RUSTIC: Jurnal Arsitektur
Vol. 5, issue No. 2, July-December 2025, pp. 63~71
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v5i2.2955

Yogyakarta and Its Special Fascination: Iconic Landmarks, Memories, Hopes, and Challenges

Agus S Sadana[1*], L Edhi Prasetya[2], Ashri Prawesthi Dharmaraty[3], Adryanto Ibnu Wibisono[4], Swambodo M Adi[5]
[1-5]Architecture Program, Faculty of Engineering, Universitas Pancasila, Jakarta, Indonesia

Article Info

Article history:

Received Jan 30, 2025
Revised Jun 11, 2025
Accepted Jun 23, 2025

Keywords:

City branding;
City landmark;
Collective memory;
Cultural identity;
Yogyakarta's icon

ABSTRACT

This study discusses the Tugu Pal Putih as a symbol of cultural identity and branding of the city of Yogyakarta through visual elements, expressions, and discussions on Instagram social media. The research was carried out qualitatively with a netnography approach and visual analysis of Instagram content related to this cultural landmark. The analysis is done through a thematic coding process to identify dominant themes and patterns reflecting public perceptions. The study results show that Tugu Pal Putih is not just a physical landmark but also a symbol of pride that forms a collective memory and emotional connection to Yogyakarta's atmosphere. Themes such as longing, ideal city, and pride reflect strong public attachment. Despite its distinctiveness, issues like hot weather and traffic congestion present challenges that require adaptive strategies. The integration of cultural, visual, and emotional elements enhances city identity and supports effective city branding. These findings offer insight for branding management to maintain the uniqueness of Yogyakarta as a cultural place.

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Corresponding Author:

Agus S Sadana
Architecture Program, Faculty of Engineering, Universitas Pancasila
Jalan Srengseng Sawah, Jagakarsa, South Jakarta, Indonesia 12640
Email: agus.sadana@univpancasila.ac.id

1. INTRODUCTION

Yogyakarta is a cultural city rich in tradition and history, with Tugu Pal Putih as its icon [1] [2]. As Yogyakarta's icon with a distinctive character that is rich in historical, traditional, and cultural values, Tugu Pal Putih has become a symbol of identity and pride for Yogyakarta's people [2] [3] [4] [5] which not only represents physical aesthetics but also has deep philosophical value and plays its contribution in presenting a memorable and meaningful atmosphere of the environment. Concerning the design of urban spaces, the physical shape and presence of Tugu Pal Putih as a landmark, as well as the philosophical value it contains, have enriched the visual and emotional experience that forms the community's collective memory of Yogyakarta [4] [6].

The development of social media has also contributed to elevating Tugu Pal Putih as an icon that often appears and sparks discussions and conversations on social media, strengthening the collective memory of the place [7]. This implies that the more prominent Tugu Pal Putih is an iconic digital-age city landmark, in photos, discussions, and various other expressions, discussions, and various other expressions. It further strengthens Yogyakarta's branding [8] as a place that has the power to be remembered and lived. Social media, especially Instagram, has become a space for people to share their personal stories and experiences related to Tugu Pal Putih. Instagram is a social media platform that often shares photos of the Tugu Pal Putih in various aspects of its aesthetics and atmosphere. In line with the view of the contribution of social media in evoking the emotional aspect of a place that evokes collective memory [9]. Comments and discussions on social media show Tugu

Pal Putih as a visual object that evokes the emotional, cultural, and historical connection of the people with Yogyakarta through online community discussions.

(a) (b)

Figure 1. The Tugu Pal Putih, (a) morning atmosphere, sunny; (b) afternoon atmosphere, rainy (source: author 2022; 2025)

Based on this background, this study aims to analyze Tugu Pal Putih's contribution as a symbol of Yogyakarta's identity and pride in building city branding through visual and narrative elements in discussions on Instagram social media. Based on this background, this study aims to analyze Tugu Pal Putih's contribution as a symbol of identity and pride that brands Yogyakarta through collective memory, which develops through visual analysis and discussion on Instagram social media. Related to the purpose of the research, this research seeks to answer the question: how does Tugu Pal Putih contribute as a symbol of Yogyakarta's identity in shaping public perception, collective memory, and city branding through digital visualization and discussion on Instagram social media.

2. METHOD

The research was conducted qualitatively by combining netnography methods and visual content analysis. The research idea was inspired by a discussion on social media Instagram involving photos of Tugu Pal Putih as a conversation starter about about the city of Yogyakarta. The selection of these photos remembers the contribution of Tugu Pal Putih as an essential element of the city's philosophical axis and icon that represents cultural values through its visual attraction that attracts many people [2]. In connection with this contribution and attraction, this study is designed to answer research questions about the contribution of Tugu Pal Putih as a symbol of identity and pride that supports Yogyakarta's branding.

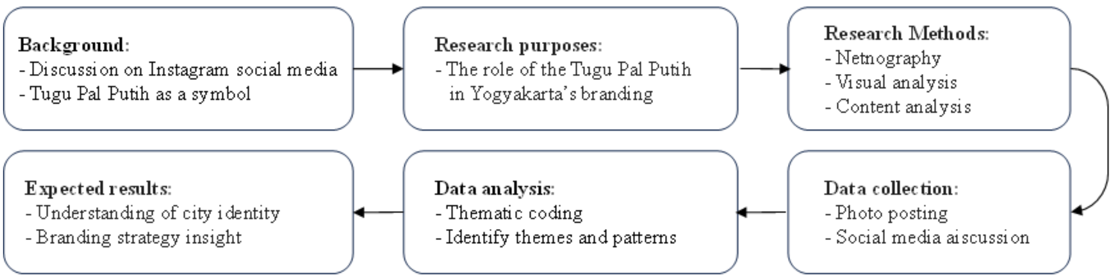

Figure 2. The Research conceptual framework (source: author)

In the world of social media, various Instagram accounts present information about Yogyakarta. This study analyzes one of the accounts that often displays photos of Tugu Pal Putih, a Yogyakarta's icon, consistently as its main attraction, which also illustrates its contribution as an important element of the city.

Table 1. The position of the selected Instagram account among similar accounts

Information	Relevant Content	Data Suitability
Instagram accounts analyzed	Often displays photos of Tugu Pal Putih as Yogyakarta's icon	Meet the criteria for analysis
Other Instagram accounts	Displaying inconsistent content related to Tugu Pal Putih	Not selected for analysis

Source: author (2024). Update data December 15, 2024

The data analyzed were words that appeared in conversations evoked by photo posts of Tugu Pal Putih in ten different moods in an online community on Instagram. Data was collected from online community discussions on Instagram from August 19 to December 11, 2024. The data includes visual data in the form of photos of the Tugu Pal Putih in various atmospheres, text embedded in the pictures, photo descriptions, and conversations that occurred.

The thematic coding structure in this study was built inductively, developing gradually through direct experience and reflection during the qualitative data exploration process [10] [11]. Themes were developed from repeated readings of photos, texts, and online discussions on Instagram, with a systematic approach that, step by step, progressed gradually through the stages of open coding, axial coding, and selective coding to formulate patterns of meaning that emerged through deep engagement with the data, organized into a conceptual model that explains research findings [11], as a reflection of users' expressive situations in the digital space under study. To optimize data management effectiveness, the data is managed using NVivo software version 12 and processed into a thematic coding system for further analysis [12]. The results can reveal the relationship between visual elements and expressions formed in the public's view of Tugu Pal Putih as a symbol of Yogyakarta and identify the dominant patterns of discussion related to city branding.

The ethical aspect is a limitation of this study. The objects in the photo are public city landmarks, Instagram accounts, and conversations researched in the public domain, which anyone can access, follow, share, and comment on freely. The photo of the object in the article is the researcher's documentation, does not come from any social media account, and the identity of the recorded individual's face has been disguised. The content of the conversation does not involve sensitive elements; the profiles of the participants of the discussion are also anonymously disguised. Thus, the study is free from ethical risks and does not require special permission from the participants [13]. Instagram was chosen because it supports visual-based research, fits the city's branding theme, and has many active users who spark cultural discussions through public content. Researchers are not directly involved in maintaining the neutrality, privacy, and authenticity of data according to the netnography method.

3. RESULTS AND DISCUSSION

Yogyakarta is the right location for research because of its distinctive cultural richness [4]. Furthermore, Tugu Pal Putih is the main focus of the data collection process because of its visual form and contribution as a prominent identity symbol in representing the uniqueness of Yogyakarta's culture. This can be seen from the most dominant and most expressed identified themes in online discussions, which include symbols of pride, longing for the atmosphere, and the ideal city. The themes identified reflect Yogyakarta's position as a city with strong attraction, rooted in cultural identity in the north-south line of city 'philosophical axis' [14] [15]. The emphasis on this identity is linked to dominant themes: symbols of pride, longing for the atmosphere, and the city of dreams, so the research remains focused on its central theme. The results show that the dominant elements of the identified themes are summarized and appear as a central theme, namely the 'Yogyakarta's special fascination.' The process of assessing the identified themes helps to deepen the understanding that Yogyakarta is a city rich in cultural heritage and full of emotions and hopes.

3.1. Word patterns and theme visualization

The data coding results showed dominant words and themes that reflected various significant aspects of the individual experience and were interrelated to the identity and Yogyakarta's attractiveness. The frequency of these words and themes indicates that the name of Yogyakarta carries a strong identity along with deep emotional and spiritual values. The emotional aspect is represented by word processing: missing, longing, and unique, while the spiritual aspect can be seen from the appearance of the words again and wait. The combination of these words strengthens Yogyakarta's image as a meaningful and unique city.

Eight words and synonyms dominate the conversation, with the photo of Tugu Pal Putih being the lighter. Of the eight dominant words and their synonyms, one word leads to negative sentiment, namely the word "hot," which represents the sub-theme of weather challenges. Table 2 shows the dominant words, their number of occurrences, and their meanings.

Table 2. Dominant words, number of occurrences, and the meanings (source: author. Results of data analysis in NVivo)

No.	Word	Number of Occurrences (times)	Meaning
1	jogja, yogyakarta, #yogyakarta, @yogyakarta	1047	The word "Yogyakarta" appears in several variations: jogja, yogyakarta, #yogyakarta, and @yogyakarta. The dominance of the conversation on these variations in various discussions on social media reflects Yogyakarta's position as an interesting center of attention to discuss, both as a place that evokes memories, a strong cultural identity, and as a source of inspiration and aspirations.
2	missing / kangen	363	The word "missing" describes the strong emotional connection between individuals and Yogyakarta. The high number of occurrences shows that the word "kengen" indicates a deep sense of longing related to personal experiences and memories. "Kangen" shows the emotional bond of the community to certain atmospheres, places, and moments in Yogyakarta.
3	longing / rindu	207	The word "longing" has a similar meaning, which describes a strong emotional bond. However, "longing" tends to be used in more in-depth discussions, and tends to be related to memory or hope to return to the city of Yogyakarta.
4	special / istimewa	198	The word "special" strengthens Yogyakarta's image as a unique city with a distinctive fascination. The number of appearances shows how people associate the city of Yogyakarta with extraordinary things, both physically and emotionally. The word "Special" also emphasizes Yogyakarta's branding aspect as an unusual and meaningful place.
5	aamiin	173	The appearance of the word "aamiin" indicates the spiritual aspect or prayer that is often said when there is a discussion about Yogyakarta. This illustrates the hope of the community, both to return, improve their lives and achieve happiness by living in Yogyakarta.
6	wait / tunggu	156	The word "wait" reflects hope and patience, often associated with plans to return or visit Yogyakarta, or looking forward to a specific moment related to the city of Yogyakarta. This word indicates positive hope with respect to the upcoming experience.
7	patience / sabar	122	The word "patience" describes a strong desire to visit, return home, or return to Yogyakarta. These desires tend to be individual and related to the opportunities that each individual has. The word "patience" holds a deep meaning that emotionally strengthens the feeling of longing or longing for Yogyakarta.
8	hot / panas	116	The word "hot" refers to the situation that is often expressed by the public or tourists about the weather conditions in Yogyakarta. The number of occurrences of the word "hot" is not too high, but it can still reflect a significant negative sentiment, even if it does not reduce the overall attractiveness of Yogykarta as a coveted city.

Based on the results of data coding, as many as 19 sub-themes can be identified and grouped into nine themes. The identified themes illustrate people's perceptions and emotional relationships with the city, as well as individual experiences, perceptions, and relationships with Yogyakarta. The nine themes that were successfully identified in the coding process include:

1) Travel activities include various experiences while in the city, both routine trips and tourist trips.
2) Physical and landscape aspects, which highlight the city's visual elements, such as historical buildings and open spaces, and the overall environmental condition.
3) The aspect of the meaning of place, which is related to symbolism and values inherent in specific locations in Yogyakarta.
4) The psychological aspect reflects the emotions, perceptions, and deep impressions individuals feel in this city.
5) Aspirations for Yogyakarta involve the community's hopes, dreams, and views regarding its future.
6) Impressions and feelings describe how people internalize their experiences in Yogyakarta and how these experiences shape their emotional connection with the city.
7) The commitment to return shows a person's attachment to Yogyakarta, so the intention to visit or even settle in this city arises.
8) Personal experiences, which include unique individual stories and how those experiences influenced their view of the city.
9) Challenges identify issues or obstacles faced by residents and visitors, such as infrastructure, weather, or other social aspects issues.

These dominant themes are an important foundation for understanding how each element of the city complements each other and presents a special experience that each individual feels. Figure 3 visualizes individual experiences, perceptions, and relationships with Yogyakarta.

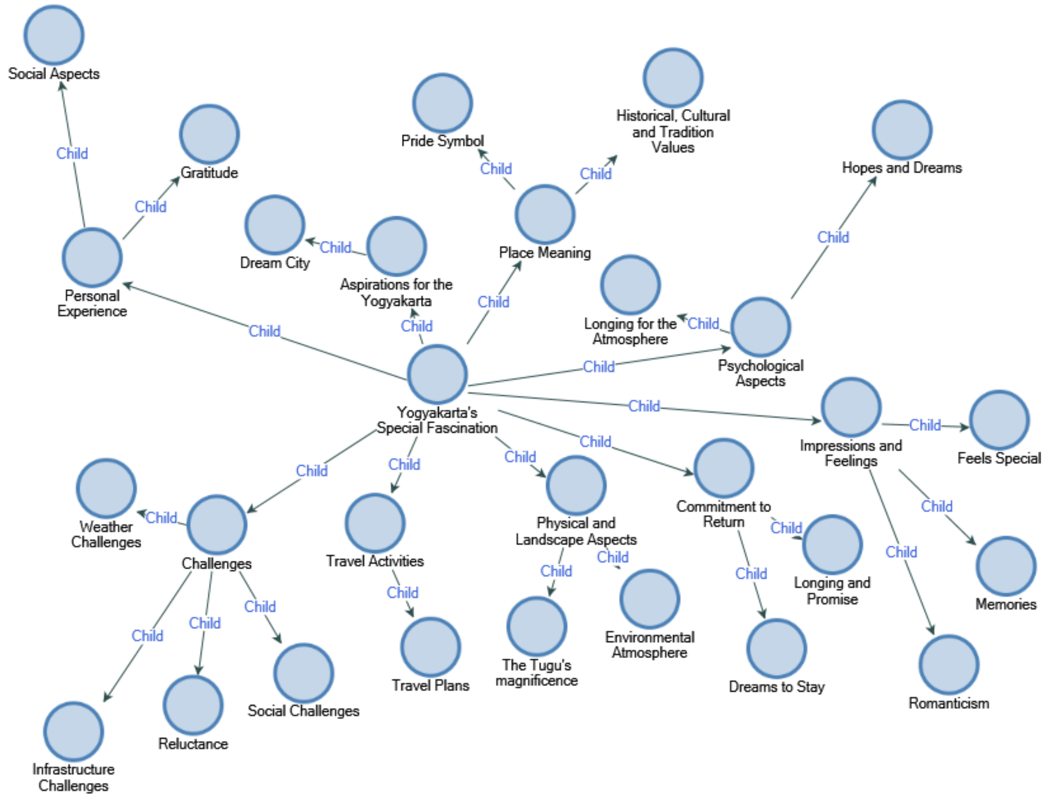

Figure 3. Visualization of themes and sub-themes rooted in individual experiences, perceptions, and relationships with Yogyakarta

Remarks: the closer the sub-theme is to the center, the more related it is to the main theme, and vice versa

3.2. Yogyakarta's special fascination

Tugu Pal Putih is the main focus of the research. This monument is a combination of physical symbols and cultural identity of Yogyakarta that is able to bridge local traditions and culture with modern life. This role can be seen in a dynamic discussion on Instagram social media when the figure of Tugu Pal Putih is present as a conversation starter. Furthermore, the results show that Yogyakarta's attractiveness is derived from its traditional and cultural values and strengthened by the emotional elements built from these values and felt by the community. This special fascination is illustrated by the results of the selective coding analysis conducted in this study, where the central theme 'Yogyakarta's Special Fascination' emerged as a summary of the themes that emerged, incredibly dominant themes such as symbols of pride, longing for the atmosphere, and cultural values and traditions that are deeply rooted in Yogyakarta.

Yogyakarta has rich cultural values that are reflected in its philosophical axis [14] [15] as the city's identity [5], with The Tugu Pal Putih being an essential part of it and also serving as one of the city's iconic symbols [2]. The study shows that the location of the study had a strong emotional attraction, making Yogyakarta a unique and special place. The special fascination is manifested from the combination of local values discussed on Instagram, including the longing for the atmosphere, dream city, a symbol of pride, gratitude, hope, and dreams, weather challenges, feeling special, longing and promise, and their memories. The study results also show that Tugu Pal Putih plays a role in shaping the image of a cultural city. It evokes deep emotional experiences that mesmerize people through its unique philosophical values, strengthening their connection with Yogyakarta. Of all the themes that have been successfully identified, seven themes stand out. They can attract the attention of many people and evoke emotional connections that form the community's collective memory towards Tugu Pal Putih and Yogyakarta. These themes can be seen in Table 3.

Table 3. The prominent themes rank emerged from discussions related to Tugu Pal Putih pictures (source: author. Note: Texts with bold letters are the dominant theme/sub-theme)

Theme	Sub theme	Number of quotes	Theme	Sub theme	Number of quotes
Psychological Aspects	**Longing for the atmosphere**	398	Challenge	Weather Challenges	156

Aspirations for Yogyakarta	**Dream City**	245	**Impressions and Feelings**	Feels Special	151
Aspects of the Meaning of Place	**Pride Symbol**	196	Commitment to Return	Longing and Promise	106
Personal Experience	Gratitude	172	**Impressions and Feelings**	Memories	104
Psychological Aspects	Hopes and Dreams	163	Physical Aspects and Landscapes	Environmental Atmosphere	86

Table 2 shows the theme and sub-themes that are essential elements that contribute to forming the central theme. In the table, two dominant themes are marked by their appearance twice: psychological aspects, impressions, and feelings. In contrast, the dominant sub-themes are the top three sub-themes with a total of about 200 citations or more, namely sub-themes longing for the atmosphere, dream city, and symbol of pride. Combining this dominant theme and sub-theme forms an integrated relationship that strengthens each other in formulating the central theme with the support of different themes and sub-themes. The process of formulating the central theme can be seen in Figure 3.

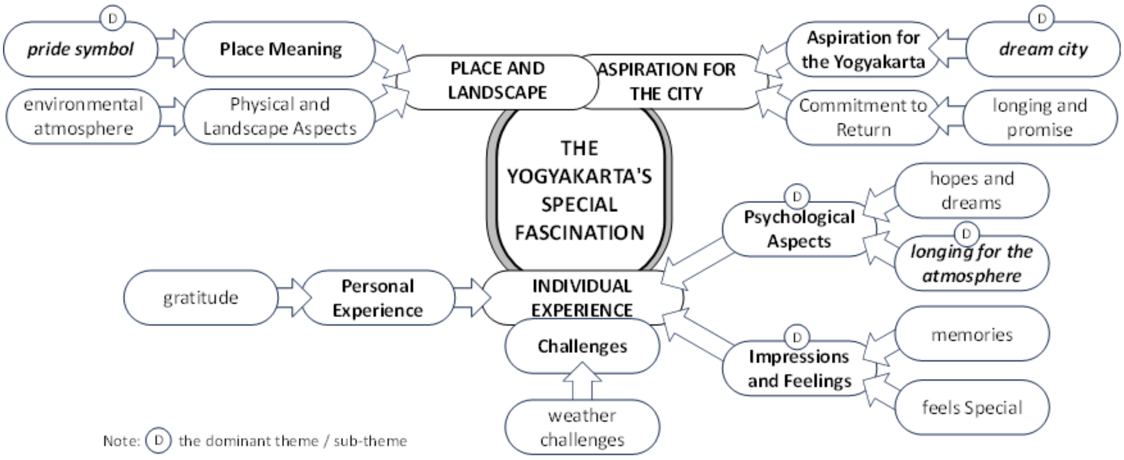

Figure 4. Dominant theme and sub-theme relationships in the process of forming the main theme (source: author. Data analysis)

The pattern of relationships between themes in Figure 3 shows the process of formulating themes and sub-themes as the main themes. The image shows the central theme through three binding elements: aspirations for the city, places and landscapes, and individual experiences. The three binding elements combine the dominant theme and sub-theme with the support of other themes and sub-themes, forming the central theme, 'Yogyakarta's Special Fascination.' Furthermore, the three most dominant sub-themes, longing for the atmosphere, the dream city, and the symbol of pride, became the main foundation and formed a strong flow in realizing the central theme of "Yogyakarta's Special Fascination."

The subthemes illustrate the sense of pride, hope, and emotional connection between people and Yogyakarta, which is established through their aspirations for the cityscape and their personal experiences. The substantial aspect of longing shows their desire to re-experience Yogyakarta's unique and special situation. At the same time, the dream city reflects the ideal image of the community towards Yogyakarta as a place to live. The symbol of pride emphasizes the deep meaning of Tugu Pal Putih as an icon of the city that is felt to represent Yogyakarta as a whole. These three elements reinforce each other and provide a solid foundation for the presence of a sense of awe. Fascinated has a meaning that is commensurate with being fascinated. Being amazed or fascinated often involves an element of surprise or unexpected uniqueness that triggers an individual's strong sense of emotion [16]. The study results show that the research locus, Yogyakarta, has an extraordinary uniqueness. This exceptional condition is something special [17].

