecture therefore offers an opportunity to improve environmental performance without compromising functionality or architectural expression.

This study explores how bioclimatic architectural principles can inform the design of a contemporary commercial plaza in Pekanbaru. Rather than focusing only on the final architectural form, the study examines how local climatic conditions influence key design decisions, including building orientation, spatial organization, facade treatment, landscape planning, material selection, and natural ventilation. These strategies are integrated into the design to improve thermal comfort, reduce dependence on mechanical cooling, and create a commercial building that responds more effectively to the humid tropical climate. The proposed design is expected to provide a practical reference for integrating bioclimatic principles into future commercial developments in similar climatic contexts.

2. METHOD

This study adopts a design-based research approach to explore the application of bioclimatic architectural principles in the design of a contemporary commercial plaza in Pekanbaru. Rather than evaluating an existing building, the study investigates how climate-responsive design strategies can be integrated into the design process to improve thermal comfort and reduce dependence on mechanical cooling systems. The design process combines site analysis, climate analysis, literature review, and architectural design development to produce a proposal that responds to the environmental characteristics of a humid tropical climate.

Both primary and secondary data were used in this study. Primary data were collected through site observations to identify the physical characteristics of the location, including site orientation, surrounding buildings, existing vegetation, access, and environmental conditions. Secondary data consisted of climate information, relevant literature on bioclimatic architecture, planning regulations, and previous studies related to sustainable commercial buildings. These data provided the basis for developing appropriate design strategies for the selected site.

The design process began with an analysis of the site's climatic conditions, including solar orientation, prevailing wind direction, temperature, rainfall, and surrounding environmental conditions. These analyses were used to identify both the opportunities and constraints that influence the building design. The findings were then interpreted using bioclimatic architectural principles proposed by Yeang (1994) and Olgyay (1963), focusing on passive strategies to improve environmental performance.

Based on the analysis, several design strategies were developed, including building orientation, spatial organization, facade treatment, natural ventilation, daylight optimization, landscape design, and material selection. These strategies were integrated throughout the design process to reduce heat gain, improve natural air movement, and maximize daylight while maintaining user comfort. The proposed design was developed using ArchiCAD 28 for architectural modeling and technical drawings, while D5 Render was used to produce three-dimensional visualizations of the final design. The resulting design was then evaluated qualitatively by examining how each design strategy responded to the site's climatic conditions and reflected the principles of bioclimatic architecture.

3. RESULTS AND DISCUSSION

The design process began with an analysis of the site and local climatic conditions to identify environmental opportunities and constraints that influence architectural decisions. The findings from the site analysis were then translated into a series of bioclimatic design strategies that respond to the humid tropical climate of Pekanbaru. Rather than applying passive elements as individual features, the proposed design integrates building orientation, spatial organization, facade treatment, vegetation, and material selection into a comprehensive climate-responsive design. This section discusses how each strategy contributes to improving thermal comfort while reducing dependence on mechanical cooling.

3.1. Site Analysis

The proposed site is located on Arifin Ahmad Street, one of the main commercial corridors in Pekanbaru. The location offers good accessibility and strong commercial potential but also presents several environmental challenges that influence the building design. These include high solar exposure, traffic noise, and the need to maintain thermal comfort in a hot and humid climate.

(a) Site Location

(b) Wind Analysis

(c) Sun Path Analysis

(d) Noise Analysis

Figure 1. Site Analysis (Source: author, 2026)

The climate analysis indicates that Pekanbaru experiences high temperatures, high humidity, and significant annual rainfall throughout the year. The strongest solar radiation occurs on the eastern and western façades, while the prevailing winds generally come from the southeast and east. These climatic conditions highlight the importance of reducing solar heat gain while maximizing natural ventilation. Consequently, the design prioritizes passive environmental strategies such as appropriate building orientation, facade shading, and vegetation to improve the building's environmental performance.

Site observations also revealed that traffic noise is concentrated along Arifin Ahmad Street. To reduce this impact, the building mass is positioned according to the required setback, while vegetation is introduced along the site boundary to function as both a thermal and acoustic buffer. In addition, the surrounding commercial buildings create opportunities for the proposed plaza to establish a stronger architectural identity while remaining responsive to the local urban context.

3.2. Application of Bioclimatic Design Strategies

3.2.1. Building Orientation and Spatial Organization

The orientation of the building was determined based on the site's solar exposure and prevailing wind direction. The main openings are positioned to receive natural daylight while minimizing direct heat gain from the east and west. The building is oriented to avoid facing east and west in order to minimize direct solar exposure. At the same time, the building layout encourages cross-ventilation by allowing air movement through the main activity spaces.

In tropical climates, building orientation plays a crucial role in controlling solar heat gain. Positioning a building to minimize direct solar exposure on the eastern facade, and particularly on the western façade, can reduce heat absorption and help maintain lower indoor temperatures. Furthermore, aligning the building with the prevailing wind direction enhances natural ventilation, improving air circulation and contributing to greater indoor thermal comfort [17].

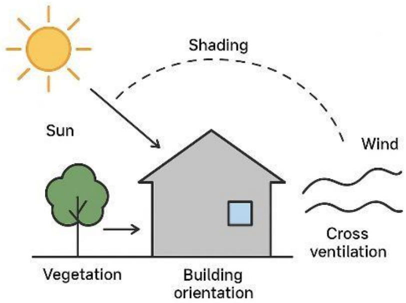

Figure 2. Building orientation (Source: author, 2026)

3.2.2. Spatial Organization

The spatial organization also reflects the functional requirements of the plaza. Public functions such as retail and culinary spaces are located on the ground floor to improve accessibility, while coworking spaces are placed on the upper floors where daylight and views are more effectively utilized. This arrangement not only supports user activities but also contributes to better environmental performance by reducing the need for artificial lighting during daytime.

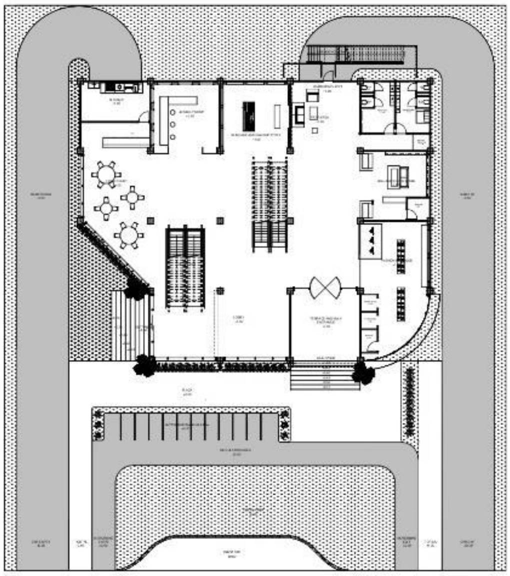

Figure 3. Spatial Organization (Source: author, 2026)

3.2.2. Facade Design and Solar Shading

Controlling solar radiation is one of the main challenges in designing buildings for humid tropical climates. For this reason, the façade incorporates several passive shading elements, including secondary skin panels and overhangs. This is also stated by [18], the application of secondary skins, canopies, and other shading devices is an effective passive strategy for reducing solar heat gain in tropical climates. Since solar radiation is the primary source of heat accumulation in buildings, these shading elements act as protective layers that intercept and reduce direct sunlight before it reaches the building envelope. As a result, heat transfer into the interior is minimized, lowering cooling loads and improving indoor thermal comfort. This approach represents a fundamental principle of passive design for buildings located in hot-humid climates.

Figure 4. Secondary Skin (Source: author, 2026)

The secondary skin functions as more than an architectural feature. It filters direct solar radiation before it reaches the building envelope, thereby reducing heat gain while still allowing daylight and natural ventilation. Different secondary skin patterns are introduced to strengthen the contemporary architectural expression without compromising environmental performance.

Horizontal overhangs are also provided above major openings and circulation areas. These elements reduce direct sunlight and protect users from heavy rainfall while creating shaded semi-outdoor spaces that improve pedestrian comfort. Together, the secondary skin and overhangs contribute to lowering cooling demand through passive solar control.

Figure 5. Overhang (Source: author, 2026)

3.2.3 Vegetation and Landscape Design

Vegetation plays an important role in improving the microclimate surrounding the building. Trees, shrubs, and climbing plants are distributed throughout the site to reduce surface temperatures and provide natural shading for outdoor spaces. According to [19], vegetation serves as a natural shading element that can reduce surface temperatures, improve the microclimate, enhance thermal comfort by moderating humidity conditions, and mitigate the urban heat island effect. In tropical public spaces, areas shaded by vegetation have been shown to exhibit lower temperatures than exposed open spaces without tree canopy or other forms of natural shade.

Green balconies are introduced as transitional spaces between the interior and exterior environments. Besides enhancing the visual appearance of the building, vegetation on the balconies helps lower façade temperatures through shading and evapotranspiration. These passive cooling effects create a more comfortable environment while maintaining adequate airflow and daylight.