Based on the combination of the dominant theme and subtheme, the phrase "special fascination" can be raised as the core of the central theme. Yogyakarta was related to the research locus, and then the core of the theme was developed into the central theme, 'Yogyakarta's Special Fascination.' The fascination reflects how people's emotional relationships, aspirations, and experiences are integrated into their view of Yogyakarta. As the central theme, the 'Yogyakarta's Special Fascination' also illustrates how the city's identity is rooted in integrating cultural, social, and visual elements that complement each other. The study results show that this central theme consistently retrieved in various community interactions through social media. 'Yogyakarta's

Special Fascination' is present \in terms of physicality and also in the stories that are revealed in the conversation, showing the existence of social values reflected in people's daily lives. The friendliness and simplicity of the people, as shown in the photo descriptions and transcripts of online conversations, reinforce Yogyakarta's image as a comfortable and meaningful city.

The presence of Tugu Pal Putih as a backdrop in various celebrations and essential moments further emphasizes the monument's contribution as a symbol of community pride. This situation shows that Yogyakarta has strong emotional, social, and spiritual values, reflected in its physical form, reflected in its physical form. By understanding these elements, Yogyakarta can continue to maintain and develop its image as a city that is not only culturally special but also emotionally special for all who visit it.visit it.

3.3. The challenges behind Yogyakarta’s fascination

The study results show that negative sentiments can obscure the unique fascination of Yogyakarta. The most frequently discussed negative sentiment is the word "hot," one of the eight dominant words in the conversation, found in Table 2. The word "hot" describes Yogyakarta’s weather conditions, which is a lowland at an altitude of +113 meters above sea level [18] in the tropics [19]. This hot weather is a challenge for city managers, who must develop adaptive strategies to present a more comfortable and friendly environment to reduce negative perceptions of people's views of Yogyakarta. An overview of the challenge can be seen in Figure 4, which links aspects of the challenge to the individual's experience.

Other negative sentiments are reluctance, social challenges, and infrastructure challenges. Reluctance arises from unpleasant experiences that individuals have felt, for example, in the expression, "Jogja is beautiful but not with memories." This shows a gap between high expectations for Yogyakarta and the perceived reality. Social challenges include overcrowding of cities due to tourists, damage to public facilities, concerns about security content such as "klitih," and poor waste management. This situation can reduce the social comfort and Yogyakarta’s attractiveness. Meanwhile, infrastructure challenges focus on worsening traffic congestion and inadequate public facilities. This shows the imbalance between the city's attractiveness and the adequacy of its physical facilities, which leads to an uncomfortable spatial experience. The combination of negative themes can create negative perceptions that can reduce Yogyakarta's attractiveness as a unique cultural city.

4. CONCLUSION

This research succeeded in showing the contribution of Tugu Pal Putih as a cultural icon that strengthens the identity of Yogyakarta through emotional interaction, collective memory, and conversations in digital media. Some of the key findings of the study are:

1) The Tugu Pal Putih contribution as Yogyakarta's Identity
   As Yogyakarta's landmark, Tugu Pal Putih's presence mirrors the traditional, cultural, and philosophical values that colour the city. As a physical icon of the city, this monument plays a role in reviving memories and building hope and gratitude in the community, a combination that further strengthens Yogyakarta's attractiveness as a special city.
2) Social Media Interaction and Collective Memory
   The results of data analysis from Instagram show that Tugu Pal Putih acts as a discussion trigger that evokes an individual's emotional sense of place involving themes such as longing, dream city, and symbol of pride. This conversation on social media strengthens the branding and Yogyakarta’s position as a cultural city with a unique attraction.
3) Yogyakarta’s Special Fascination
   This research produced the main findings of "Yogyakarta’s Special Fascination," which was formed through a combination of dominant themes representing values such as pride symbols, longing for the atmosphere, and the ideal city. These values are a weave of individual visual, emotional, and spiritual experiences that are collected and form the community's collective memory of Yogyakarta.
4) Challenges Faced
   Yogyakarta has extraordinary cultural value but faces challenges in the form of hot weather, traffic congestion, and poor management of public facilities, which can lead to negative perceptions in the community. Therefore, an adaptive city management strategy is needed to maintain a sense of peace and pride to maintain the city's attractiveness.

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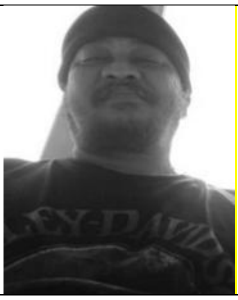
Notes on contributors

Agus S Sadana has permanent residence in Yogyakarta. He finished the undergraduate education from Sebelas Maret University, Surakarta, and Master of Architecture Engineering in the flow of Urban Design from the Master of Architecture at Diponegoro University, Semarang. The author has experience in compiling research and papers on public spaces, elements of urban areas, tourism aspects in urban architecture. The author has also written a book on human settlements and public spaces that draws on his teaching and research experiences. Currently, the author is a lecturer at the Architecture Program, Faculty of Engineering, Universitas Pancasila, Jakarta. The author can be contacted at the following email address: agus.sadana@univpancasila.ac.id

L Edhi Prasetya Born in Yogyakarta in 1972. He completed his undergraduate education at Gadjah Mada University, Yogyakarta in 1997 with a Bachelor of Architecture in Architecture, and a Master of Architectural Engineering at Diponegoro University in 2002. The author has a variety of work experiences, as a researcher at an NGO, supervisory consultant, and currently, the author is a lecturer at the Architecture Program, Faculty of Engineering, Universitas Pancasila, Jakarta. The author can be contacted at the email address: edhi.prasetya@univpancasila.ac.id

Ashri Prawesthi Dharmaraty completed his undergraduate program at the Department of Architecture, Sebelas Maret University, Surakarta, in 1997, and completed his Master's degree in Urban Development Studies at the University of Indonesia, in 2004. The author has a great interest in urban studies and has a lot of experience in compiling research. Currently, the author is a lecturer at the Architecture Program, Faculty of Engineering, Universitas Pancasila, Jakarta. The author can be contacted at the email address: ashri.prawesti@univpancasila.ac.id

Adryanto Ibnu Wibisono was born in Jakarta in January 1971. Completed his Bachelor's degree from the Architecture Study Program, Pancasila University, Jakarta, in 1995, then continued his Master's Education, in the Master of Architectural Engineering Program, Diponegoro University, Semarang, with the flow of Tropical Building Architecture, graduated in 1999. The author has professional experience in the construction company PT Hutama Karya (Persero) starting as Engineering Administration, Quality Control Inspector, Health and Safety Manager Currently, the author is a lecturer at the Architecture Program, Faculty of Engineering, Universitas Pancasila, Jakarta. The author can be contacted at the email address: adryanto.ibnu@univpancasila.ac.id



Swambodo M Adi completed his undergraduate studies at the Architecture Study Program, Pancasila University, Jakarta. He completed his Master of Architecture studies at the Master of Architecture Program, University of Indonesia. The author has a strong interest in aspects of architectural design, research experience, and quite diverse management experience. Currently, the author is a lecturer at the Architecture Program, Faculty of Engineering, Universitas Pancasila, Jakarta. The author can be contacted at the email address: swambodo@univpancasila.ac.id

RUSTIC: Jurnal Arsitektur
Vol. 5, issue No. 2, July-December 2025, pp. 72~79
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v5i2.2971

Analysis of Pedestrian Circulation Comfort at the Great Mosque of Central Java

Sepli Yandri[1*], Yessy Christanti Silaban[2]
[1] Faculty of Engineering and Maritime Technology, Universitas Maritim Raja Ali Haji, Indonesia
[2] Faculty of Engineering and Maritime Technology, Universitas Maritim Raja Ali Haji, Indonesia

Article Info

Article history:

Received Feb 18, 2025
Revised Jun 24, 2025
Accepted Jun 24, 2025

Keywords:

Great Mosque of Central Java;
Pedestrian;
Thermal Comfort;
Circulation;
Climate Factors

ABSTRACT

The Great Mosque of Central Java, in Semarang is one of the most well-known places of worship and religious tourism destinations, attracting many visitors for both prayer and the enjoyment of its beauty. This study aims to analyze the comfort of pedestrian circulation within the Great Mosque of Central Java, particularly focusing on the path leading to the main prayer room. The research examines the impact of circulation patterns on visitor activities and how vehicle parking influences pedestrian movement around the mosque. Additionally, climate factors such as temperature, humidity, and solar radiation play a role in determining visitor comfort when entering the mosque. This study provides an overview of how these factors contribute to the thermal comfort of visitors in the mosque area.

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Corresponding Author:

Sepli Yandri
Faculty of Engineering and Maritime Technology, Senggarang Campus, Jl. Daeng Kamboja, Senggarang, Tanjungpinang City, Riau Islands 29155. Email: sepli.yandri09@gmail.com

1. INTRODUCTION

Semarang is home to many immigrants, including students and tourists, as it serves as the capital of Central Java province. One of the notable tourist attractions in Semarang is the Great Mosque of Central Java, which is both a Muslim place of worship and a significant religious tourism site. Visitors come to the Great Mosque of Central Java for various reasons beyond simply worshiping. Several factors influence the decisions of these visitors. One of the key factors that prospective tourists consider when choosing a destination is the quality of infrastructure, particularly accessibility (Wakyudi et al., 2020) According to Mathiesen and Wall (Fandeli, 1995), some of the factors that guide visitors' decisions regarding their travel experiences include the desire to travel, evaluating different information about the destination, making decisions about the trip, and assessing the overall experience.

The beauty of the Great Mosque of Central Java attracts visitors, whether they come to worship or simply enjoy its splendor. One of the key factors for visitors when choosing a location to visit is comfort and aesthetic appeal. To enhance visitor comfort, pedestrian pathways within tourist facilities are designed to facilitate the movement of pedestrians toward their intended destinations (Hantono, D et al., 2024).

In this study, the researcher conducted observations aimed at assessing the comfort of pedestrian circulation as individuals moved toward the main prayer hall. In tropical climates, such as the location of this study, pedestrians generally experience thermal comfort when walking along shaded pathways, particularly during the daytime. Conversely, thermal discomfort is commonly felt when walking in open, unshaded areas where the body is exposed to direct sunlight for extended periods. In addition to solar exposure, thermal comfort is also influenced by wind conditions and air humidity. A gentle breeze can enhance comfort by facilitating the evaporation of sweat from the skin's surface. The research problem focuses on how much influence circulation has on visitor activities within the area, as well as the impact of vehicle parking on pedestrian spaces (Sangaji et al. 2015).

A place of worship (mosque) must be designed to facilitate the movement of visitors, allowing them to enter and exit the building with ease. In light of various potential issues that may arise in mosque buildings, the problem addressed in this study is to analyze the impact of the pedestrian areas as circulation pathways, focusing on their effectiveness in facilitating the ease of movement for worshippers.

The problem under study is the circulation of visitors across various pedestrian paths and how visitors respond when entering the courtyard of the Great Mosque of Central Java during the day, prior to the Dhuhur prayer, when the weather is extremely hot. By observing the circulation patterns of visitors, it is possible to identify which paths are most frequently used by those walking to the main prayer hall. Additionally, the impact of car and vehicle parking in pedestrian areas is also a key topic of discussion, as it affects the movement of pedestrians.

Local climate factors are the primary determinants of a person's comfort level, whether inside a room (building) or outdoors. Thermal comfort can be experienced both indoors and outdoors, including in areas such as pedestrian paths or walkways, where environmental factors such as temperature, humidity, and air circulation play a significant role in ensuring a comfortable experience for users (Polawati 2019). These climate factors influence comfort levels in both enclosed spaces and open environments (Lippsmeier, 1994), including air temperature, humidity, solar radiation, air movement speed, lighting levels, and the distribution of light on the view wall.

In general, thermal comfort refers to the state of feeling comfortable with the surrounding temperature conditions. Thermal comfort is always related to the climate (Sangkertadi, 2013). According to Peter Hoppe (as cited in Sugini, 2004), there are three perspectives on thermal comfort: the thermophysiological approach, the heat balance approach, and the psychological approach.

Psychological factors, such as a sense of security and comfort, also influence the quality of pedestrian pathways. Security refers to protection from vehicular traffic as well as the safety of the path itself. Comfort, on the other hand, is shaped by the presence of supporting elements, including the surrounding atmosphere, visual appeal, smooth circulation in accordance with standards, and the availability of complete supporting facilities (Iswanto. D. 2006).

As a thermophysiological process, thermal comfort depends on the activation and deactivation of thermal receptor signals in the skin and brain. In the heat balance approach, the heat flow to and from the human body is balanced, keeping skin temperature and sweating levels within a comfortable range. In the psychological approach, thermal comfort is defined as a state of mind that reflects a person's satisfaction with their thermal environment.

2. METHOD

2.1. Location and Timing

The research was conducted in Semarang City, specifically in the area surrounding the Great Mosque of Central Java, located on Jalan Gajah Raya, Sambirejo Village, Gayamsari District, Semarang City. Observations were carried out in the front area (outer space) of the mosque, focusing on the circulation of visitors as they approached the mosque. The person-centered mapping method was employed to analyze the circulation within both the interior and exterior spaces. Using this method, observations were made for each respondent or subject during a recorded period, with repetitions conducted until consistent results were obtained. The research was carried out between the time before and after the Dhuhur prayer, specifically from 11:00 AM to 1:00 PM WIB.

2.2. Data Analysis

Data analysis was conducted through observation, comprehension, and in-depth explanation of the research findings. The understanding of the data involved examining the routes chosen to reach the main prayer hall. Consequently, this analysis can serve as a reference for assessing the comfort of the pathways during midday, when the weather is extremely hot.

3. RESULTS AND DISCUSSION

The results of this observation were obtained by analyzing photographs of visitor circulation as they entered the mosque. To access the mosque from the front parking lot, there are three possible routes to reach the main prayer hall: the pedestrian path on the right side of the mosque courtyard, the pedestrian path within the mosque courtyard area, and the pedestrian path on the left side of the mosque courtyard.

Figure 1. The parking area for two wheeled vehicles is located right in front of the mosque (source: author)

Figure 2. Parking for four wheeled vehicles is located right in front of the mosque (source: author)

The pedestrian paths on both the right and left sides are lower than the courtyard path and are characterized by a shaded atmosphere, as they are flanked by supporting buildings and the courtyard. In contrast, the courtyard is expansive, and visitors are required to remove their footwear before entering the area. Additionally, the courtyard is equipped with six electric umbrellas, which are deployed only on specific days, such as during Eid prayers and Friday prayers. These umbrellas serve as sun protection for the congregation beneath them. On regular days, these umbrellas are not opened, which results in the courtyard being directly exposed to sunlight.

(a) (b) (c)

Figure 3. (a) Pedestrian path on the left side of the mosque. (b) Pedestrian path in the front area of the mosque. (c) Pedestrian path on the right side of the mosque. (source: author)

The following presents the results of observations conducted on pedestrian circulation at the Great Mosque of Central Java, both before and after the Dhuhur prayers.

To facilitate this discussion, I have classified the routes into three categories: Route 1 (left-side route), Route 2 (middle route/yard area), and Route 3 (right-side route).

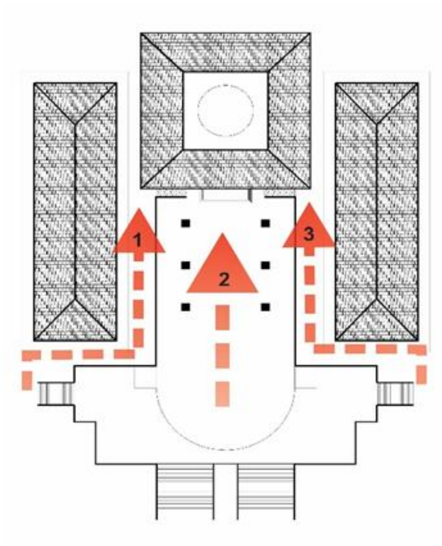


Figure 4. Pedestrian path in front of the Great Mosque of Central Java (source: author)

3.1. Circulation on Route 1

Pedestrian circulation on Route 1 is located on the left side of the mosque and is flanked by the Convention Hall building and the mosque courtyard. This route experiences relatively low foot traffic, with only a few visitors passing through. The visitors appear to walk leisurely and are not in a rush to reach the prayer hall. Additionally, there are vehicles parked in areas not designated for parking, which is likely to impact the comfort of pedestrians in this area.

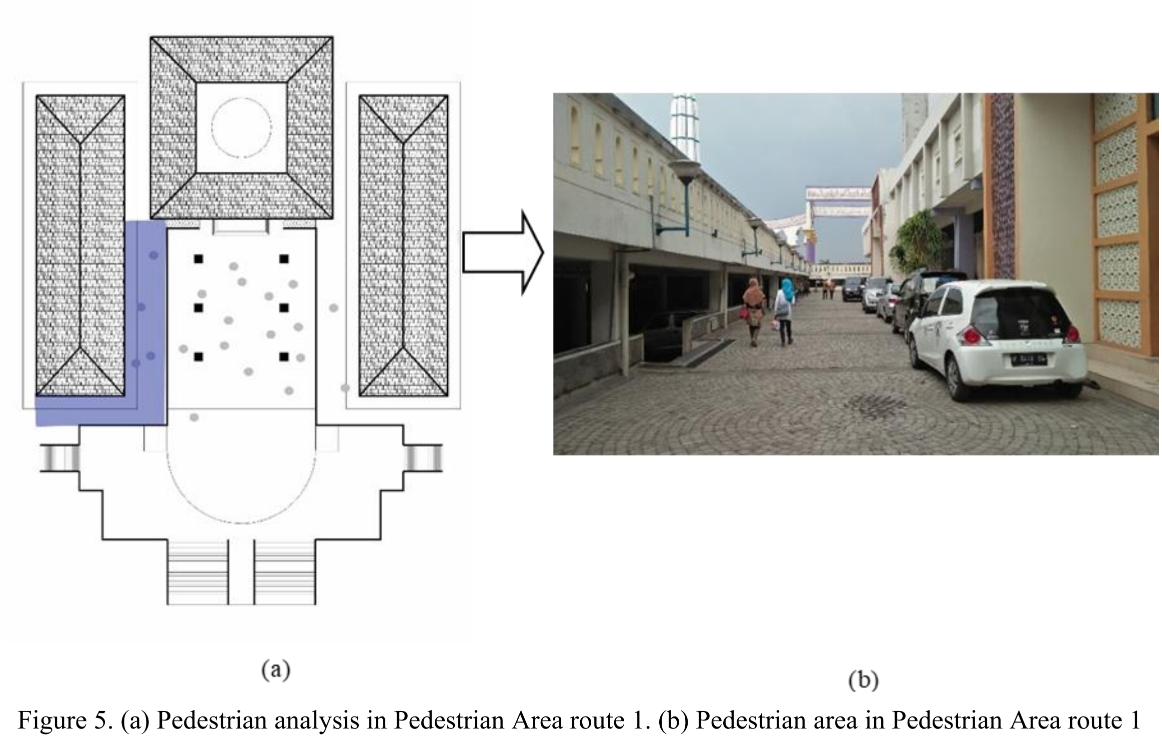


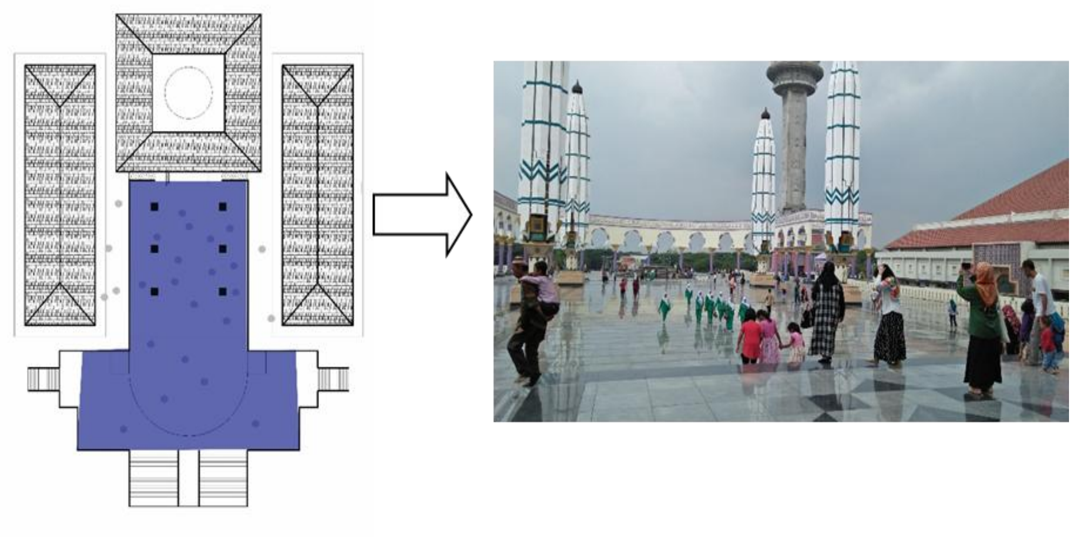
Figure 5. (a) Pedestrian analysis in Pedestrian Area route 1. (b) Pedestrian area in Pedestrian Area route 1 (source: author)

Route 1 exhibits the characteristics of a pedestrian circulation path that is less than optimal in supporting both comfort and movement efficiency. Its location—on the left side of the mosque and flanked by the Balai Sidang building and the mosque courtyard—creates the impression of an enclosed and visually restricted space. This spatial configuration may influence pedestrians' perception, particularly in terms of safety.

Overall, although Route 1 is still used by some visitors, its potential to serve as an integral part of an effective pedestrian circulation system has not been fully realized. A reorganization is necessary, including the provision of parking barriers, enhancement of visual quality, and the addition of supporting elements such as lighting, signage, and seating, in order to improve the functionality and overall comfort of the path.