Figure 6. Green Balcony (Source: author, 2026)

The landscape design also contributes to user comfort by creating shaded pedestrian areas and outdoor gathering spaces. Instead of functioning solely as decorative elements, the landscape becomes an integral component of the building's environmental strategy.

Figure 7. Landscape design (Source: author, 2026)

3.2.4. Building Materials and Natural Ventilation

Material selection was guided by both environmental performance and architectural character. Low-E glazing is used to reduce solar heat gain while maintaining daylight penetration. Natural stone is applied in outdoor areas because of its durability and compatibility with the tropical climate, while wood is incorporated into interior finishes to create a warmer and more comfortable atmosphere.

Natural ventilation is enhanced through the placement of large openings on multiple sides of the building. This arrangement supports cross-ventilation and allows fresh air to circulate through the interior spaces, reducing dependence on mechanical cooling. Together with the shading devices and vegetation, these strategies demonstrate how passive environmental design can improve thermal comfort in commercial buildings.

Figure 8. Building materials and natural ventilation (Source: author, 2026)

3.3 Discussion

The proposed design demonstrates that bioclimatic principles can be integrated into contemporary commercial architecture without limiting architectural expression. Instead of treating passive design elements as additional features, the proposed plaza incorporates climate-responsive strategies from the earliest stages of the design process. Building orientation, façade shading, vegetation, natural ventilation, and material selection work together to improve environmental performance while supporting the functional requirements of a commercial plaza.

Table 1. Application of Bioclimatic Design Strategies (Source: author, 2026)

Bioclimatic Design Strategies	Design Application
Building Orientation	• The building is oriented to avoid facing east and west in order to minimize direct solar exposure.
Spatial Organization	• The spatial organization reflects the functional requirements of the plaza performance by reducing the need for artificial lighting during daytime
Facade Design and Solar Shading	• The secondary skin functions as more than an architectural feature. It filters direct solar radiation before it reaches the building envelope, thereby reducing heat gain while still allowing daylight. • Horizontal overhangs reduce direct sunlight and protect users from heavy rainfall while creating shaded semi-outdoor spaces that improve pedestrian comfort.
Vegetation and Landscape Design	• Vegetation on the balconies helps lower façade temperatures through shading and evapotranspiration. • The landscape design also contributes to user comfort by creating shaded pedestrian areas and outdoor gathering spaces.
Building Materials	• Low-E glazing is used to reduce solar heat gain while maintaining daylight penetration. Natural stone is applied in outdoor areas because of its durability and compatibility with the tropical climate, while wood is incorporated into interior finishes to create a warmer and more comfortable atmosphere.
Natural Ventilation	• Natural ventilation is enhanced through the placement of large openings on multiple sides of the building. This arrangement supports cross-ventilation and allows fresh air to circulate through the interior spaces, reducing dependence on mechanical cooling.

The findings also support previous studies that emphasize the importance of passive environmental strategies in tropical climates. As suggested by [9] and [10], responding to local climatic conditions through orientation, shading, and natural ventilation can improve thermal comfort while reducing dependence on mechanical cooling. In this study, these principles are translated into practical architectural strategies suitable for commercial developments in Pekanbaru.

Although the study does not include quantitative energy simulations or thermal performance measurements, it demonstrates a systematic approach to integrating bioclimatic principles into architectural design. Future studies may combine this design approach with building performance simulations to evaluate the effectiveness of each strategy in reducing energy consumption and improving thermal comfort.

4. CONCLUSION

This study explored the application of bioclimatic architectural principles in the design of a contemporary commercial plaza in Pekanbaru. The design process demonstrates that climate-responsive strategies can be integrated into architectural decisions from the early planning stage. Building orientation, spatial organization, facade shading, natural ventilation, vegetation, and material selection were developed as complementary passive strategies to improve thermal comfort while reducing dependence on mechanical cooling.

The findings suggest that bioclimatic principles can support both environmental performance and contemporary architectural expression. Rather than treating sustainability as an additional design feature, the proposed approach integrates climate considerations into the overall design concept. This integration allows the building to respond more effectively to the humid tropical climate while maintaining its functional and aesthetic qualities as a commercial plaza.

Although this study is based on a design proposal and does not include quantitative performance evaluation, it provides a practical framework for applying bioclimatic principles to commercial buildings in tropical cities. Future research may incorporate building performance simulations or post-design evaluations to measure the effectiveness of the proposed strategies in improving thermal comfort and reducing energy consumption.

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