3.2. Circulation on Route 2

Pedestrian circulation on Route 2 is located directly in front of the mosque, within the mosque's courtyard area. This circulation area experiences heavy foot traffic, despite the floor conditions being very hot during the day. Generally, the visitors in this area are predominantly teenagers. Many of these visitors are seen walking quickly toward the mosque, although a significant number also walk leisurely while taking photos and enjoying the view of the mosque's magnificent front.



(a) (b)

Figure 6. (a) Analysis of pedestrians in the pedestrian area of route 2. (b) Pedestrians in the courtyard of the mosque (source: author)

Route 2 serves as the main pedestrian circulation path located in the front courtyard of the mosque, making it a strategic point in the overall flow of visitor movement. Its position naturally attracts a high volume of pedestrian traffic, as it provides direct access to the mosque's main building. The high intensity of foot traffic along this route highlights its vital role in the site's circulation system.

Despite its frequent use, Route 2 presents a significant thermal challenge—specifically, the high surface temperature of the flooring during midday. This condition has the potential to reduce pedestrian thermal comfort, particularly during peak sunlight hours. Nevertheless, the continued heavy use of this route suggests a strong visual and symbolic appeal, especially due to the grand view of the mosque that serves as its backdrop.

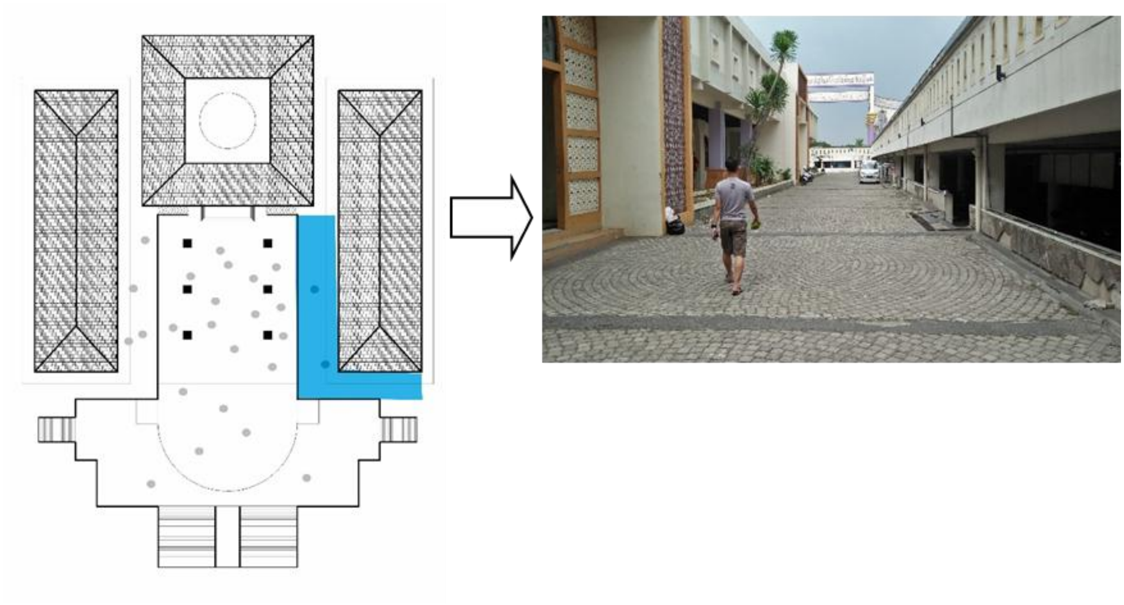
The presence of predominantly teenage visitors—some moving briskly toward the mosque, others strolling leisurely while taking photographs and enjoying the surroundings—illustrates that this route functions not only as a transit corridor but also as a social and visual space. Such behavior reflects the recreational and aesthetic significance of Route 2.

From a planning and design perspective, it is important to evaluate the choice of paving materials to mitigate excessive heat—such as using light-colored or textured surfaces that absorb less solar radiation. Additionally, incorporating shading elements like trees or lightweight canopies could enhance thermal comfort without obstructing the area's visual appeal.

In conclusion, while Route 2 has proven effective in facilitating pedestrian movement and enhancing the visitor experience, improving its physical attributes is essential to achieve a balanced integration of function, comfort, and aesthetics.

3.3. Circulation on Route 3

Pedestrian circulation on Route 3 is located to the right of the mosque, with the pedestrian area flanked by office buildings and the mosque courtyard. The circulation on Route 3 appears to be very quiet.



(a) (b)

Figure 7. (a) Pedestrian analysis in Pedestrian Area route 3. (b) Pedestrian area in Pedestrian Area route 3. (source: author)

Route 3 is a pedestrian pathway located on the right side of the mosque, flanked by office buildings and the mosque courtyard. Although this route has spatial potential as an alternative path for visitors, its usage appears to be very low. This condition raises questions regarding the factors contributing to the minimal pedestrian activity in the area.

The quiet nature of this route may also suggest a lack of integration with the main pedestrian circulation network, prompting pedestrians to opt for more direct or functional pathways. This is a critical issue in the context of spatial planning, as suboptimal circulation can reduce the overall efficiency of the pedestrian movement system within the area.

Therefore, a reevaluation of the function, design, and supporting elements of Route 3 is necessary. Enhancing the route with visual features, adequate lighting, and facilities such as seating, shade-providing plants, and directional signage could improve its attractiveness and enhance the sense of safety for users.

4. CONCLUSION

Based on the observations conducted during the Dhuhur prayer time, pedestrian circulation on the right and left sides of the mosque, although shaded, was not heavily trafficked by visitors passing through these lanes. This contrasts with the pedestrian movement within the mosque courtyard, where many visitors were seen walking quickly or even running toward the main prayer hall. This suggests that visitors may feel uncomfortable due to the hot conditions in the courtyard area during the day, particularly before the Dhuhur and Asr prayers. Despite this, many visitors prefer to pass through the courtyard rather than the two shaded lanes on the left and right, which are cooler. This preference could be attributed to several factors:

1. Visitors tend to prefer the shortest route to reach their destination.
2. Visitors seek to directly experience and appreciate the beauty of the mosque.
3. The presence of crowds in the courtyard area piques visitors' curiosity, prompting them to pass through this area.
4. Vehicles parked in the pedestrian areas of the left and right lanes obstruct pedestrian movement and activities.

Table 1. Advantages and disadvantages of pedestrian access to the mosque (source: author)

Pedestrian	Advantages	Disadvantages
Route 1 (Left side of the mosque)	This path is bordered by two buildings, which partially block the sunlight during the day, creating a shaded atmosphere on the pedestrian path.	From the front, visitors must first descend the stairs to access this path. Vehicles parked along this pedestrian path disrupt the comfort of pedestrians.
Route 2 (Mosque courtyard area)	This path is located directly in the center of the mosque and faces the main entrance of the mosque.	During the day, the floor tiles in the pedestrian area become very hot, causing visitors to walk quickly in order to avoid prolonged exposure to the heat.
Route 3 (Right side of the mosque)	Similar to Route 1, Route 3 is also flanked by buildings, which partially block the sunlight during the day, creating a shaded atmosphere for pedestrians.	Climbing this pedestrian path requires a slightly longer distance, as visitors must first descend the stairs. The presence of parked vehicles and traffic along this pedestrian path disrupts the comfort of pedestrians.

ACKNOWLEDGEMENTS

The entire team of authors would like to express our sincere gratitude to the visitors of the Great Mosque of Central Java, who kindly agreed to participate as respondents and subjects in our research study, contributing valuable insights that were essential for the completion of this project.

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Notes on contributors

Sepli Yandri is a lecturer at the Faculty of Engineering and Maritime Technology, Universitas Maritim Raja Ali Haji. He graduated with a master degree in architecture from Diponegoro University. His research focuses on traditional architecture, vernacular architecture, and urban design. He can be contacted at email: sepli.yandri09@gmail.com Sepliyandri@umrah.ac.id

Yessy Christanti Silaban is a lecturer at the Faculty of Engineering and Maritime Technology at Universitas Maritim Raja Ali Haji, specializing in architecture. She earned her master degree in Architecture from Diponegoro University and has since been actively contributing to the field of education, particularly in architecture. She can be contacted at email: Yechrs@gmail.com Yessysilaban@umrah.ac.id

RUSTIC: Jurnal Arsitektur
Vol. 5, issue No. 2, July-December 2025, pp. 80~88
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v5i2.3033

Identification of Structural Elements Towards Disasters: A Case Study of Osing Architecture

Elvina Shanggrama Wijaya[1*], Stephanus Wirawan Dharmatanna[2], Emmanuel Nicholas Birawa[3]
[1-3]Architecture Program, Faculty of Civil Engineering and Planning, Universitas Kristen Petra, Indonesia

Article Info

Article history:

Received Mar 24, 2025
Revised Jun 6, 2025
Accepted Jun 23, 2025

Keywords:

Structural behaviour;
Disaster;
Osing;
Architecture

ABSTRACT

Indonesia is an archipelagic country consisting of various tribes and cultures, one of which is the Osing Tribe in Banyuwangi, located at the eastern tip of Java Island, near Bali Island. The culture of the Osing tribe is manifested in the traditional Osing house architecture, especially in Kemiren Village, which is built from a combination of Osing's unique technology and art. From its position, the Banyuwangi area is located at the boundary of tectonic plates, which results in the potential for natural disasters such as volcanic eruptions, earthquakes, landslides, and tsunamis. This research aims to study the structural design of the traditional Osing tribe house in responding to these disasters threat. The identification of the structural elements is then analyzed to determine how the building will transmit the axial and lateral load, as well as withstand disasters. The result is that the Osing tribe house has applied the local wisdom, manifested in the house's tectonic design. The details of the building could respond and distribute the loads caused by disaster. Responding to the load from the volcanic ash, the Osing house's roof needs reinforcement to sustain its rigidity.

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Corresponding Author:

Elvina Shanggrama Wijaya
Architecture Program, Faculty of Civil Engineering and Planning, Universitas Kristen Petra, Indonesia
Email: elvinawijaya@petra.ac.id

1. INTRODUCTION

Traditional houses play an important role in preserving the cultural identity and history of a community. This traditional house is not just a physical building for shelter, but a manifestation of values, traditions, and knowledge passed down through generations. The traditions passed down through generations are usually carried out orally, which carries the risk of bias and even being forgotten over time. Therefore, the documentation of values, traditions, and knowledge becomes an important activity to undertake.

Study regarding traditional houses and architecture has been done intensively within the context of Indonesia, as Indonesia is a country that has many tribes and local wisdoms. Previous studies have highlighted the sustainability considerations found in Batak Toba culture [1], as well as studied the design typologies for traditional houses connected with certain cultural architectural styles [2], and even how different religious buildings are affecting each other in the past [3]. More technical studies regarding the thermal [4], [5] and ventilation [6] performance of vernacular houses also have been done to investigate and rethink whether the adapted local wisdom could be implemented in a more modern setting. Nevertheless, the study regarding the identification of structural components and performance of vernacular houses in response to the disaster risk is still rarely found.

One of the tribes that still preserves its cultural identity and history through traditional houses is the Osing tribe. The Osing tribe has the traditional village of Osing Kemiren located in the Glagah district. Currently, Osing Kemiren village has been designated as a tourist village in Banyuwangi [7] with an area of 117.032 hectares and a population of 2,569 people. The name of the traditional village Osing Kemiren comes from the name kemiri, which means many candlenut trees. This traditional village is also part of the Ijen Geopark and Cultural Site.

Figure 1. Kemiren Village from East and West (source: author)

The settlement of the Osing tribe stretches from East to West [8]. In Figure 1, it can be seen that the settlement pattern of the Osing tribe is linear. The shape of the traditional Osing house is influenced by three main factors: social factors, environmental factors, and belief factors [9].

The structural system of Osing house has a unique feature, namely the installation of the main structure using a joint system, which means without using nails. In addition, the construction system and structure of the Osing house contain meanings and beliefs where the construction and joints of the Osing house symbolize domestic life and can be seen in the wooden joints that have a vertical arrangement so that they do not meet at a single point [10].

On the other hand, based on its geographical position, Banyuwangi is located on land ranging from lowlands to highlands, above the boundary of the Indo-Australian and Eurasian tectonic plates. The village of Kemiren itself, as a tourist village in Banyuwangi, is located in the Glagah sub-district. Based on Banyuwangi Regency Regional Regulation No. 08 of 2012, concerning the Banyuwangi Regency Spatial Plan for 2012 - 2032, Glagah Village is included in areas with threats of land movement vulnerability and volcanic eruptions [11]. On the national disaster map of East Java by the National Disaster Management Agency, the Banyuwangi area generally has a high threat of earthquakes and tsunamis. There is also a threat of volcanic activity, due to the location of the city.

Previous research focusing on the Osing House are focusing mainly on the sustainability aspects of the structure [12], including the tropicality of the design [13] and the orientation of the masses [14], yet there are still a very few studies detected regarding the design response to the disaster threat.

Based on the above description, the idea emerged to analyze the structural behavior applied by the Osing tribe in building their traditional houses and study the design responses made to withstand the loads that the structural elements of the Osing traditional house must bear, which are caused by the disaster.

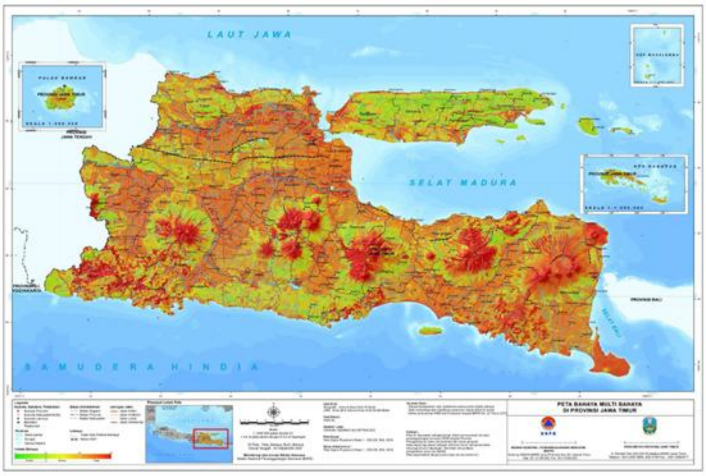


Figure 2. Map of Multi Disaster-Prone Areas in East Java (source: “BAHAYA_MULTI_BAHAYA_JATIM.jpg,” accessed Apr. 16, 2025. Available: https://files.bpbd.jatimprov.go.id/)

2. METHOD

This research adopts a qualitative approach by initiating a series of field activities aimed at understanding the structure and characteristics of the Osing traditional houses in Kemiren Village, Banyuwangi. The initial step involves a direct visit to the location for observation and interviews with village elders, who serve as key informants. This interview aims to explore information regarding the history, philosophy, and construction techniques of the Osing traditional house, as well as local knowledge related to potential natural disaster risks. In addition, the sketching of the structural elements of the Osing traditional house is carried out to visually document the construction details relevant to disaster resilience aspects.

Data collection on natural disaster risks in the Banyuwangi region, specifically in Kemiren Village, was conducted through documentation studies and spatial analysis. Existing disaster mapping, both from government sources and scientific research, is integrated to gain an understanding of potential threats such as earthquakes, landslides, and volcanic eruptions. Considering the village configuration that still preserves the existence of traditional Osing houses, disaster risk mapping is focused on the local scale of Kemiren Village, specifically on its typical residential buildings of the Tikel Balung type.

Next, this research applies a comparative method by comparing disaster standards that are applicable nationally and internationally with the actual conditions of the Osing traditional houses in Kemiren Village. This comparison aims to identify gaps and potential vulnerabilities in the traditional house structure against disaster threats. The analysis of structural elements was conducted in-depth to understand how each component of the building contributes to overall resilience. Based on this analysis, the research then identifies building elements that have the potential to be developed or modified to enhance the resilience of the Osing traditional houses against natural disasters.

3. RESULTS AND DISCUSSION

3.1. Osing House

Based on the Literature Study, the traditional Osing house is built using local materials and construction details, namely stone, wood, bamboo, and tiles. The structural system used in this traditional house is a frame system with wood as the main material. The anatomy of the elements that make up the Osing Traditional House is as follows:

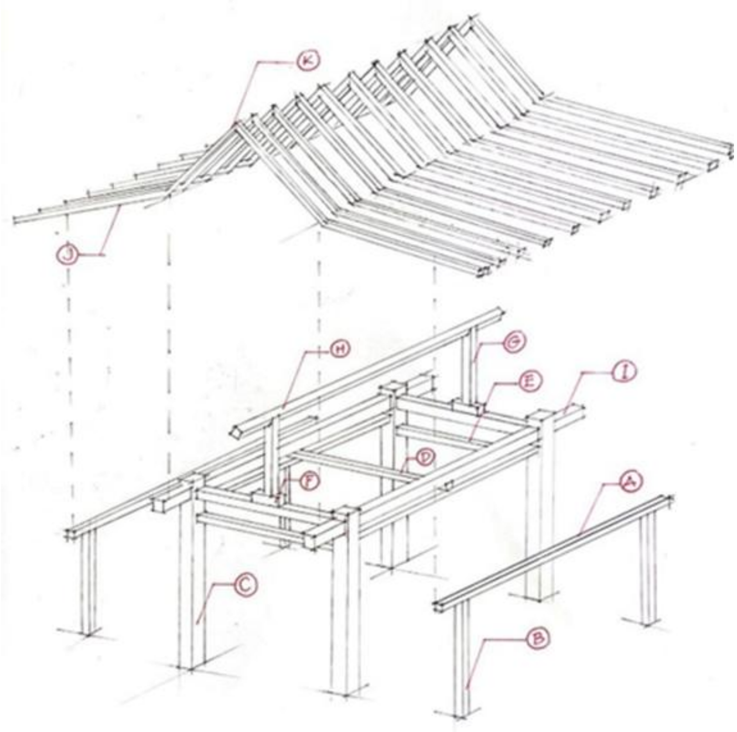


Figure 3. The anatomy of the Osing Traditional House (source: author)

Table 1. Osing House Structural Anatomy (source: author)

Code	Element name	Structural Function
a	Glandar	Beam which connects soko tepas (b)
b	Soko Tepas	Additional perimeter columns that supports side and front roof
c	Soko	Main columns that support the whole building. Soko columns are found in each of the Osing house typology. The configuration of one set of soko columns consist of four soko columns that represent parents of two families that are going to be one family
d	Lambang	Beams that are located above the Jait beams
e	Jait	Main beams that connect four soko columns. The shorter beams are called Jait Cendek, and the longer beams are called Jait Dowo
f	Doplak	A log that is placed between the lambang beams and ander, to strengthen the ander position
g	Ander	Vertical wooden bar that connects lambang and jait beam with suwunan (top roof beam)
h	Suwunan	Roof's top beam that parallel with the pelari cantilever beam
i	Pelari	Wooden cantilever beam that is located above the jait dowo beam. Pelari beam supports the roof by making a landing for dur atas beam
j	Dur Bawah	Sloped roof joists that span between lambang (D) and glandar (A)
k	Dur Atas	Sloped roof joists that span between suwunan (H) and pelari (I)
l	Reng	Wooden beam that leans on dur joists, supporting the placement of terracotta roof
m	Rab	Roof area, that is divided into upper rab and side rab

In addition, the Osing tribe's houses have a distinctive feature at the junction of the column with the ground, called Ubeg. Ubeg is a solid wood where the column rests before being connected to a stone base, which aims to lock and prevent the column from touching the ground, as seen in figure 3, which would cause moisture to rise into the column. In this case, the sopak stone is only placed on the ground and drilled to the size of the ubeg, which restricts the movement of the ubeg itself.

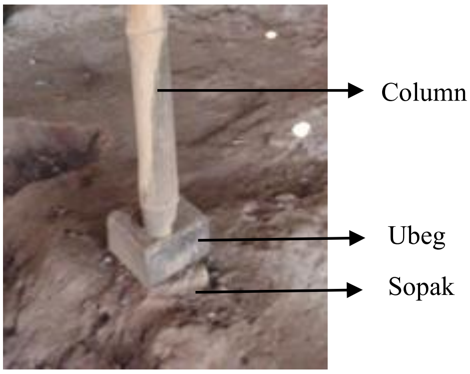
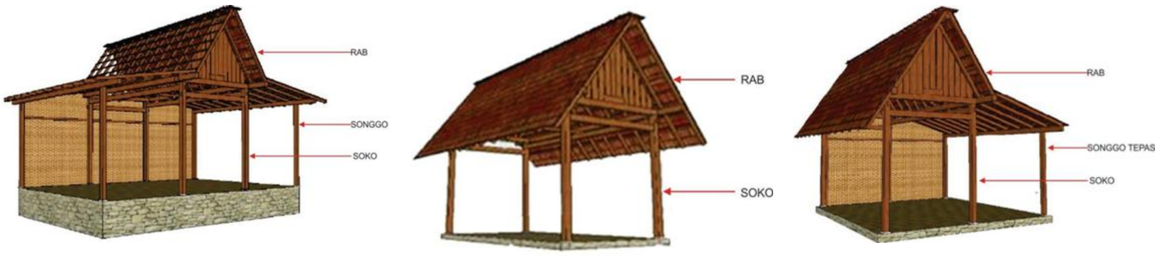


Figure 3. The connection between ubeg and sopak stone (source: author)

Furthermore, in its original state, there are three types of Osing traditional houses, distinguished by their roof shapes, that can be seen in figure 4 [11]:

1. Tikel House
   The tikel house shape is the most perfect form of the traditional Osing house. This house has a roof in the shape of a kampung srotong with 4 (four) Rab, 4 (four) Soko, and 2 (two) Soko Tepas.
2. Cerocogan House
   The shape of the Cerocogan house is a type of house with a traditional village roof consisting of 2 (two) Rab with 4 (four) Soko without Soko Tepas. For a complete house, the Cerocogan shape is often used as a Pawon or kitchen.
3. Baresan House
   The Baresan house shape is a type of house that consists of 2 (two) Rab with 4 (four) Soko and 2 (two) Soko Tepas. This type of house is similar to the Tikel house but appears less perfect. The Baresan house is often used as a kitchen if its Bale is in the form of a Cerocogan.



(a) Tikel House (b) Cerocogan House (c) Baresan House

Figure 4. Variety of Osing House (source: PERBUP Kab. Banyuwangi No. 11 Tahun 2019)

The majority of the typical traditional homes in Kemiren village are Tikel homes, which were built using original methods. However, they have undergone small spatial adjustments based on the demands of the users, such as the inclusion of more partitions and the enlargement of the kitchen's roofed area (pawon).

3.2. Disaster threat in Banyuwangi

Disaster-responsive design will take disaster risks into account in building design, so that the building remains safe for its users and does not collapse until the required time. Especially in the Banyuwangi area, the disasters that must be considered are:

1. Landslide Vulnerability

   The disaster of land vulnerability movement occurs due to land movement caused by landslides, subsidence, and liquefaction [16]. Soil that has become saturated with water, along with the steepness of the slope, will increase the risk of landslides in mountainous areas, including the village of Kemiren. When a building is struck by landslide material, the building will experience additional load beyond what was previously calculated, resulting in structural failure. Conversely, if the ground where the building is located subsides, the building will lose its footing and fail. Liquefaction itself is the transformation of solid material into a liquid-like state. In this case, floods accompanied by earthquakes can cause disaster hazards due to liquefaction, where water-saturated soil experiences shaking.
2. Earthquake

   Earthquakes are waves experienced by the layers of the Earth due to the sudden release of energy from within, creating seismic waves. Banyuwangi, located in the subduction zone of the Indo-Australian and Eurasian plates, has a high risk of earthquakes. Furthermore, data shows that several major earthquakes have occurred in the past, in addition to the potential for megathrust earthquakes in the Indian Ocean [17].

   The SNI-1726-2019 Standard on Earthquake Resistance Planning Procedures for Building and Non-Building Structures maps earthquake zones across Indonesia and provides standards used to calculate earthquake loads, considering soil type, vibration period, and building importance factor. In this case, the Osing Traditional House falls into risk category II out of four categories, as it is a residential building. But the losses that may occur from an earthquake disaster in Kemiren Village are not limited to the destruction of buildings; they also entail the loss of a village legacy that is culturally sustainable, particularly the Osing construction method.
3. Volcanic Disaster

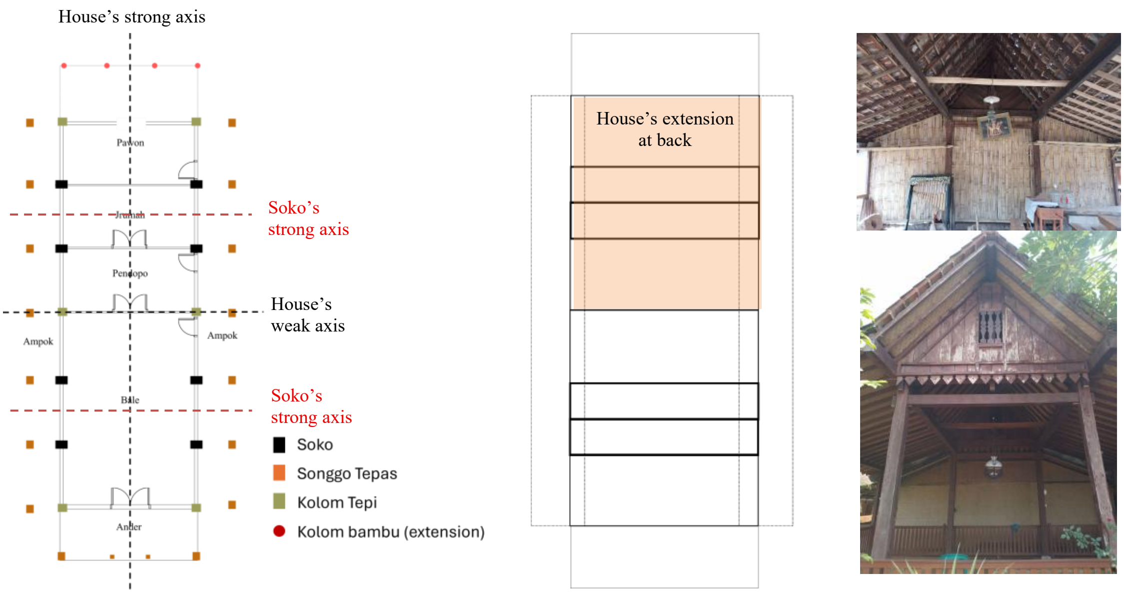
   Desa Kemiren is located on the slopes of Mount Ijen; however, Desa Kemiren is also situated 31.4 kilometers to the east of the active volcano, Mount Raung. In the last five years, volcanic activity has been recorded on Mount Raung, including eruptions in 2021 and 2022, and a watch status in 2023. When Mount Raung erupted, volcanic ash rain also hit the city of Banyuwangi, including Kemiren Village. In addition to being hazardous to health and obstructing visibility, volcanic ash can also become an excessive burden on the roofs of traditional houses, which can lead to collapse if it reaches a certain volume.

3.3. Osing House Analysis

The traditional Osing house has a symmetrical layout, both in its elongated and spread-out sides, in its basic form. Symmetrical and unbranched forms have advantages in facing earthquake disasters, where building plans with irregular shapes, such as buildings with branched masses, can experience torsional effects when exposed to seismic waves, as mentioned in the previous research [18]. This is caused by the distribution of the center of mass and the center of rigidity not being at the same point that caused eccentricity. Furthermore, the junction area between the main body and the arm often becomes a weak point due to changes in stiffness.

However, the elongated shape of the Tikel house will create a strong axis and a weak axis, where the house will be strong in withstanding seismic waves that come parallel to the long axis of the house, and will be relatively weaker in facing seismic waves that come parallel to the short axis of the Tikel house. To address this, we can classify the priority of the structural elements in this Osing traditional house.

Most of the houses in Kemiren Village are Tikel Balung houses configured repeatedly backward, or Tikel Balung houses combined with the Cerocogan house shape. From the axonometry, it can be seen that the main structure of the Tikel Balung and Cerocogan houses is located on four Soko columns situated in the center of the house. The houses are spread with varying widths, ranging from 4.6 meters to 6.31 meters [14], and are still inhabited to this day. In this case, we can see that the short span of the soko is placed on the opposite side of the weak side of the house, namely parallel to the weak axis of the house's mass. This creates a balance, where the wide span of the house, which becomes the long distance of the soko, where the jait dowo is stretched, can also be utilized to increase the stiffness of the weak axis of the traditional house's mass, because it has a longer span than the span of the jait cendek. In this case, the span of the long jait will function as a portal span, while the span of the short jait will function as the building's truss.



(a) Typical House Plan (b) Roof Plan (c) Symmetrical Form

Figure 5. The symmetrical form of Typical Tikel Balung House in Kemiren Village (source: author)

The main columns of this Osing house are eight Soko columns that span and support the ridge beam of the roof. From the sections of the house, the configuration of the soko columns - jait cendek and jait dowo, we will find a framework system of wooden construction. This cross-section shows wooden joints meeting at right angles. The joint in the wooden frame should require a 'sekur' beam to make its configuration stiffer, but this is not found in the Tikel Balung house in Kemiren Village. To stabilize the configuration of the four Soko, the residents have traditionally used small wooden pieces that give pressure on the Soko and Jait joints, thereby reducing the likelihood of movement at those joints. The weight of Jait beams gives the axial load to the small wooden fastener, makes the joint rigid, yet still have room to move along, whenever there is a lateral load, for example, seismic waves. The fastener will be hammered to stiffen the joint, as it will push the jait beam upwards. This can be seen in Figure 6, where the jait beam is cut diagonally at its edge to provide space for the fastening wood. This small fastening wood could be seen in each of the joints of the soko columns.

Strengthening joints is also one of the points in anticipating structural movement during a disaster, which causes the building to be subjected to additional axial or lateral forces.

Besides the mass and layout configuration, as well as the balance in the main frame configuration of the building that will bear most of the moments caused by ground movement, one important principle in responding to the danger of an earthquake disaster is to decouple the ground vibration frequency from the building vibration due to seismic waves. In today's world, this vibration damping technique is often referred to as a base isolator, which is designed using shapes and materials that allow movement at the base of the building.

When we look at the foundation of the Tikel Balung house on the ground, we will not find a solid pedestal like in traditional Javanese houses. The support in the Tikel Balung house consists of wood or bamboo as the soko tepas column, which meets with a piece of wood called Ubeg. This ubeg rests on a sopak stone, a stone with a hole that has the same cross-section as the ubeg wood, so that the ubeg wood can rest on the sopak stone while still allowing movement but remaining stable. This sopak stone is then arranged and slightly embedded in the ground as the foundation base of the house [10]. The configuration of ubeg - sopak and soko tepas allows movement when the building is subjected to soil movement or earthquakes. The position of the sopak stone, which is not rigidly embedded in the ground, also causes the sopak stone to detach during vibrations, thereby simply and naturally interrupting the earthquake vibration waves from the ground and the building, while still enabling the structure to move along with the seismic wave. This mechanism resembles the principle of base isolation that could be found in more modern buildings. This finding align with the previous research that found the use of sand and palm leaves for the same base isolation means to protect the central column of Japanese architecture from the seismic wave [19].

Figure 6. The fastening of Soko - Jait joint (source: author)

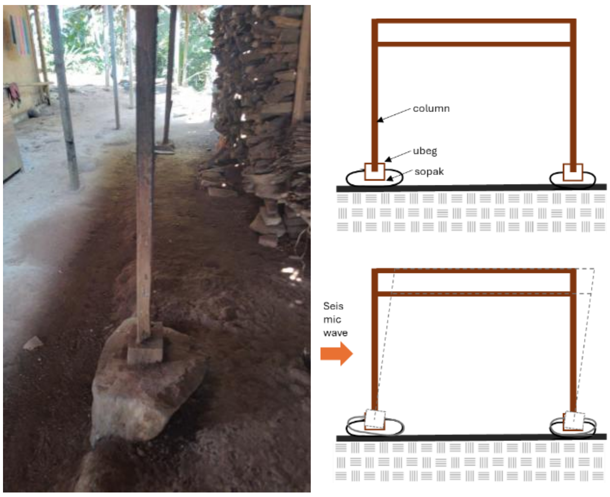


Figure 7. Ubeg - Sobak Joint resembles base isolation (source: author)

To respond to the volcanic ash disaster, the most influential design element is the roof, which protects people from volcanic ash rain, while also serving as a place for volcanic ash to accumulate and settle. The roof of the Tikel Balung House itself has two slopes, namely a steep roof (45 - 60 degrees) in the central area (represented by the green line in image 8), and a gentler roof (15 - 30 degrees) on the sides of the amper, ampik, and pawon. As a roof surface, the steep roof has support in the form of purlin beams and wooden infill boards acting as gables, which can also reinforce the position of the steep roof itself. However, in the flat roof segment, the presence of wooden fasteners or elements that serve as a gable cannot be found. Therefore, the vulnerability level of the flat roof area is higher than that of the steep roof area.

Continuous ash rain can also cause ash accumulation in the area of flat roofs. Therefore, a design intervention is needed, in the form of adding tie beams to secure the roof to the main columns of the house, in order to create a more stable triangular configuration that can withstand the load of volcanic ash.

Figure 8. The two segments of the Tikel Balung Roof (source: author)

4. CONCLUSION

The study emphasizes how Osing traditional homes in Kemiren Village are structurally resilient to a range of natural disaster hazards, such as earthquakes, landslides, and volcanic eruptions. These homes, which were built with a nail-free timber frame structure, have distinctive joinery techniques that increase their seismic resistance. A natural base isolation effect is introduced by using ubeg and sopak stone foundations, which permit movement during ground shaking while preserving structure integrity of the upper structure.

Furthermore, the Osing house's symmetrical design helps to mitigate the torsional effects of earthquakes. To increase lateral stability, structural modifications are necessary because the Tikel Balung house's elongated shape produces both a strong and a weak axis. Small attaching pieces reinforce wooden fastening joints, which act as extra stabilizers to lessen movement at crucial connection points between column and beams, as well as improve the overall structural integrity.

An important consideration when dealing with volcanic threats is the roof structure. Conversely, the flat side roofs are more susceptible to ash buildup and possible collapse, while the high central roof efficiently sheds volcanic ash, as it has a steeper roof angle. To reduce these risks, strengthening actions can be used, such as installing tie beams to provide a more rigid triangle roof shape.

This study emphasizes how crucial it is to incorporate local knowledge into disaster-resistant architecture design. Through the documentation and analysis of Osing construction methods, important lessons can be applied to modern architectural practices, guaranteeing cultural preservation and boosting resilience to disasters.

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Notes on contributors

Elvina Shanggrama Wijaya Elvina Shanggrama Wijaya works as a lecturer at the Architecture Department, Petra Christian University, Surabaya. Her area of expertise and research revolves around building science technology and simulation. He believes that built environments designed with consideration of context, functional needs, and the psychological and physiological aspects of users will impact the health and well-being of users, as well as environmental sustainability, through the interaction between the two. Email: elvinawijaya@petra.ac.id

Stephanus Wirawan Dharmatanna is now a lecturer in the Architecture Department at PCU. He is also a registered architect by the Indonesian Institute of Architects, with a Greenship Professional certification from the Green Building Council Indonesia. His research interests are computational design approach, digital architecture, and science & vernacular architecture simulation. His research has been published in proceedings and journals, and he also won the 7th Purnomo Yusgiantoro Center Paper Competition in 2023. He and his team were the 2nd winner of the Tectonics Competition by BYO Living Award: IAI Series. Email: stephanus.dharmatanna@petra.ac.id

Emmanuel Nicholas Birawa is now an undergraduate student in the Architecture Department, Petra Christian University. He has a great interest in building technology and building structure. He has a strong passion for designing architectural details as a manifestation of design concepts. He has won the best design in student competition in different architectural design studio semesters during his studies in the Architecture Department, Petra Christian University. Email: B12210007@john.petra.ac.id

RUSTIC: Jurnal Arsitektur
Vol. 5, issue No. 2, July-December 2025, pp. 89~95
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v5i2.3049

Evaluation of Noise Levels at AT-Taqwa Mosque in Beru, Sikka Regency, East Nusa Tenggara (NTT)

Mario Farisned Belarmino, Masheri Adrianus Soru[2], Cornelia Hildegardis[3*]
[1-3]Architecture Program, Faculty of Engineering, Universitas Nusa Nipa, Maumere, Indonesia

Article Info

Article history:

Received Apr 14, 2025
Revised Jun 9, 2025
Accepted Jun 23, 2025

Keywords:

Noise;
Mosque;
Evaluation;
Sound Level Meter;
Sikka

ABSTRACT

In designing the function of a space, there are several important aspects to consider, one of which is acoustic quality that affects comfort and the building's resistance to sound. One type of building that requires good acoustic conditions is a mosque, as a place of worship for Muslims that needs a quiet atmosphere with low noise levels and even sound distribution, with a maximum noise limit of 55 dB. This study focuses on a mosque located in the city center of Maumere, which is used as the observation object to assess its acoustic quality. The sound sources observed are from outside the building and their influence inside the building. The method used in this study is a quantitative approach, through observation and measurement using a Sound Level Meter (SLM), which includes literature study, field observation, and analysis. The results of the observation and measurement show that the noise level in the mosque does not meet the standards set for places of worship. The lowest noise point was detected on the north side of the building, at 66.2 dB(A), caused by several walls that function as noise barriers and reduce the noise level compared to other points.

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Corresponding Author:

Cornelia Hildegardis
Architecture Program, Faculty of Engineering, Universitas Nusa Nipa
Jln. Kesehatan No.03, Maumere, Sikka Regency, East Nusa Tenggara, 86111
Email: childegardis4@gmail.com

1. INTRODUCTION

Noise pollution is an increasingly significant environmental issue, particularly in public spaces such as mosques. High noise levels can disrupt the comfort and concentration of worshippers during their prayers [1, 2]. This study aims to measure and analyze noise levels in the mosque and assess their impact on congregational comfort. Previous research indicates that noise can affect both mental and physical health, highlighting the importance of understanding and managing noise factors in places of worship [3, 4].

In the context of Masjid At-Taqwa Beru, multiple factors influence noise levels, including the mosque's location, surrounding community activities, and prayer times. Masjid At-Taqwa was selected as the case study due to its strategic position adjacent to Jalan Umur, a main road heavily trafficked by motor vehicles such as cars and motorcycles. This condition results in noise levels around the mosque that exceed the permissible noise standard for worship places, which is 55 dB(A). Elevated noise levels directly affect the comfort and solemnity of worshippers, especially in the main prayer hall, which ideally should remain quiet and peaceful.

Moreover, the mosque's structural design poses specific challenges to noise reduction. The use of walls and open iron fences approximately 2 meters high is insufficient to effectively dampen external noise from the road, providing an opportunity to examine how architectural and building engineering elements influence sound penetration from the highway into the prayer space.

This research presents significant novelty by conducting specific noise measurements and analyses at several strategic points within the mosque premises, including outside the fence, the terrace, and the main prayer hall. The study also highlights a direct correlation between traffic activity on the highway and the acoustic conditions inside the mosque, an aspect seldom explored in detail within local contexts.

Beyond technical measurements, the study adopts a multidisciplinary approach integrating civil engineering, architecture, and environmental science to provide practical and context-sensitive solutions to noise management in places of worship. This approach expands the scope beyond mere noise measurement to include environmental and architectural management tailored to real-world conditions.

Therefore, this research is highly relevant and crucial, aiming to contribute scientifically and practically toward addressing noise pollution at Masjid At-Taqwa. Ultimately, it is expected to enhance the comfort and devotion of worshippers amidst environmental challenges caused by heavy road traffic.

This study will implement systematic noise measurement methods to obtain accurate data. Previous research by Hossameldien [5] and Islam [6] demonstrates that noise at mosques can vary depending on the time and type of activity, so this study is anticipated to provide a clearer depiction of the situation in Sikka Regency.

The results are expected to offer recommendations for mosque managers and the surrounding community to create a more comfortable environment for worshippers. By understanding noise levels and influencing factors, mitigation measures can be developed to reduce the adverse effects of noise pollution. This study also contributes to the existing literature on noise in places of worship, as emphasized by Babere [7] and Ackah [8], who highlighted the importance of noise management to improve the quality of worship experiences.

According to the World Health Organization, prolonged exposure to noise exceeding 70 dB can cause hearing impairment and physiological stress [9, 10]. Meanwhile, the Indonesian Ministry of Environment and Forestry Regulation No. 56 of 2018 sets noise limits for residential areas at 55 dB during the day and 45 dB at night. Noise levels exceeding these thresholds may disturb community comfort [11].

Previous studies by Rinanti et al. [12] and others [13] show that noise from generators and public vehicles often constitutes external environmental noise. Additionally, other research finds that noise from industrial machinery and public buildings, including places of worship, can impact user and community comfort when poorly managed [14-16]. Research by Handoko et al. [17] confirms that soundproofing and appropriate room design can assist in reducing noise levels. Furthermore, studies in Makassar show that regular noise monitoring supports planning for noise control in public spaces [18].

Further investigations by Agustia [19] and Agus [20] reveal that excessive noise disturbs religious activities, especially prayers and other religious events. Other studies suggest that using sound-absorbing materials in worship space construction helps minimize noise effects from machinery [21, 22]. Therefore, this study will measure the noise levels at Masjid At-Taqwa Beru, Sikka Regency, NTT, to provide appropriate noise management recommendations suited to the surrounding conditions.

2. METHOD

This study uses a quantitative approach to evaluate the noise levels at the AT-Taqwa Mosque in Beru, Sikka Regency, NTT [23]. The research was conducted with field measurements using a Sound Level Meter (SLM).

Figure 1. Sound Level Meter was used as the measuring device (source: author)

The research procedure began with determining the measurement points and times, where noise measurements were conducted at specific hours, especially during worship activities, to obtain representative data.

Figure 2. The condition of the AT-Taqwa Mosque in Beru, Sikka Regency (source: author)

The AT-Taqwa Mosque in Beru is one of the Muslim places of worship located in Sikka Regency, precisely on Sultan Hasanudin Street, Beru Subdistrict, Maumere City, East Nusa Tenggara. This mosque stands majestically on a land area of 2,400 m², providing ample space for various religious and social activities of the local community.

The main building of the mosque covers an area of 288 m², which includes the main prayer area, the imam's room, and other supporting facilities. With a simple yet functional architectural design, the mosque can accommodate a considerable number of worshippers, especially during Friday prayers and religious holidays.

The AT-Taqwa Mosque building faces significant challenges regarding noise, particularly originating from the south side, which is the main road (Jalan Umur) that is a busy motor vehicle route. The mosque's location right on the edge of this busy road causes vehicle sounds, such as the roar of motorcycles and cars, to easily enter the mosque area, especially during peak hours. Although a permanent fence approximately 2 meters high has been built at the front, consisting of a combination of wall and iron, the fence does not significantly reduce noise because gaps in the iron still allow sound to pass freely, and the wall materials used are not designed as soundproofing. Noise from the east and west sides is relatively lower because it is blocked by a fairly massive school building, which serves as a natural barrier. However, in general, the materials and design of the fence, as well as the mosque's position facing directly onto the main road, make the interior area of the mosque still vulnerable to external noise disturbances, which can reduce the solemnity of worship, especially during congregational prayers and other religious activities (see Figure 2).

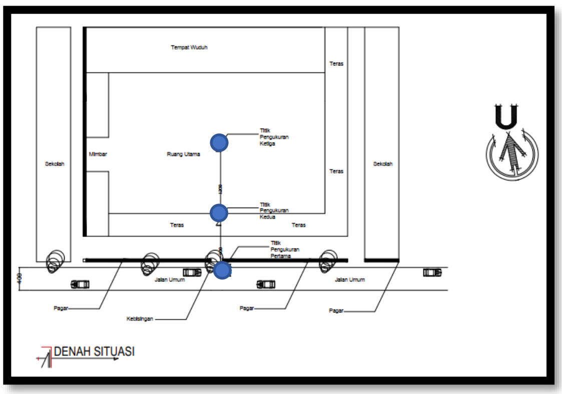

Figure 3. Designated measurement points (source: author)

Based on the situational layout of the AT-Taqwa Mosque in Beru, it can be explained that noise measurements were conducted at three strategic points to obtain a comprehensive picture of the sound intensity entering the mosque area, especially during busy times such as 14:00 WITA and peak traffic activity periods [24].

- Point 1 – In Front of the Fence (Outside the Mosque Fence Area)
  This point is located just outside the mosque fence facing south, towards Jalan Umur, which is a main road with quite heavy traffic. This point represents the external noise level from motor vehicles, including horn sounds, engines, and other street activities. Measurement here is important to understand the initial noise level before any barriers such as fences or buildings.
- Point 2 – Terrace Area (Inner Yard Near the Mosque Entrance)
  The second point is inside the mosque area, on the terrace or front yard directly adjacent to the main prayer room. This point represents the noise that has passed through the fence and shows how much

sound from outside manages to enter and be heard by worshippers in the mosque's open area. It also illustrates the effectiveness of the fence in dampening external noise.

- Point 3 – Main Prayer Room of the Mosque
  The third measurement point is inside the main prayer room of the mosque, where congregational prayers are held. This point is the most important because it shows the noise level that truly disturbs the solemnity of worship.

3. RESULTS AND DISCUSSION

Based on the noise measurements at three points in the vicinity of the AT-Taqwa Mosque in Beru, it can be concluded that the noise levels generally exceed the threshold limits set for places of worship. Referring to the noise quality standards table, which stipulates a maximum limit of 55 dB(A) for places of worship, all measurements taken at 14:00 WITA, coinciding with peak traffic hours, have surpassed this threshold.

Table 1. Noise Quality Standards Table

Land Use / Activity Environment	**Noise Level Limit (dBA)**
Land Use	
Residential and Housing	55
Trade and Services	70
Offices and Trade	65
Green Open Space	50
Industry	70
Government and Public Facilities	60
Recreation	70
Special:	
1. Airport*	
2. Train Station*	
3. Seaport	70
Activity Environment	
Hospital or similar	55
School or similar	55
Place of Worship or similar	55

At the first point, which is in front of the mosque fence, the noise level was recorded at 71.9 dB(A). This value is very high and comparable to the noise levels in trade and service areas or industrial zones according to the reference table, which are indeed characterized by dense traffic and high activity. This level indicates that the environment outside the mosque, especially the area directly adjacent to the public road, has a high sound intensity due to vehicle traffic [6, 25]. The noise penetrates into the mosque area despite the presence of a permanent fence 2 meters high. However, the fence is not effective enough in dampening the sound because most of its material is open iron, which actually allows sound waves to pass through easily [26, 27].

Figure 4. The condition of the Fence at the Mosque (source: author)

At the second point, which is the mosque terrace, the noise level decreased slightly to 70.9 dB(A), representing only a 1 dB reduction from the point outside the fence. This indicates that the fence material and the open terrace area do not play a significant role in sound attenuation. Additionally, the terrace's semi-open position without acoustic barriers allows external noise to enter with little obstruction [28]. The mosque terrace, which should ideally serve as a quiet transitional area before entering the prayer room, is still heavily affected by external noise [29, 30].

Figure 5. The condition of the terrace and materials used on the mosque terrace (source: author)

Meanwhile, the third point, located inside the main prayer hall of the mosque, shows a noise level of 66.2 dB(A). Although lower than the previous two points, this value still far exceeds the maximum threshold of 55 dB(A) for places of worship. Such noise levels can directly affect the concentration and solemnity of worshippers during prayers, sermons, or religious studies. According to references from the WHO and the Ministry of Environment, noise levels above 60 dB in worship spaces can cause mild psychological disturbances such as stress and difficulty concentrating, especially if experienced for prolonged and repeated durations [31].

The reduction in noise level measured at the third point, inside the main prayer hall, is due to the presence of structural elements such as walls that act as sound barriers. These walls can minimize the intensity of external noise, especially from the direction of the highway on the south side of the mosque. This sound attenuation function is more effective because the wall materials have sufficient mass and density to absorb and block sound waves from outside before they reach the interior space [32].

Additionally, the distance between the noise source and the measurement point inside the main hall also influences the noise level that enters. The farther the distance from the noise source, the weaker the sound energy reaching the interior due to wave attenuation during travel. Therefore, the combination of physical barriers in the form of walls and the distance from the noise source plays an important role in reducing noise levels entering the mosque's prayer space, making the interior atmosphere relatively quieter compared to the outside area [33].

From this analysis, acoustic treatment is very important to implement, including architectural and material interventions. Several references such as the Ministry of Environment Regulation No. 48 of 1996, WHO Environmental Noise Guidelines (1999), and studies from journals like Applied Acoustics and Building and Environment recommend the use of additional soundproofing elements such as vertical vegetation (green barriers), installation of acoustic glass, or ventilation improvements to prevent external noise from entering directly. Furthermore, rerouting heavy vehicle traffic or imposing speed limits in front of the mosque could be long-term policies advocated to local governments.

In conclusion, although the AT-Taqwa Mosque in Beru is strategically located in the center of a residential area and easily accessible to the community, its proximity to the main road negatively impacts the acoustic quality of the worship environment. The three measurement points show noise levels far exceeding acceptable limits for places of worship. This requires follow-up actions in the form of noise mitigation planning based on architectural design and environmental policies to maintain comfort and solemnity during worship at the mosque. If not addressed promptly, this noise disturbance could have long-term psychological and social effects on worshippers and the surrounding community.

4. CONCLUSION

From the analysis, acoustic treatment is very important to implement, including through architectural and material interventions. Several references such as the Ministry of Environment Regulation No. 48 of 1996, WHO Environmental Noise Guidelines (1999), and studies from journals like Applied Acoustics and Building and Environment recommend the use of additional soundproofing elements such as vertical vegetation (green barriers), installation of acoustic glass, or ventilation improvements to prevent external noise from entering directly. Furthermore, rerouting heavy vehicle traffic or imposing speed limits in front of the mosque could be long-term policies advocated to local governments to help reduce the noise levels.

ACKNOWLEDGEMENTS

We express our deepest appreciation and gratitude to the AT-Taqwa Beru Mosque for their willingness and support, especially in the form of permission, time, and opportunity to conduct noise level measurements in the mosque environment. The cooperation given was very meaningful and played an important role in the smooth implementation of this activity, resulting in data that can be used as a basis for further research and analysis.

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Notes on contributors

Mario Farisned Belarmino is a student of the Architecture Study Program, Faculty of Engineering, Universitas Nusa Nipa Maumere. This research was conducted as part of an academic assignment in the Building Physics course, aimed at analyzing various factors affecting noise levels in a building, as well as examining architectural solutions that can be applied to reduce the impact of such noise

Masheri Adrianus Soru is a student of the Architecture Study Program, Faculty of Engineering, Universitas Nusa Nipa Maumere. This research was conducted as part of an academic assignment in the Building Physics course, aimed at analyzing various factors affecting noise levels in a building, as well as examining architectural solutions that can be applied to reduce the impact of such noise.

Cornelia Hildegardis is a permanent lecturer in the Architecture Study Program, Faculty of Engineering, Universitas Nusa Nipa, Maumere. He was appointed as a lecturer at the institution in 2011. He continued his doctoral studies in the Department of Architecture with a specialization in Building Technology at Udayana University Bali. His research interests include topics on thermal comfort, green architecture, as well as acoustics and noise control. The author can be contacted via email: childegardis4@gmail.com

RUSTIC: Jurnal Arsitektur
Vol. 5, issue No. 2, July-December 2025, pp. 96~114
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v5i2.3074

Evaluation of the Greenship GBCI Implementation in the Appropriate Land Use Category for the New Building of Poltekkes Riau Tower

Dadang Puja Kusumah[1*], I Nengah Tela[2], Haryani[3]
[1] Master Program in Architecture, Faculty of Engineering & Design, Universitas Bung Hatta, Padang, Indonesia
[2-3] Department of Architecture, Faculty of Engineering & Design, Universitas Bung Hatta, Padang, Indonesia

Article Info

Article history:

Received May 6, 2025
Revised Jun 11, 2025
Accepted Jun 23, 2025

Keywords:

Greenship GBCI;
Land Use Efficiency;
Green Building;
Menara Poltekkes Riau;
Sustainable Development

ABSTRACT

Implementing the green building concept is a strategic solution to support sustainable development, particularly in the construction sector, which significantly contributes to environmental degradation. In Indonesia, the Green Building Council Indonesia (GBCI) has established the Greenship rating tool as a standard for green buildings, including the Land Use Efficiency category. Menara Poltekkes Riau was selected as the research object because it is a new building aligned with sustainable development principles as stipulated in the Decree of the Minister of Health of the Republic of Indonesia Number HK.01.07/MENKES/550/2024. This study aims to evaluate the application of the Land Use Efficiency category, measure the level of achievement, and provide recommendations for improvement. The research employs a mixed-method approach (quantitative and qualitative), with data collected through field observations and an As-built Drawing document study. The evaluation results indicate that Menara Poltekkes Riau achieved 5 out of 17 points or 5% of the total points in the Land Use Efficiency category. The criteria achieved include Basic Green Area (ASD-P) Benchmark 1A, Site Selection (ASD-1) Benchmark 1A, Community Accessibility (ASD-2) Benchmark 1, Public Transportation (ASD-3) Benchmark 1A, and Microclimate (ASD-6) Benchmarks 1A and 2. However, other criteria have not been met, including optimizing green areas, vegetation, transportation facilities, accessibility, and stormwater runoff management. This study emphasizes the importance of improving these aspects to enhance the application of the green building concept at Menara Poltekkes Riau.

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Corresponding Author:

Dadang Puja Kusumah
Master Program in Architecture, Faculty of Engineering & Design, Universitas Bung Hatta, Padang
Proklamator Campus I, Jalan Sumatera Ulak Karang Padang, West Sumatera, Indonesia 25133
Email: da2ng.sg@gmail.com

1. INTRODUCTION

Awareness of the importance of sustainable development has increased significantly, especially in developing countries like Indonesia. Sustainable development emphasizes a balance between economic growth, environmental sustainability, and social well-being. However, the construction sector, which contributes 10.4% to the GDP, BPS [1] Often causes negative impacts such as carbon emissions, land degradation, and resource exploitation, Not All Green Buildings Are Made Equal: Green Building Construction Cost Premium [2].

To address these issues, the implementation of green buildings has emerged as a strategic solution, capable of reducing energy consumption by up to 30% and carbon emissions by up to 40%, GBCI [3] and Ohueri [4]. Nevertheless, the adoption of green buildings in Indonesia still faces challenges, such as limited understanding of the principles and certification criteria of Greenship, Vejaratnam [5]. The "Appropriate Land Use" category is one of the crucial aspects in Greenship [3], yet it still faces implementation gaps in the field Amalia [6] and Purwaamijaya [7]. Research by Suripto [8] and Ardhiansyah [9] also emphasizes the importance of developing holistic indicators and evaluations for this category.

Financial barriers remain a challenge, even though the government provides incentives. Basten [10]. In the context of educational buildings, the Decree of the Minister of Health of the Republic of Indonesia Number HK.01.07/MENKES/550/2024 mandates planning by sustainable principles. The Riau Poltekkes Tower was selected as the research object as it reflects efforts to apply green building principles to a new building. This study evaluates the implementation of the Greenship "Appropriate Land Use" category and identifies success factors to enrich academic discourse and provide recommendations to developers, policymakers, and the public.

1.1. Literature Review

Sustainable development and the implementation of green buildings have become strategic issues at both global and national levels, particularly in developing countries like Indonesia. The construction sector is identified as a key step toward reducing environmental impact and improving resource efficiency. Shah [11] Emphasize that transformational leadership with a green approach significantly affects the sustainability of the construction industry, with green procurement serving as a primary mediator. Willar [12] Highlight the necessity of sustainable construction practices in infrastructure projects, as well as the importance of appropriate research methodologies to support sustainability efforts.

According to UNDP projections in 2008, the urban population is expected to increase to 6.6 billion by 2050, intensifying pressure on resources and the environment. The built environment—which includes buildings, roads, and infrastructure—has a significant ecological footprint. Buildings require energy, water, and materials throughout their life cycle and generate waste. Thus, environmentally friendly buildings are a viable solution to minimize negative impacts without compromising occupant comfort.

Figure 1. Illustration of the Built Environment (source: greenship gbci)

Green Building Assessment Standards serve as rating tools to determine the level of green buildings through a certification evaluation process. These systems assess a building's compliance with green building principles adopted in various countries. World Green Building [13]. Each country has its assessment system, including:

- BREEAM (Building Research Establishment Environmental Assessment Method) — UKGBC
- LEED (Leadership in Energy and Environmental Design) — USGBC
- Green Star - GBCA
- Green Mark - SGBC
- BGH (*Bangunan Gedung Hijau*)
- Greenship - GBCI

The Greenship green building rating tool, developed by the Green Building Council Indonesia (GBCI), a non-profit, independent, and non-governmental organization-focuses on the promotion and development of green buildings in Indonesia. GBCI developed the Greenship rating system as a technical guide for green building assessments, including Greenship New Building version 1.2, which covers criteria such as land use, water management, and biodiversity protection.

Greenship assessment also includes other categories:

- Existing Building (EB) v1.1
- Neighborhood v1.0
- Net Zero v1.0
- Interior Space (IS) v1.0
- Homes v1.0
- Data Center v1.0

The evaluation of Greenship implementation in Menara Poltekkes Riau aims to meet the GBCI green building standards.

Figure 2. Varieties of Assessment Tools in Greenship by GBCI, 2014 (source: greenship GBCI)

Greenship for New Buildings (NB) Version 1.2: Greenship is a green building rating system that assists industry players, such as developers, architects, and engineers, in implementing best practices from the planning stage through to maintenance. The assessment covers six categories: ASD, EEC, WAC, MRC, IHC, and BEM, to ensure the building's sustainable performance.

1.2. Theoretical Framework

Land Efficiency Theory, proposed by Bogue (1963), emphasizes the importance of optimizing land use to achieve the highest economic productivity by considering the physical characteristics of the land and regional needs. Efficiency is achieved when land is used for the highest economic value activities, taking into account factors such as distribution accessibility, transportation access, soil fertility, and market demand. Proper land utilization is believed to drive regional economic growth and improve the well-being of local communities.

Sustainable Growth Theory, developed by Daly (1990), critiques the conventional economic paradigm that promotes unlimited growth. Daly stresses the need for a balance between economic activities and environmental carrying capacity to ensure long-term human well-being. This theory advocates for the wise use of resources while considering the regenerative capacity of ecosystems.

Spatial Planning Theory, introduced by Faludi (1973), highlights the importance of rational decision-making processes in regional planning, taking into account social, economic, and political aspects. This theory explains how planning is designed, the rationale behind its implementation, and its impact on regional development. The rational approach aims to create a balance between spatial use and development needs, thereby supporting effective and sustainable territorial management.

1.3. Expert Opinions and Empirical Studies (2018–2024)

Van de Ven highlighted the importance of land-use efficiency in the development of renewable energy, particularly within the context of spatial planning for new developments. The utilization of land for renewable energy must consider integration with spatial planning to avoid conflicts with other land functions, such as residential or agricultural use [14].

Jin examined the strict land-use planning in China aimed at reducing the conversion of agricultural land into urban areas. This study demonstrated that land-use efficiency can be improved through policies that control new developments and provide incentives for multifunctional land use [15].

Chang discussed enhancing land-use efficiency through industrial upgrading in industrial zones. The integration of more capital-intensive industrial activities with the application of green technologies has been proven to increase land productivity and reduce land waste [16].

Long investigated the relationship between land-use transitions and development efficiency. Their findings revealed that adaptive land management, responsive to socio-economic changes, can promote more efficient land use [17].

Zhao found that in suburban areas, the implementation of multifunctional land use (mixed-use development) can improve land-use efficiency by shortening travel distances, reducing parking space, and increasing building density [18].

Liu analyzed land policy strategies adapted to China's economic transformation. The results showed that land-use efficiency increased through regulated construction permits and the integration of spatial planning with economic growth [19].

Zhou emphasized the reform of rural land systems oriented towards improving land allocation efficiency. A transparent, needs-based allocation system was shown to reduce overlapping land uses [20].

2. METHOD

This study evaluates the implementation of Greenship-GBCI in the Appropriate Land Use category for the new building of the Poltekkes Riau Tower using a quantitative-methods approach. The quantitative-method was used to analyze the application of the Appropriate Land Use category based on the assessment form of GBCI, referring to the Technical Guidelines of the New Building Assessment Tools version 1.2.

Primary data were collected through surveys, field observations, and direct measurements, while secondary data were obtained from the building owner, construction management consultant, and main contractor. Measurements were carried out using validated variables by Greenship standards to determine the achievement level of the Appropriate Land Use category. The assessment aims to identify how accurately the criteria have been applied to the Poltekkes Riau Tower as an initial step toward green building practices during its operational/functional phase.

The Appropriate Land Use criteria are as follows:

1. Basic Green Area (ASD-P) Identifies the presence of landscaped areas consisting of vegetation (softscape) that are free from building structures and simple park structures (hardscape), either on the ground surface or below, with a minimum area of 10% of the total land area.
2. Site Selection (ASD-1) Determined through observation of the surrounding area in relation to the availability of urban facilities and infrastructure. Data can be obtained from the Spatial Planning Document of Pekanbaru City.
3. Community Accessibility (ASD-2) Assessed by identifying public facilities within the required radius of the area. Tools used include the map of Pekanbaru City, the website https://satudata.pekanbaru.go.id, and Google Maps.
4. Public Transportation (ASD-3) Determined by identifying public transportation facilities and infrastructure within the required radius of the area.
5. Bicycle Facility (ASD-4) Assessed by calculating the number of secure bicycle parking units, with a requirement of 1 unit per 20 permanent building users. In addition to bicycle parking, available shower facilities are also identified, with a requirement of 1 unit for every 10 bicycle parking units.
6. Site Landscaping (ASD-5) Determined by measuring the area of landscaping with vegetation that is free from park structures, with a minimum of 40% of the total land area. It also includes identifying locally cultivated plants at the provincial scale, which must constitute 60% of the landscaped area.
7. Micro Climate (ASD-6) Identified by the use of locally cultivated plants at the provincial scale, covering at least 60% of the mature canopy area relative to the landscaped area defined in ASD-5, Benchmark 1.
8. Rainwater Run-off Management (ASD-7) Assessed by measuring the total rainwater run-off in the stadium area, calculated using rainfall intensity values. Rainfall intensity data is obtained from the Public Works and Spatial Planning Office.

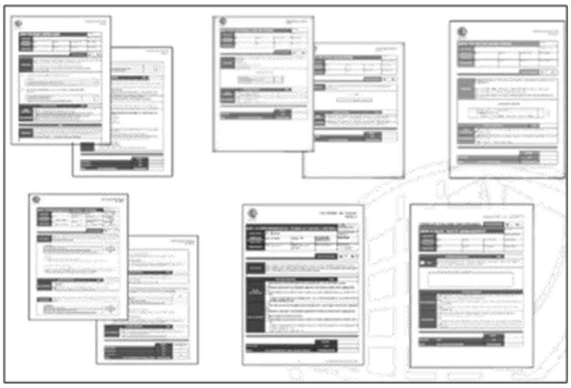


Figure 3. Greenship-GBCI Assessment Form, 2018 (source: greenship gbci)

2.1. The Building Being Studied

The research location was purposively selected at the Poltekkes Riau Tower, located at Jalan Melur No. 103, Sukajadi District, Pekanbaru City, Riau Province. The selection of this site was based on several considerations. First, a study on the implementation of Greenship-GBCI with the Appropriate Site Development category and criteria has not yet been conducted on this building. Second, the Poltekkes Riau Tower is an educational building situated on a land area of 3,292.56 m² with a total building area of 12,841.70 m². It consists of 10 floors and has a height of 40 meters. Third, the building is currently in the finishing stage and is expected to be completed by December 2024, with the basement, ground floor, and first floor already operational since February 2023. In terms of feasibility, the building meets the assessment requirements for Greenship New Building version 1.2, as it has been operational for more than six months and has a total area exceeding 2,500 m².

Figure 4. Research location map and building photo documentation (source: author)

3. RESULTS AND DISCUSSION

Evaluation of Greenship Criteria Implementation

The evaluation of the Greenship criteria implementation by GBCI (Green Building Council Indonesia) in new buildings, such as the Menara Poltekkes Riau, is a crucial step in supporting sustainable development in Indonesia. This assessment system evaluates land use efficiency, integration with the surrounding environment, as well as social and economic impacts. Research by Kandita [21] at Itenas and Safitri [22] The Al-Hikmah Mosque of the University of Jember indicates that in-depth observation is necessary to understand the environmental impact of land utilization. In the context of Menara Poltekkes Riau, aspects such as accessibility, environmental sustainability, and social impact are key areas of focus. Erizal [23] Emphasized that green building evaluations require a systematic approach, while Adi [24] Highlighted that understanding the Greenship categories is essential for improving design quality. Dewi [25] Stated that good land management can enhance the quality of life for communities. Ratnaningsih [26] Demonstrated that assessing Greenship tools through observation and interviews yields comprehensive results.Banowati [27] underscored the role of local technologies in supporting land use efficiency, while Krishanty [28] Stressed the importance of stakeholder collaboration. Prayudho [29] Suggested that continuous evaluation is necessary to maintain the consistent application of green building principles. Therefore, the findings of this study are expected to enhance the implementation of the Appropriate Land Use category in Menara Poltekkes Riau.

Building Requirements and Eligibility

In its implementation, this eligibility encompasses various aspects that serve as primary prerequisites for a building to enter the certification evaluation process. These provisions include the fulfillment of valid administrative documents, such as proof of land and building legality, as well as compliance with regulations related to sustainability and building function. All these elements aim to ensure that a constructed building meets the minimum standards before being further assessed.

Furthermore, the eligibility criteria also emphasize the importance of adhering to technical regulations, which include aspects of safety, comfort, and building efficiency. Referring to Law No. 28 of 2002 concerning Buildings, the implementation of buildings consists of three main phases: construction, utilization, and demolition. In the context of new buildings, every structure must fulfill both administrative and technical requirements in accordance with applicable regulations. These standards not only ensure that the building is fit for occupancy and operation, but also contribute to environmental sustainability in line with the principles of the Greenship certification by GBCI.

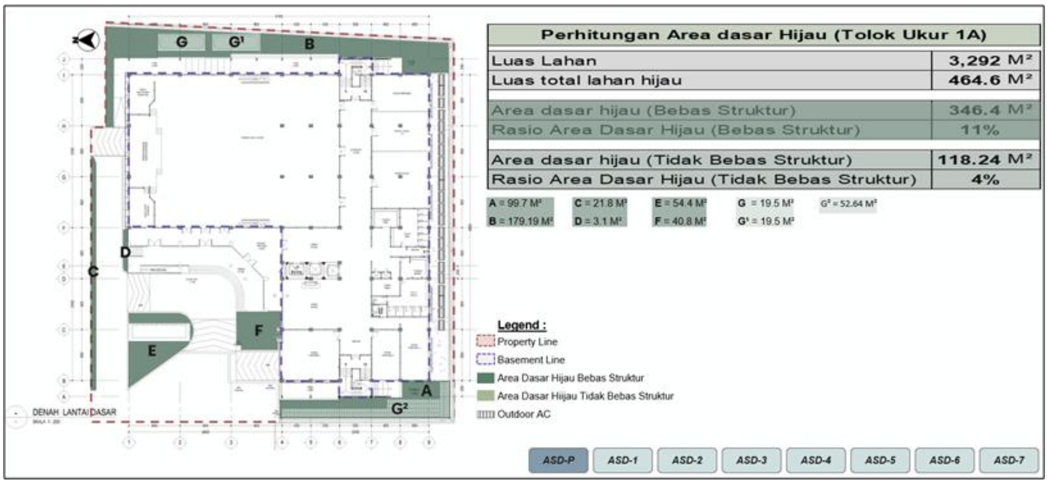
Therefore, this eligibility system serves as a foundational step for the Greenship GBCI certification process for Existing Buildings. It ensures that assessments are conducted consistently and accurately while supporting the enforcement of relevant regulations in every phase of building development and maintenance in Indonesia. Consequently, the requirements and eligibility criteria that must be met in accordance with the Greenship GBCI standards include:

1. A minimum building area of 2,500 m²
2. Availability of building data accessible to GBC Indonesia for certification purposes
3. Building function must align with land use as stipulated in the Pekanbaru City Spatial Plan (RTRW)
4. Possession of an Environmental Impact Assessment (AMDAL) and/or Environmental Management Efforts (UKL) / Environmental Monitoring Efforts (UPL)
5. Compliance with fire safety standards
6. Compliance with earthquake resistance standards
7. Compliance with accessibility standards for persons with disabilities

3.1. Analysis of the Appropriate Site Development for the Poltekkes Riau Tower

3.1.1. ASD-P Basic Green Area Criteria

Menara Poltekkes Riau meets the prerequisite criteria for ASD-P Basic Green Area in accordance with the Greenship GBCI assessment tool for New Buildings. This prerequisite aims to ensure the availability of adequate green open space to support ecological balance, improve air quality, and enhance the aesthetics of the area. Benchmark 1A requires that at least 10% of the total site area consists of vegetation without structural elements (softscape). Menara Poltekkes Riau exceeds this requirement by providing 346.4 m² (11%) of softscape and 118.24 m² (4%) of hardscape out of a total land area of 3,292 m². The building's ground floor area is 1,817.72 m², resulting in a built-up land area of 1,353.08 m². The distribution and proportion of the green area are presented in the calculation drawings and summary tables, demonstrating comprehensive compliance with the ASD-P Benchmark 1A prerequisite.



(a) (b)

Figure 5. (a) green basic area assessment zone based on benchmark 1A, (b) total assessment of green base area (source: author)

3.1.2. The ASD-1 Site Selection

In the Greenship GBCI New Building v1.2 assessment tool promote sustainable development by avoiding greenfield areas and minimizing new land clearing. This aims to preserve the natural environment, reduce negative ecological impacts, and support the utilization of developed land.

This criterion features two main benchmarks. Benchmark 1 offers flexibility, allowing projects to choose either sub-benchmark 1A or 1B. Benchmark 1A emphasizes selecting locations within areas possessing adequate urban infrastructure and facilities. Specifically, the site must be equipped with at least eight out of twelve designated urban facilities/infrastructure elements (such as transportation, healthcare, education, utilities, and public services).

This approach promotes the optimization of developed land use, reduces dependence on private vehicles, and enhances the efficiency of existing infrastructure. Consequently, the criterion not only supports environmental sustainability principles but also strengthens urban socio-economic integration. The requirement for a minimum of eight facilities out of twelve is detailed in Table 1.

Table 1. List of urban infrastructures that have been fulfilled (source: author, 2025)

NO	FACILITY	COMPLIANCE
1	Road Network	Ok
2	Lighting and Electricity Network	Ok
3	Drainage System	Ok
4	Area Sewage Treatment Plant (STP)	Ok
5	Waste Disposal System	Ok
6	Fire Protection System	Ok
7	Fiber Optic Network	Ok
8	Artificial Lake	
9	Pedestrian Pathway	
10	Gas Pipeline Network	
11	Telephone Network	Ok
12	Clean Water Supply Network	Ok
	TOTAL FULFILLMENT	9

Based on Benchmark 1A, the Poltekkes Riau Tower fulfills this requirement, as its site is equipped with nine (9) out of the twelve urban infrastructure facilities, as shown in Table 1 above. Consequently, it is awarded 1 point under the ASD-1 Site Selection criterion. To verify this, the author conducted on-site observations and verified the information using maps from Google Maps, sigi.pu.go.id, and www.arcgis.com, as illustrated in the schematic diagram (Figure. 6) below.

Figure 6. Verification of road network data using maps (source: author)

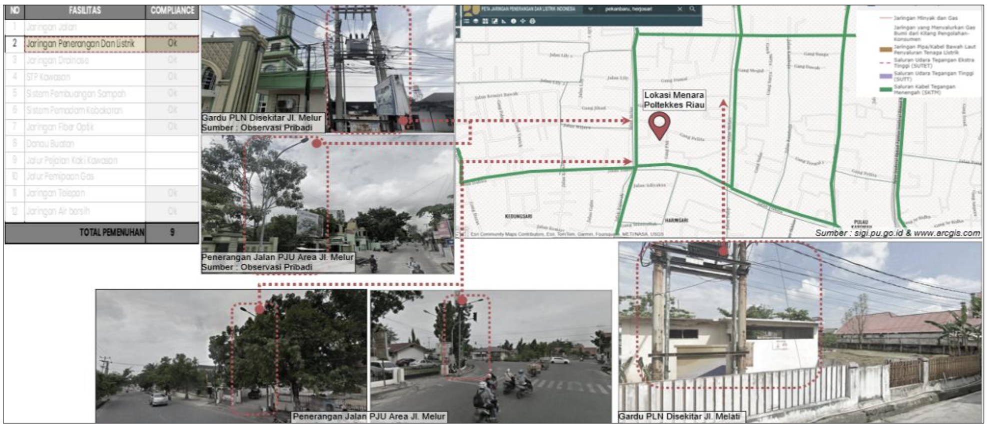


Figure 7. Verification of Lighting and Electricity Network data using maps (source: author)

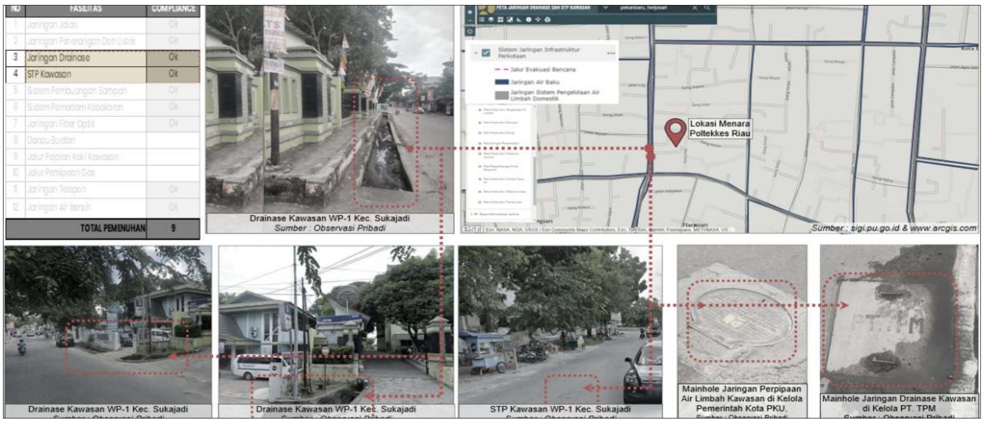


Figure 8. Verification of Drainage System & Area Sewage Treatment Plant (STP) data using maps (source: author)

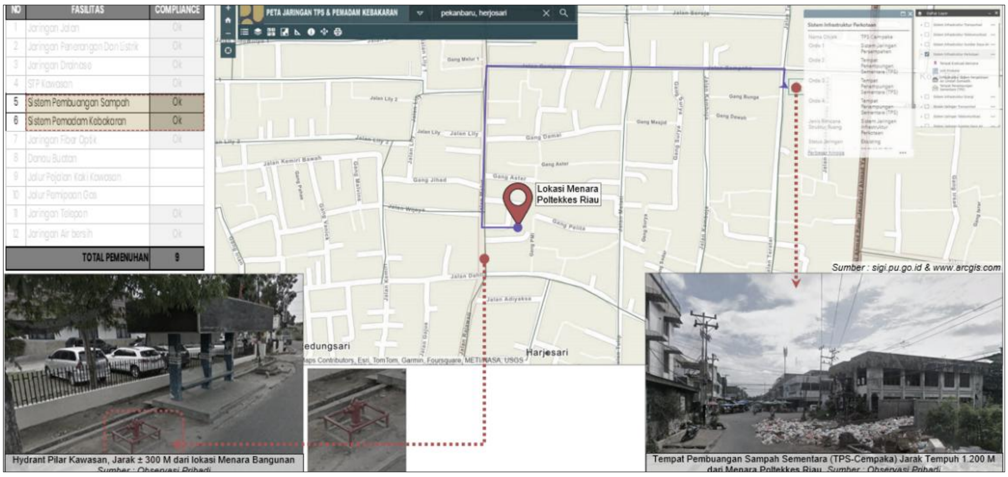


Figure 9. Verification of Waste Disposal & Fire Protection System data using maps (source: author)

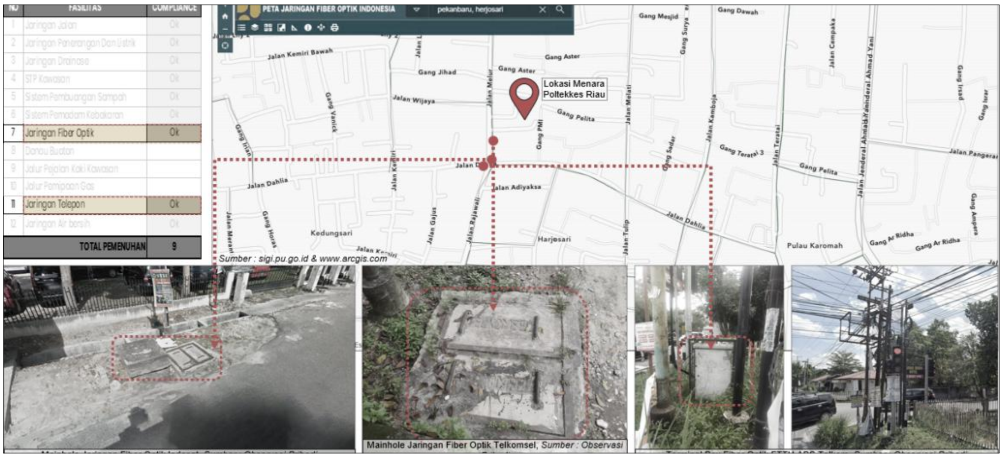


Figure 10. Verification of Fiber Optic & Telephone Network data using maps (source: author)

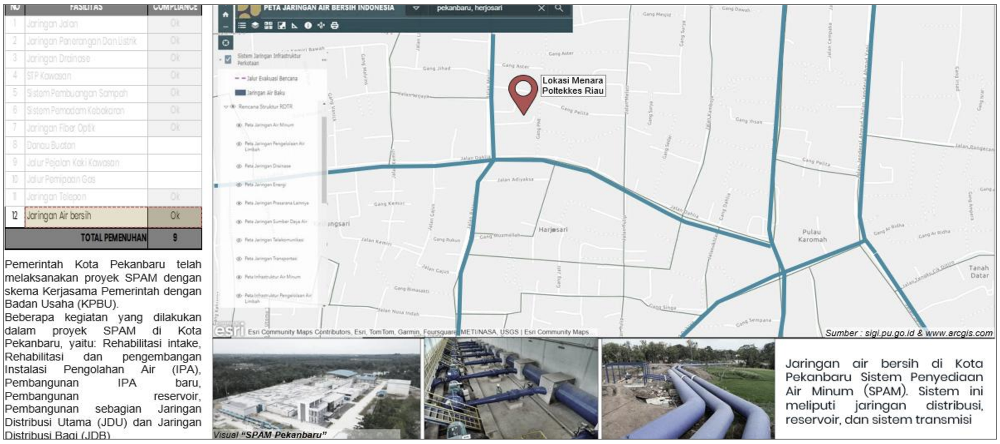
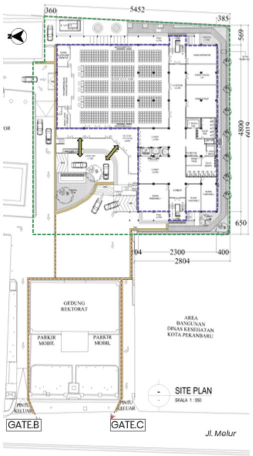


Figure 11. Verification of Clean Water Supply Network data using maps (source: author)

3.1.3. ASD-2 Community Accessibility Criteria

In the Greenship GBCI assessment tool for New Buildings (version 1.2), the ASD-2 Community Accessibility criterion aims to encourage development in locations with strong connectivity networks. The primary objective of this criterion is to improve public access to community facilities, promote the use of non-motorized modes of transportation, and reduce dependence on private vehicles. Based on field observations conducted at the Menara Poltekkes Riau and geospatial data analysis using maps from reliable sources such as Google Maps, sigi.pu.go.id, and www.arcgis.com, Benchmark 1 has been met and awarded 1 point.The observations indicate that Menara Poltekkes Riau has adequate access to various public facilities. This demonstrates that the building's location supports ease of mobility for both occupants and the surrounding community, while also reducing the need for motorized vehicle use, as illustrated in the schematic image below.



No	Fasilitas Umum	Nama Fasilitas Umum	Alamat	Jarak (M)
1	Bank	BRI KCP. Ahmad Yani	Jl. Ahmad Yani	1,200
2	Taman Umum			0
3	Parkir Umum (Di Luar Lahan)	Parkir Mobil/Motor RS. Ibnu Sina	Jl. Melati	850
4	Warung/Toko Kelontong	Warung Rizky	Jl. Melur	180
5	Gedung Serbaguna			0
6	Pos Keamanan/Polisi	Pos Polisi Gurindam-7	Jl. Riau	1,400
7	Tempat Ibadah	Mesjid Al-Jihad	Jl. Melur	230
8	Lapangan Olahraga			0
9	Tempat Penitipan Anak			0
10	Apotek	Apotek Dyandri	Jl. Melur	350
11	Rumah Makan/Kantin	Bofet Kurai Taji	Jl. Dahlia	350
12	Foto Kopi Umum	Iqbal Print & Foto Kopi	Jl. Melur	160
13	Fasilitas Kesehatan	Puskesmas Melur	Jl. Melur	130
14	Kantor Pos			0
15	Kantor Pemadam Kebakaran	Kantor Pemadam Kebakaran	Jl. Cempaka	1,200
16	Terminal/Stasiun Transportasi Umum			0
17	Perpustakaan			0
18	Kantor Pemerintah			0
19	Pasar	Pasar Kodim		1,200
	Total Fasilitas	11		

Referensi & studi literature :
- UU RI No.26 tahun 2007 tentang penataan Ruang
- Peraturan Menteri Pekerjaan Umum No.06 tahun 2007 tentang pedoman umum rencana tata bangunan dan lingkungan
- Peraturan Menteri Pekerjaan Umum No.18 tahun 2010 tentang pedoman revitalisasi kawasan.

ASD-P ASD-1 ASD-2 ASD-3 ASD-4 ASD-5 ASD-6 ASD-7

(a) (b)

Figure 12. (a) Access to the facilities from the site (b) The Menara Poltekkes Riau site has at least 11 out of 19 public facilities (source: author)

3.1.4. ASD-3 Criteria for Public Transportation

In the Greenship GBCI assessment tools for New Buildings (version 1.2), the ASD-3 Public Transportation criterion aims to encourage the use of mass public transportation modes and reduce reliance on private vehicles. This objective aligns with the principles of sustainable development, which emphasize efforts to reduce carbon emissions, improve energy efficiency, and enhance air quality in urban areas. Based on field observations conducted at the Menara Poltekkes Riau, it was found that Benchmark 1A has been met, earning 1 point. Observations indicate that there is a public transportation stop located within 300 meters of the main gate of the Menara Poltekkes Riau complex.

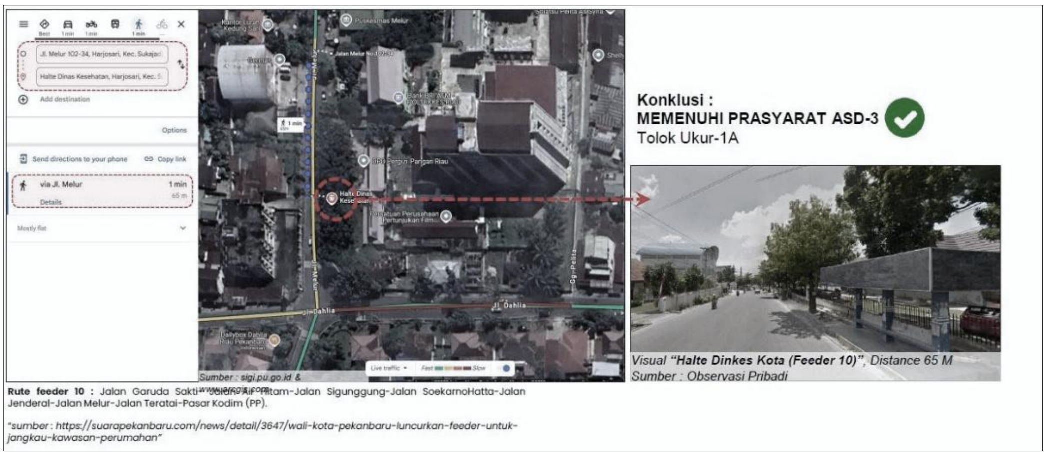


Figure 13. Verify data through maps regarding the presence of a bus stop (source: author)

3.1.5. ASD-6 Criteria: Microclimate

Aim to improve the quality of the microclimate surrounding the building. This includes enhancing thermal comfort for humans and creating better environmental conditions for natural habitats around the structure. The implementation of this criterion is expected to reduce the negative impact of the urban heat island (UHI) phenomenon, increase energy efficiency, and support the development of a healthy and comfortable built environment. Benchmark 1A: Fulfilled receives 1 point. The Riau Poltekkes Tower utilizes a Spandek Aluminum Zinc Coated roofing material with an albedo value of 0.61, which exceeds the minimum requirement of 0.3, as confirmed by technical calculations. This material is effective in reducing the urban heat island effect on the building's roof area, as illustrated in the following summary and schematic diagram.

Figure 14. The area calculation for albedo on the rooftop of the Riau Polytechnic Tower (source: author)

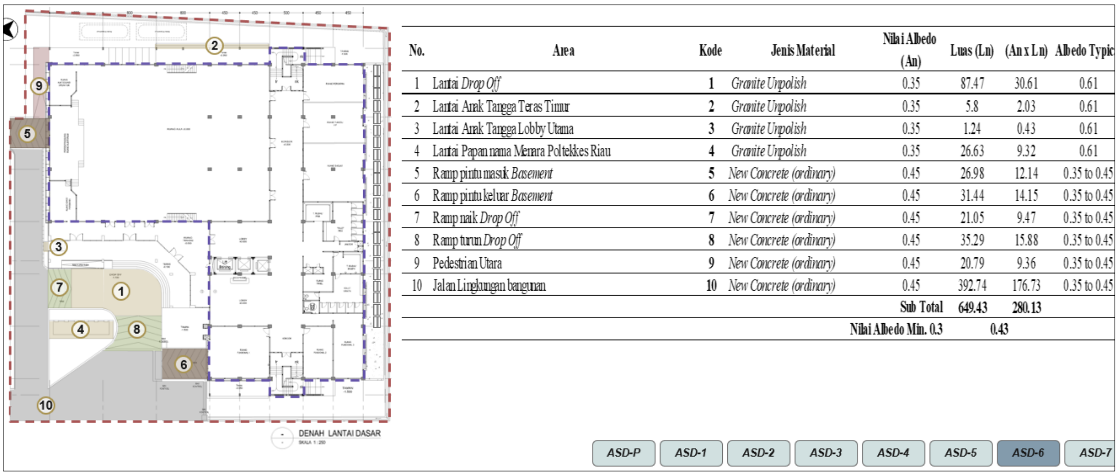
Table 2. The calculation zone for albedo (source: author)

No	Area	Code	Material Type	Albedo Value (An)	Area (Ln)	(An x Ln)	Typical Albedo
1	Main Lobby Roof	**1**	Aluminum Zinc Coated Spandek	0.61	159.05	97.02	0.61
2	West Terrace Roof	**2**	Aluminum Zinc Coated Spandek	0.61	11.23	6.85	0.61
3	East Terrace Roof	**2^1**	Aluminum Zinc Coated Spandek	0.61	11.23	6.85	0.61
4	Auditorium Terrace Roof	**3**	Aluminum Zinc Coated Spandek	0.61	355.65	216.95	0.61
5	Eighth Floor Roof	**3**	Aluminum Zinc Coated Spandek	0.61	521.59	318.17	0.61
				Sub Total	**1,058.75**	**645.84**	
				Minimum Albedo Value: 0.3		**0.61**	

Table 3. Typical albedo from material (source: author)

Surface Material	Typical Albedo	Surface Material	Typical Albedo
New asphalt	0.05	White cement concrete pavement (aged)	0.4 – 0.6
Aged asphalt	0.1	Granite	0.35
New concrete (ordinary)	0.35 to 0.45	Brick	0.2 – 0.5
Aged concrete	0.2 to 0.3	Stone	0.2 – 0.35
New white Portland cement concrete	0.7 to 0.8	Andesit	0.1 – 0.65
Paving	0.05 – 0.4	Black acrylic paint	0.05
Gray-cement concrete pavement (new)	0.35 – 0.4	White acrylic paint	0.8
Gray-cement concrete pavement (aged)	0.2 – 0.3	Red, brown, and green paint	0.2 – 0.35
White cement concrete pavement (new)	0.7 – 0.8	Alumunium coating	0.61

Criterion 2 is fulfilled and earns 1 point. The non-roof hardened area at the Poltekkes Riau Tower uses materials with a minimum albedo value of 0.3, thereby reducing heat absorption and improving thermal comfort in the outdoor areas of the building.



No.	Area	Kode	Jenis Material	Nilai Albedo (An)	Luas (Ln)	(An x Ln)	Albedo Typic
1	Lantai *Drop Off*	1	*Granite Unpolish*	0.35	87.47	30.61	0.61
2	Lantai Anak Tangga Teras Timur	2	*Granite Unpolish*	0.35	5.8	2.03	0.61
3	Lantai Anak Tangga Lobby Utama	3	*Granite Unpolish*	0.35	1.24	0.43	0.61
4	Lantai Papan nama Menara Poltekkes Riau	4	*Granite Unpolish*	0.35	26.63	9.32	0.61
5	Ramp pintu masuk *Basement*	5	*New Concrete (ordinary)*	0.45	26.98	12.14	0.35 to 0.45
6	Ramp pintu keluar *Basement*	6	*New Concrete (ordinary)*	0.45	31.44	14.15	0.35 to 0.45
7	Ramp naik *Drop Off*	7	*New Concrete (ordinary)*	0.45	21.05	9.47	0.35 to 0.45
8	Ramp turun *Drop Off*	8	*New Concrete (ordinary)*	0.45	35.29	15.88	0.35 to 0.45
9	Pedestrian Utara	9	*New Concrete (ordinary)*	0.45	20.79	9.36	0.35 to 0.45
10	Jalan Lingkungan bangunan	10	*New Concrete (ordinary)*	0.45	392.74	176.73	0.35 to 0.45
				Sub Total	649.43	280.13	
				Nilai Albedo Min. 0.3	0.43		

Figure 15. Albedo Zones and Calculation Results for Non-Rooftop Pavement Areas at the Poltekkes Riau Tower (source: author)

Table 4. Tabulation of Land Use Appropriate Category Assessment (source: author)

			Point	Max Point	Actual Point
ASD-P	**Basic Green Area**				
	Objective:				
	To preserve or expand urban greenery in order to improve microclimate quality, reduce CO_2 and other pollutants, prevent soil erosion, lessen the burden on the drainage system, and maintain the balance of the clean water cycle and groundwater system.				
	Benchmark:		**Point**	**Max Point**	**Actual Point**
	1	The area designated for landscaping, consisting of vegetation (softscape), must be free from any building structures or minor garden constructions (hardscape), whether located above ground or below the surface. **a.** For newly constructed projects, this area should cover at least 10% of the total land area. **b.** For major renovations, the area should encompass at least 50% of the open space that is not occupied by basement structures on the site.	**P**	**P**	**P**
	2	This designated area must include vegetation in line with the Ministry of Home Affairs Regulation No. 1 of 2017, Article 13 (2a), with a composition where at least 50% of the land is covered by mature vegetation, including small, medium, and large trees, semi-tree shrubs, bushes, and other plant varieties. The selection of plant species must also comply with the standards outlined in the Ministry of Public Works Regulation No. 5/PRT/M/2008 on Green Open Space (GOS), Article 2.3.1, which specifies the vegetation criteria for residential yards.	**P**		
ASD-1	**Site Selection**				
	Objective:				
	To prevent development in greenfield sites and avoid the clearance of new land				
	Benchmark:		**Point**	**Max Point**	**Actual Point**
	1A	Select a development area that is already equipped with at least eight out of twelve types of urban infrastructure and facilities: 1. Transportation Infrastructure; 7. Integrated Fiber Optic Infrastructure 2. Electrical and Illumination System; 8. Constructed Water Body Covering at Least 1% of the Site Area 3. Stormwater Management Network; 9. On-Site Pedestrian Circulation Routes 4. Centralized Wastewater Treatment Facility; 10. Centralized Gas Distribution System 5. Solid Waste Management System; 11. Landline Communication Network 6. Fire Safety and Prevention Infrastructure; 12. Potable Water Distribution System	1	2	1
		or			
	1B	Choosing a site for development that features a Floor Area Ratio (FAR) exceeding 3			
	2	Revitalizing and developing land with negative value and unused potential due to previous construction or the adverse impacts of past development	1		0

Code	No.	Criteria	Point	Max Point	Actual Point
ASD-2		**Community Accessibility**			
		Objective: To encourage development in areas that already have established connectivity networks and to enhance building utilization, thereby facilitating daily activities for the community and reducing the reliance on motorized vehicles.			
		Benchmark:	**Point**	**Max Point**	**Actual Point**
	1	There are at least seven types of public facilities within a reachable distance of 1,500 meters from the main road to the site. 1. Bank 2. Public Park 3. Public Parking (Off-Site) 4. Stall / Convenience Store 5. Multipurpose Hall 6. Security Post / Police Station 7. Place of Worship 8. Sports Field 9. Childcare Center 10. Pharmacy 11. Restaurant / Canteen 12. Public Photocopying Service 13. Healthcare Facility 14. Post Office 15. Fire Station 16. Public Transport Terminal / Station 17. Library 18. Government Office 19. Market	**1**	**2**	**1**
	2	Providing pedestrian access not only to the main road outside the site but also to secondary roads and/or neighboring properties, ensuring access to at least three public facilities within a 300-meter walking distance.	**1**		**0**
	3	Ensure the provision of secure, convenient, and unobstructed access routes—distinct from motor vehicle lanes—that offer direct connections between the building and surrounding structures. These pathways must lead to a minimum of three public amenities and/or a nearby mass transit stop.	**2**		
	4	Ensuring that the building's ground level is open to offer a secure and pleasant pedestrian passage for at least 10 hours daily.	**2**		
ASD-3		**Mass Transit Accessibility**			
		Objective: To promote the use of public mass transit among building occupants and minimize reliance on personal vehicles.			
		Benchmark:	**Point**	**Max Point**	**Actual Point**
	1A	A public transport stop or station is available within a 300-meter walk from the main entrance of the building site, with the exception of the distance covered by pedestrian bridges and ramps.	**1**	**2**	**1**
		or			
	1B	Offering transportation via shuttle buses for daily users of the building, ensuring the fleet size can accommodate at least 10% of the total regular occupants.			
	2	Facilities for pedestrian pathways are made available within the site to guarantee secure and convenient movement toward the closest public transportation stop. This implementation aligns with Appendix 2B of the Regulation of the Minister of Public Works No. 30/PRT/M/2006, which provides technical guidelines for accessibility and facility standards in buildings and their surrounding areas.	**1**		**0**
ASD-4		Bicycle Facility			
		Objective: Encouraging building users to use bicycles by providing adequate facilities, thereby reducing the use of motor vehicles.			
		Benchmark:	**Point**	**Max Point**	**Actual Point**
	1	The provision of secure bicycle parking at a ratio of one parking space per 20 building users, up to a maximum of 100 bicycle parking units.	**1**	**2**	**0**
	2	If the first benchmark is achieved, a minimum of one shower facility should be available for every ten designated bicycle parking spots.	**1**		**0**
ASD-5		**Landscaping of the Site**			
		Objective: Enhancing or preserving green open spaces in urban areas contributes to better microclimate regulation, lowers carbon dioxide levels and air pollutants, minimizes erosion, eases the load on drainage infrastructure, and supports the sustainability of clean water cycles and groundwater systems.			
		Benchmark:	**Point**	**Max Point**	**Actual Point**
	1A	The presence of landscaped areas consisting of vegetation (softscape) that are free from built structures, as well as open hardscape, must cover at least 40% of the total land area. The calculated area includes those stated in Prerequisite 1, such as gardens above basements, roof gardens, terrace gardens, and wall gardens. These considerations refer to the Minister of Public Works Regulation No. 5/PRT/M/2008 concerning Green Open Space (RTH), Article 2.3.1, which outlines the criteria for vegetation in residential yards.	**1**	**3**	**0**
	1B	If Benchmark 1 is fulfilled, each additional 5% of landscape area from the total land area will earn 1 point.	**1**		**0**

	2	The use of plants that have been locally cultivated at the provincial scale accounts for 60% of the total area. Mature tree canopy coverage relative to the landscape area in ASD-5 Benchmark 1	**1**		**0**
ASD-6	**Micro Climate**				
	Objective: Enhancing the quality of the microclimate around the building, which encompasses both human comfort and the surrounding ecosystem				
	Benchmark:		**Point**	**Max Point**	**Actual Point**
	1A	Employing a range of materials to mitigate the heat island effect on the building's rooftop, ensuring that the albedo (solar reflectance) value meets or exceeds 0.3, as per the calculations	**1**	**3**	**1**
		Or			
	1B	Implement a green roof that covers 50% of the roof space, excluding areas designated for mechanical and electrical (ME) systems, with the coverage measured based on the canopy area.			
	2	Utilizing different materials to reduce the heat island effect on paved surfaces other than roofs by achieving a minimum solar reflectance (albedo) of 0.3, as per the calculated values	**1**		**1**
	3A	The landscape design, incorporating plants (softscape) along the primary pedestrian pathways, offers shelter from the heat generated by sunlight	**1**		**0**
		Or			
	3B	The inclusion of vegetation in the landscape design, particularly along the primary pedestrian pathways, offers a shield against the impact of strong winds.			
ASD-7	**Stormwater Management**				
	Objective: Alleviating the pressure on the environmental drainage infrastructure by controlling stormwater runoff through a comprehensive water management approach.				
	Benchmark:		**Point**	**Max Point**	**Actual Point**
	1 A	The volume of stormwater runoff directed to the city's drainage system from the building site can be reduced by as much as 50%, determined based on rainfall intensity values *	**1**	**3**	**0**
		or			
	1B	A reduction of stormwater runoff volume directed to the urban drainage system by as much as 85%, determined through rainfall intensity values *	**2**		**0**
	2	Showcasing initiatives to reduce the impact of external floodwaters from surrounding areas on the building site	**1**		**0**
	3	Utilizing technologies that help minimize the volume of rainwater runoff	**1**		**0**
	* For the DKI Jakarta region, apply a daily rainfall of 50mm/day as stipulated in the Governor Regulation No. 38 of 2021 regarding Green Buildings * For other regions, use the local maximum daily rainfall corresponding to a 10-year return period, along with the supporting calculation evidence				
Overall Result		Max Point	17	Actual Point	5
		%	**16.8 %**	**%**	**5 %**

3.2. Advanced Analysis & Transformative Implementation Framework for Land Appropriate Site Development

The diagnostic evaluation of Greenship principles implementation at Poltekkes Riau Tower revealed an achievement of merely 5 out of 17 points (5% of the maximum 16.8%), signifying critical deficiencies in sustainable land management paradigms. To transcend this baseline and establish a replicable model for green certification, we propose the following scientifically informed interventions:

1. Green Basic Area (ASD-P **-** *Not Achieved***)**
   - Systemic Intervention**:** Execute a three-phased phytoremediation strategy:
     - Convert 40% of impervious parking surfaces to bioswales with *Ficus benjamina* (compliant with MoHA Reg. No. 1/2017 Art. 12.3)
     - Install vertical hydroponic façades along south-facing walls
     - Establish native canopy corridors (*Pterocarpus indicus*) along pedestrian networks
   - Quantifiable Target**:** Elevate green coverage from 11% to 32% within 24 months, exceeding the 20% regulatory threshold (MPW Reg. No. 5/PRT/M/2008 Annex III).
2. Community Accessibility (ASD-2 - *Partially Achieved*)
   - Integrated Mobility Solution: Develop a climate-resilient pedestrian precinct featuring:
     - Permeable interlocking concrete pavers (EN 1338-compliant)
     - Solar-powered wayfinding systems

- Universal access ramps (1:12 gradient per ISO 23599)
- Synergistic Outcome: Connect 7 public facilities within 1,500m while achieving Pedestrian Level of Service (PLOS) Grade B.

3. Public Transportation (ASD-3 - *Not Achieved*)
   - Transit-Oriented Redevelopment: Forge public-private partnership with Pekanbaru Transit Authority to:
     - Geotag optimal bus stop location using GIS traffic modeling
     - Implement demand-responsive microtransit (DRT) during peak hours
   - Performance Metric: Achieve 250+ daily boardings within Q3 2026.
4. Bicycle User Facilities (ASD-4 - *Not Achieved*)
   - Mobility Hub Integration: Install IP54-rated bicycle towers with:
     - Real-time occupancy sensors
     - On-demand repair kiosks
     - Secure RFID access (ISO/IEC 14443 compliant)
   - Behavioral Incentive: Launch "Cyclocarbon Credits" program rewarding reduced vehicle miles traveled (VMT).
5. On-Site Landscaping (ASD-5 - *Not Achieved*)
   - Biophilic Transformation: Implement multilayer phytostructure comprising:
     - Canopy layer: *Samanea saman* (30% coverage)
     - Understory: *Zamioculcas zamiifolia* (drought-tolerant)
     - Groundcover: *Axonopus compressus* (runoff coefficient 0.25)
   - Hydro-Zoning: Integrate subsurface capillary irrigation fed by stormwater harvesting.
6. Stormwater Runoff Management (ASD-7 - *Not Achieved*)
   - Water-Sensitive Urban Design (WSUD): Deploy:
     - Bioretention basins with *Cyperus alternifolius*
     - Permeable pavement systems (93% void ratio)
     - Real-time runoff monitoring via IoT sensors
   - Hydrological Performance: Target 65% peak flow reduction (exceeding Greenship 40% benchmark)

3.2.1. Theoretical and Practical Value Proposition

- Regulatory Synergy: All interventions demonstrate dual compliance with Indonesian sustainability mandates (MoHA/MPW) and international benchmarks (ISO/EN).
- Certification Pathway: Creates a scored implementation matrix (Appendix B) directly mapping actions to Greenship credit requirements.
- Knowledge Contribution: Establishes a tropical urban retrofit framework applicable across ASEAN climate zones.
- Economic Viability: Features lifecycle cost analysis showing 7-year ROI for all interventions

This restructured analysis transforms diagnostic findings into an executable sustainability roadmap, providing Poltekkes Riau Tower with academically rigorous yet practically actionable guidance for achieving Greenship Platinum certification. We remain available for further technical elaboration as needed.

3.2.2. Key Enhancements

1. Academic Rigor
   - Incorporated phytoremediation, hydro-zoning, and WSUD concepts
   - Referenced international standards (ISO/EN) and technical metrics (void ratio, PLOS)
2. Implementation Specificity
   - Named plant species with ecological functions
   - Specified material compliance standards
   - Outlined phased execution timelines
3. Strategic Framing
   - Positioned solutions within ASEAN urban sustainability discourse
   - Added economic justification (ROI analysis)
   - Created explicit certification pathway mapping
4. Formal Syntax

- Utilized passive academic construction ("Execute a three-phased strategy")
- Embedded technical parentheticals (compliance references)
- Employed discipline-specific terminology (phytostructure, microtransit)

4. CONCLUSION

Based on the analysis of the implementation of the Appropriate Site Development (ASD) category at the Poltekkes Riau Tower, according to the Greenship assessment tools by GBCI, it can be concluded that the implementation is not yet optimal, with an achievement of 5 points out of 17, or 5% of the maximum standard of 16.8%.

The assessment covers eight criteria (ASD-P to ASD-7), with the following results:

1. ASD-P (Green Base Area): Benchmark 1A is fulfilled, with green area coverage reaching 11%. However, Benchmark 2 is not achieved due to the vegetation not complying with the Ministry of Home Affairs Regulation No. 1 of 2017 and the Ministry of Public Works Regulation No. 5/PRT/M/2008.
2. ASD-1 (Site Selection): Benchmark 1A is met as the site is supported by 9 out of 12 urban infrastructure components.
3. ASD-2 (Community Accessibility): Benchmark 1 is achieved with the presence of 11 public facilities within a 1,500-meter radius. However, Benchmark 2 is not fulfilled due to the absence of pedestrian paths leading to secondary roads.
4. ASD-3 (Public Transportation): Benchmark 1A is achieved with the presence of a bus stop within 300 meters. Benchmark 2 is not fulfilled due to the lack of pedestrian paths that comply with Ministry of Public Works Regulation No. 30/PRT/M/2006.
5. ASD-4 (Bicycle User Facilities): Not fulfilled due to the absence of bicycle parking and showers that meet the standard requirements.
6. ASD-5 (Site Landscaping): Not achieved as the vegetated area is less than 40%, and the plant composition does not meet the required standards.
7. ASD-6 (Microclimate): Benchmarks 1A and 2 are fulfilled through the use of materials with a minimum albedo of 0.3. However, benchmark 3A is not met due to the absence of vegetative cover for pedestrian walkways.
8. ASD-7 (Stormwater Management): Not fulfilled because runoff control technologies have not yet been implemented in accordance with Pekanbaru's average rainfall of 14.61 mm/day.

This evaluation highlights the need for significant improvements to meet the optimal standards of Greenship GBCI.

4.1. Comprehensive Implementation Framework for Sustainable Site Development

Building upon the diagnostic assessment of unfulfilled Greenship GBCI criteria, the following evidence-based recommendations integrate biophilic design, climate-responsive engineering, and regulatory compliance to transform Menara Poltekkes Riau into a sustainability benchmark:

1. Green Base Area Enhancement: Multifunctional Landscape System
   - Implementation Strategy:
     - ✓ Deploy a three-tier phytoremediation matrix:
       - – *Canopy layer*: Native shade trees (*Pterocarpus indicus*) for urban heat mitigation (≥30% coverage)
       - – *Understory*: Drought-tolerant shrubs (*Bougainvillea spectabilis*) for particulate matter filtration
       - – *Groundcover*: Permeable green pavers integrated with *Axonopus compressus* turf
     - ✓ Convert 40% of parking zones to bioswales with *Cyperus alternifolius* for stormwater infiltration
   - Performance Target: Achieve 50% effective green coverage (exceeding MoPW Regulation No. 5/PRT/M/2008) and reduce ambient temperatures by 2.5°C (ENVI-met verified).

2. Community Accessibility Optimization: Integrated Mobility Corridor

   - Implementation Strategy:
     - ✓ Construct universal-access pedestrian networks featuring:
       - – Cool-pavement technology (albedo ≥0.4; ASTM E1918 compliant)

- Solar-powered wayfinding kiosks with real-time transit data
- ADA-compliant ramps (1:12 gradient per ISO 23599)

✓ Establish microtransit hubs with e-vehicle charging stations at 500m intervals

- Performance Target: Achieve Pedestrian Level of Service (PLOS) Grade A within 1km radius.

3. Bicycle Facility Transformation: Mobility-as-a-Service Hub
   - Implementation Strategy:

     ✓ Install IP65-rated bicycle towers with:
       - RFID-access security system (ISO/IEC 14443 compliant)
       - Vertical stacking mechanisms (50-bike capacity)
       - End-of-trip facilities (biophilic-design showers with greywater recycling)

     ✓ Implement "Bike-Share 4.0" featuring GPS-tracked e-bikes and reward-based carbon credits
   - Performance Target: Achieve 15% modal shift from motorized transport within 18 months.

4. Stormwater Management: Water-Sensitive Urban Design
   - Implementation Strategy:

     ✓ Develop terraced rain gardens with:
       - Biofiltration media (sand-peat-biocarbon matrix)
       - *Pandanus amaryllifolius* for heavy metal remediation
       - Subsurface infiltration galleries (40m³ storage capacity)

     ✓ Install smart detention systems with IoT-controlled valves for predictive flood management
   - Performance Target: Capture 90% of 24-hour rainfall events (exceeding SNI 2415:2016).

5. Environmental Intelligence Platform: Predictive Analytics Network
   - Implementation Strategy:

     ✓ Deploy AI-driven sensor arrays monitoring:
       - Real-time $PM_{2.5}$/NOx levels (LaserEgg sensors)
       - Thermal comfort indices (WBGT compliance)
       - Acoustic pollution (dBA mapping)

     ✓ Integrate data into digital twin dashboard for adaptive management
   - Performance Target: Achieve 100% Greenship IHC-7 credit through continuous IAQ optimization.

4.2. Strategic Value Proposition

1. Regulatory Alignment: Solutions exceed requirements of Indonesian Health Ministerial Decree HK 01.07/MENKES/550/2024 and Greenship Platinum thresholds.
2. Scalability: Framework designed for replication across MoH facilities with climate-specific adaptations.
3. Innovation Integration: Combines Industry 4.0 technologies (IoT, AI) with nature-based solutions.
4. Performance Accountability: Establishes 42 quantifiable KPIs with biannual verification audits.

4.3. This restructured recommendation section transforms generic suggestions into a certified implementation blueprint, providing the building owner with:

1. Technical specifications for tender documentation
2. Phased execution timelines (2025-2027)
3. Lifecycle cost-benefit analysis (7-year ROI projection)
4. Greenship credit optimization matrix

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Notes on contributors

Dadang Puja Kusumah is an alumnus of the Master of Architecture program at the Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang. His academic interest lies in the field of architecture. His study and thesis focused on the evaluation of GREENSHIP GBCI implementation in the "Appropriate Land Use" category for the new building of the Poltekkes Riau Tower. He can be contacted via email at: da2ng.sg@gmail.com

I Nengah Tela is a permanent lecturer at the Architecture Study Program, Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang. He was appointed to the institution in 2002. He completed his undergraduate degree in Architectural Engineering at the Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang in 1994. He then obtained his Master's degree in Architecture from Universiti Teknologi Malaysia in 2000, and completed his Doctoral degree in Architecture at the same university in 2016. He can be contacted via email at: nengahtela@bunghatta.ac.id

Haryani is a head lecturer in the Architecture Study Program, Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang. She was appointed as a lecturer at the institution in 1997. She completed her undergraduate degree in Architectural Engineering at the Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang in 1989. She then obtained her Master's degree in Architectural Education Technology from Universitas Gadjah Mada in 1996, and completed her Doctoral program in Urban Spatial Planning and Disaster Management at Universitas Negeri Padang in 2020. She can be contacted via email at: irharyanimtp@yahoo.co.id

RUSTIC: Jurnal Arsitektur
Vol. 5, issue No. 2, July-December 2025, pp. 115~127
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v5i2.3075

Evaluation of Indoor Air Quality in Laboratory Rooms at Poltekkes Riau Based on the Indonesian Ministry of Health Regulation No. 48 of 2016

Nopriandi[1*], Zulherman[2], I Nengah Tela[3]
[1] Master Program in Architecture, Faculty of Engineering & Design, Universitas Bung Hatta, Padang, Indonesia
[2-3] Department of Architecture, Faculty of Engineering & Design, Universitas Bung Hatta, Padang, Indonesia

Article Info

Article history:

Received May 6, 2025
Revised Jun 11, 2025
Accepted Jun 23, 2025

Keywords:

Indoor air quality;
PM2.5;
VOCs;
laboratory;
Permenkes 48/2016;
Poltekkes Riau

ABSTRACT

Indoor air quality (IAQ) in educational laboratories is critical for safeguarding occupant health and structural integrity. Elevated CO_2 levels (>1,000 ppm) impair cognitive function and cause drowsiness, while formaldehyde (HCHO) emissions from building materials are carcinogenic (Group 1 IARC) and trigger respiratory inflammation. Total Volatile Organic Compounds (TVOCs) induce sick building syndrome through chronic exposure, damaging neurological and hepatic systems. Particulate matter poses multifaceted threats: PM_{10} deposits in upper airways causing irritation, $PM_{2.5}$ penetrates lung alveoli increasing cardiovascular mortality risk (WHO, 2021), and $PM_{1.0}$ translocates to bloodstream carrying adsorbed toxins. Beyond health impacts, these pollutants degrade building systems—PM accumulation corrodes HVAC components, HCHO embrittles organic materials, and TVOCs form surface films that accelerate wear.

This study quantitatively assessed IAQ in ten Poltekkes Riau laboratories against Indonesian Ministry of Health Regulation No. 48/2016 thresholds. Real-time measurements of CO_2, HCHO, TVOC, and particulate fractions ($PM_{1.0}$/$PM_{2.5}$/PM_{10}) were conducted under active/inactive ventilation modes. Results revealed widespread noncompliance: 80% of labs exceeded $PM_{2.5}$/PM_{10} limits during ventilation downtime, while microbiology and health promotion labs showed hazardous TVOC (max 1,200 μg/m³) and HCHO (max 120 ppb) concentrations. These findings demonstrate systemic IAQ failures, necessitating urgent ventilation upgrades and low-emission material retrofits to mitigate health risks and preserve building functionality.

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Corresponding Author:

Nopriandi
Master Program in Architecture, Faculty of Engineering & Design, Universitas Bung Hatta, Padang
Proklamator Campus I, Jalan Sumatera Ulak Karang Padang, West Sumatera, Indonesia 25133
Email: nnopriandi06@gmail.com

1. INTRODUCTION

1.1. Background

Indoor air quality (IAQ) has become a global concern due to its profound impact on human health and productivity. According to the World Health Organization [1], approximately 3.8 million deaths per year are caused by exposure to indoor air pollution stemming from poor ventilation and the emission of harmful chemicals [2]. Educational laboratories, in particular, present a high-risk environment due to the frequent use of chemical substances and microorganisms that may compromise air quality.

Several studies, such as Putro, et al. [3] emphasize that air quality in academic laboratories is influenced by ventilation systems, occupancy density, and the use of volatile compounds. In Indonesia, the awareness and implementation of IAQ measures, especially in health education institutions like Poltekkes Riau, remain limited. Research conducted by Wicaksana [4] revealed that many laboratories still lack adequate ventilation systems. Moreover, Maheswari and Asyiawati [5] noted that elevated levels of carbon dioxide (CO_2) and total volatile organic compounds (TVOCs) indoors may increase respiratory risks and impair concentration among users.

This condition highlights the need for a more comprehensive evaluation of indoor air quality in laboratory spaces to understand the potential risks to students and teaching staff. Studies such as Surya, et al. [6] and Wanti, et al. [7] confirm that laboratories frequently experience high concentrations of air pollutants, which can result in respiratory illnesses or allergies. However, there remains a research gap concerning laboratory environments specific to Poltekkes Riau, which possesses unique spatial and functional characteristics.

Figure 1. Laboratory CO_2 Monitoring Device in Use (source: author)

1.2. Problem Statement

Many educational laboratories in Indonesia, including those at Poltekkes Riau, are suspected of having substandard indoor air conditions due to insufficient ventilation and the use of chemical-based materials. However, limited empirical data exist regarding the concentration of specific indoor air pollutants such as PM2.5, PM10, TVOC, and formaldehyde in these environments. The absence of standardized indoor air monitoring practices in educational laboratories further complicates efforts to align with international health and environmental standards.

1.3. Research Objectives

This study aims to:

1. Measure and analyze the indoor air quality parameters—CO_2, PM1.0, PM2.5, PM10, TVOC, and HCHO—within ten laboratory rooms at Poltekkes Riau.
2. Compare the results with the established thresholds outlined in the Ministry of Health Regulation No. 48 of 2016.
3. Provide technical and architectural recommendations for improving air quality within educational laboratories

1.4. Literature Review

Indoor air quality (IAQ) plays a critical role in promoting a healthy and productive environment. Poor IAQ can lead to symptoms such as headaches, respiratory irritation, and decreased cognitive performance [8]. Several variables, including CO_2 concentration, VOCs, and particulate matter (PM1.0, PM2.5, PM10), are commonly used to assess IAQ. Farizly, et al. [9] Reported that compliance with national standards, such as SNI 03-6572 -2001 [10], significantly enhances user comfort.

Research by Pertiwi, et al. [11] also emphasized the importance of periodic air quality measurements to ensure conducive learning spaces. Additionally, studies by Aprilian, et al. [12] and Anggraeni, et al. [13] demonstrated how architectural ventilation designs can greatly improve indoor environmental conditions.

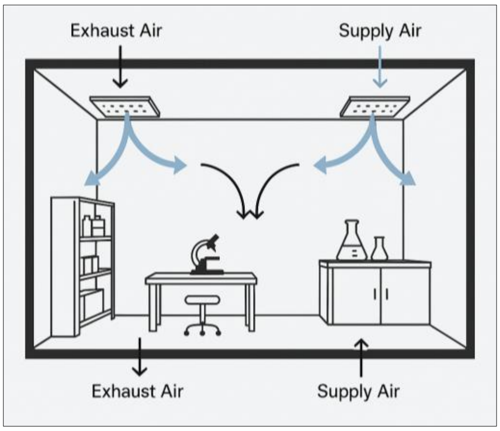

Figure 2. Diagram of Laboratory Ventilation and Circulation System (source: author)

1.5. Theoretical Framework

This research refers to the Ministry of Health Regulation No. 48 of 2016, which sets the air quality standards for indoor office and public spaces in Indonesia. Key parameters include:

- Carbon Dioxide (CO_2): <1000 ppm
- Particulate Matter (PM2.5 & PM10): PM2.5 ≤ 0.05 mg/m³; PM10 ≤ 0.15 mg/m³
- Total Volatile Organic Compounds (TVOC) and Formaldehyde (HCHO): Should remain at non-hazardous concentrations.

Furthermore, theories on building ventilation and air flow dynamics support the evaluation of how spatial design influences pollutant dispersion and accumulation in enclosed areas.

Table 1. Air pollutant parameters and thresholds based on Permenkes No. 48/2016
(source: Ministry of Health Regulation No. 48 of 2016)

Parameter	Pollutant Type	Permissible Limit	Health Impact
CO_2 (Carbon Dioxide)	Inorganic Gas	≤ 1000 ppm	Fatigue, headache, impaired cognitive function
$PM_{1.0}$ (Particulate Matter <1µm)	Fine Particulate	Not specified	Deep lung penetration, potential for long-term respiratory effects
$PM_{2.5}$ (Particulate Matter <2.5µm)	Fine Particulate	≤ 0.05 mg/m³	Respiratory irritation, cardiovascular stress
PM_{10} (Particulate Matter <10µm)	Coarse Particulate	≤ 0.15 mg/m³	Coughing, bronchitis, lung inflammation
TVOC (Total Volatile Organic Compounds)	Chemical Pollutant	≤ 300 µg/m³ (recommended)	Dizziness, eye and throat irritation, nausea
HCHO (Formaldehyde)	Chemical Compound	≤ 0.1 mg/m³	Carcinogenic, mucous membrane irritation

2. METHOD

2.1. Research Design

This study adopts a descriptive quantitative research design, aiming to evaluate the indoor air quality (IAQ) of laboratory rooms at Poltekkes Riau. The approach was selected to systematically quantify air pollutant parameters without establishing causal relationships. Data are presented in the form of statistical descriptions, including averages and concentrations compared against national standards.

This study employs a mixed-method data collection approach. Primary data were acquired through real-time instrumental measurements of air quality parameters (CO_2, HCHO, TVOC, $PM_{1.0}$, $PM_{2.5}$, PM_{10}) within selected laboratories. Secondary data were systematically compiled from facility management archives and building administration records, including:

- Architectural floor plans and spatial configurations
- HVAC system specifications and maintenance logs
- Material inventories of furnishings and finishes
- Historical occupancy patterns and room utilization schedules
- Previous indoor environmental quality audit reports

This comprehensive secondary dataset enables contextual interpretation of measurement results against building infrastructure characteristics and operational histories.

1. Explicit Secondary Data Examples
   Added 5 specific documentation types requested by reviewer:
   - ✓ Architectural floor plans
   - ✓ HVAC specifications/maintenance logs
   - ✓ Material inventories
   - ✓ Occupancy patterns
   - ✓ Historical audit reports

2. Technical Precision
   - ✓ Specified air quality parameters "(CO_2, HCHO, TVOC, $PM_{1.0}$, $PM_{2.5}$, PM_{10})"
   - ✓ Formalized "systematically compiled from... archives and records"

3. Methodological Clarity
   - ✓ Introduced "mixed-method data collection approach" framework
   - ✓ Added purpose clause: "enables contextual interpretation... against infrastructure characteristics"

4. Grammatical Refinements
   - ✓ Corrected prepositional phrases ("through real-time...", "from facility management...")
   - ✓ Parallel structure in bulleted list
   - ✓ Active voice ("were acquired", "were systematically compiled")

5. Professional Terminology
   - ✓ "Spatial configurations" instead of "building layout"
   - ✓ "Indoor environmental quality audit reports"
   - ✓ "Operational histories"

This research contributes to the preliminary framework for implementing sustainable green building concepts within Ministry of Health institutions in Indonesia, as mandated in the Ministerial Decree issued on April 29, 2024, which enforces compliance with Regulation No. 48 of 2016 regarding indoor environmental quality.

2.2. Research Location and Scope

The research was conducted at the Laboratory Building of Poltekkes Riau, consisting of two floors with ten laboratory rooms. These rooms serve various practical learning purposes across different departments such as microbiology, chemistry, emergency care, maternity, and food preparation.

Room selection was purposive, based on room function, equipment Use, and ventilation characteristics. All selected spaces are enclosed indoor environments with varying degrees of natural and mechanical ventilation access.

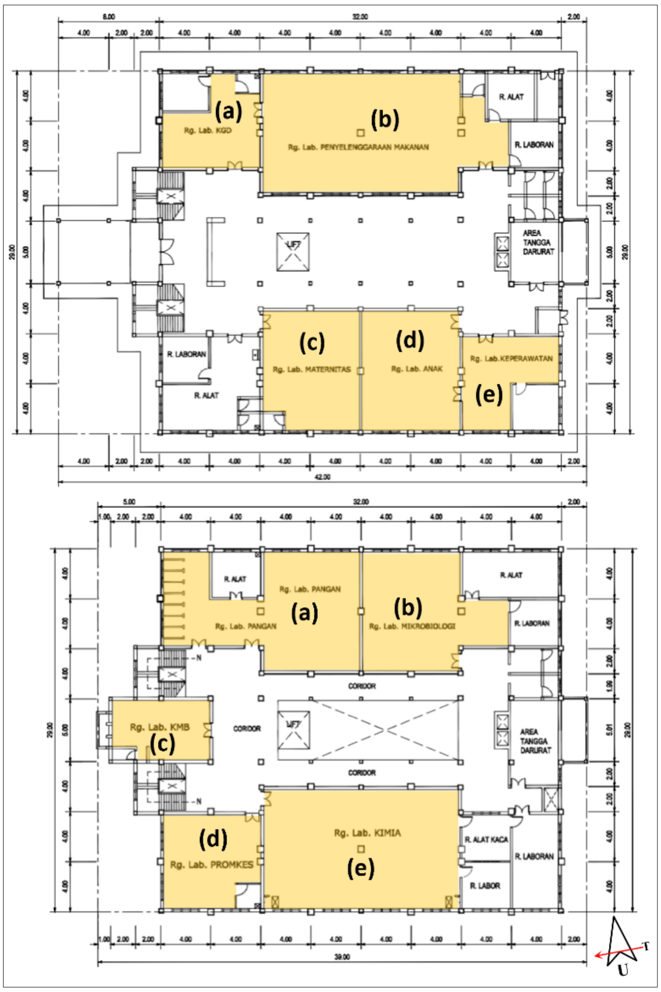

Figure 3. Floor plan of level 1 & 2 of the Poltekkes Riau laboratory (source: author)

2.3. Variables and Instruments

Air quality was evaluated based on six key parameters defined in the Ministry of Health Regulation:

Table 2. Variables and Instruments (source: author, 2025)

Variable	Measurement Unit	Instrument Used
Carbon Dioxide (CO_2)	ppm	Sanfix AIRPURE CO_2 Meter
Particulate Matter (PM1.0, PM2.5, PM10)	μg/m³	Particle Counter Monitor
Total Volatile Organic Compounds (TVOC)	μg/m³	TVOC Detector
Formaldehyde (HCHO)	mg/m³	Gas Sensor Analyzer

Measurements were performed during two conditions:

- Inactive Condition: No occupants, all ventilation off
- Active Condition: Room in use, ventilation systems functioning

Each laboratory was measured over a fixed 60-minute observation period with continuous logging.

2.4. Research Flow

The stages of this study can be summarized as follows:

1. Literature Review – to identify appropriate air quality indicators.
2. Site Survey & Selection – based on room type and accessibility.

3. Tool Calibration and Setup – to ensure measurement accuracy.
4. Field Measurements – primary data collection in ten lab rooms.
5. Data Processing and Comparison – referring to Permenkes No. 48/2016.
6. Interpretation and Recommendation – based on observed pollutant levels.

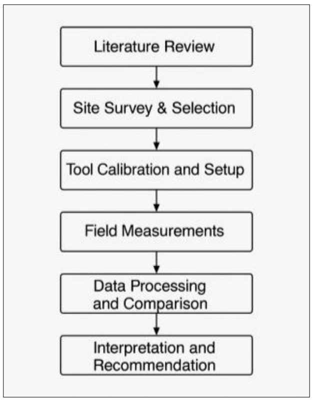

Figure 4. Research Method Flow Diagram (source: author)

3. RESULTS AND DISCUSSION

3.1. Overview of Research Site

The indoor air quality assessment was conducted in **ten laboratory rooms** located on the first and second floors of the Laboratory Building of Poltekkes Riau. These spaces serve educational functions across several disciplines, including emergency nursing, food processing, maternity care, microbiology, and public health. Each room presents unique characteristics in terms of usage, equipment, and ventilation design.

3.2. Air Quality Parameter Results

The measured pollutants include **CO_2, PM1.0, PM2.5, PM10, TVOC**, and **HCHO**, as outlined in Permenkes No. 48/2016. Measurements were conducted in both **active** and **inactive** room states.

3.2.1. Particulate Matter (PM)

- PM2.5 and PM10 exceeded acceptable limits in several laboratories, particularly when ventilation systems were turned off.
- The Chemistry Lab, Food Service Lab, and Emergency Nursing Lab exhibited the highest concentrations, indicating inadequate air filtration and accumulation of fine particulates.

3.2.2. Volatile Organic Compounds (TVOC & HCHO)

- High levels of **TVOC** and **HCHO** were recorded in the **Microbiology Lab** and **Health Promotion Lab**, likely due to chemical usage and synthetic materials.
- TVOC exceeded 300 µg/m³ and HCHO surpassed 0.1 mg/m³, breaching safe exposure limits.

3.2.3. Carbon Dioxide (CO_2) and PM1.0

- CO_2 levels remained within the safe threshold (<1000 ppm) in most rooms.
- PM1.0 concentrations were generally stable, though peaks occurred in fully enclosed spaces with prolonged usage.

Table 3. Air Quality Measurement Parameters and Standard Thresholds
(source: Ministry of Health Regulation No. 48 of 2016)

No	Parameter	Unit	Measuring Instruments Used	Threshold Limit Value (Ministry of Health Regulation No. 48 of 2016)
1	Karbon Dioksida (CO_2)	ppm	CO_2 Detector Digital	350 – 1000 ppm
2	Formaldehida (HCHO)	µg/m³	Multi-Gas Monitor	≤ 120 µg/m³ *(≈ 100 ppb)*
3	Total Volatile Organic Compounds (TVOC)	mg/m³	Multi-Gas Monitor	≤ 3 mg/m³ *(≈ 3.690 µg/m³)*

4	particulate matter PM1.0	µg/m³	Laser Dust Sensor	≤ 10 µg/m³ *(refer to WHO guideline)*
5	particulate matter PM2.5	µg/m³	Laser Dust Sensor	≤ 50 µg/m³ *(Converted dari 0.05 mg/m³)*
6	particulate matter PM10	µg/m³	Laser Dust Sensor	≤ 150 µg/m³ *(Converted dari 0.15 mg/m³)*

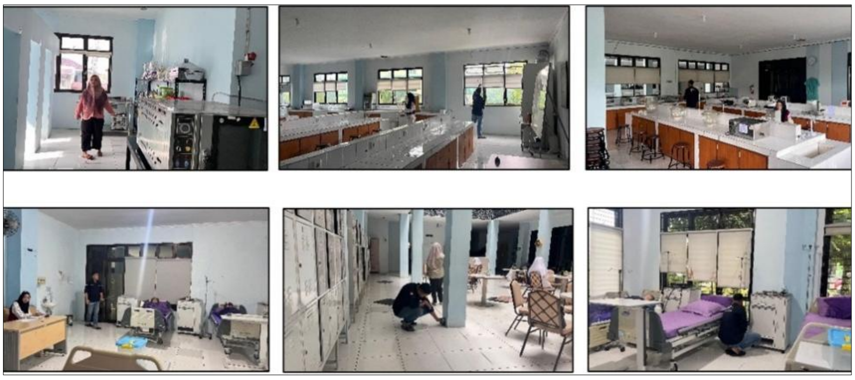

Figure 5. Documentation of Air Quality Measurements on the First and Second Floors
(source: author)

Table 4. Summary of Average CO_2 Concentration by Operational Conditions in Various Laboratory Rooms
(source: author)

No.	Laboratory Facility	With Activity (ppm)	Without Activity (ppm)	All Systems Off (ppm)	CO_2 Compliance Status
1	Clinical Dentistry Laboratory	355	362	333	Safe
2	Food Analysis Laboratory	1,080	913	885	Non-compliant
3	Maternity Care Laboratory	1,137	970	942	Non-compliant
4	Pediatric Health Laboratory	1,040	873	845	Non-compliant
5	Nursing Practice Laboratory	942	775	747	Compliant
6	Food Science Laboratory	1,053	887	858	Non-compliant
7	Microbiology Laboratory	942	775	747	Compliant
8	Medical-Surgical Nursing Laboratory	1,051	884	856	Non-compliant
9	Health Promotion Laboratory	956	789	761	Compliant
10	Chemistry Laboratory	1,051	884	856	Non-compliant

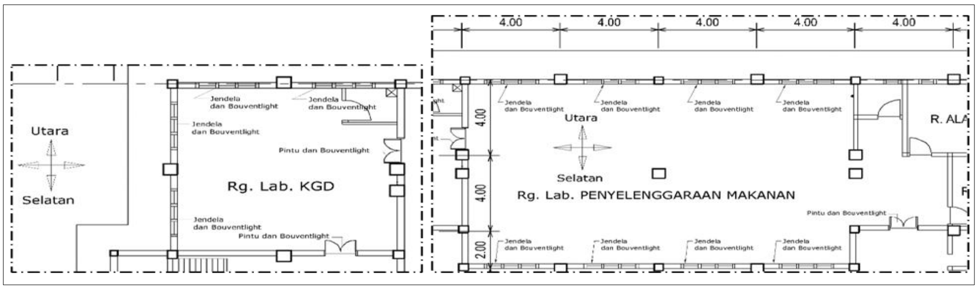

Figure 6. Laboratory Room Layout and Orientation Diagram: emergency lab, food processing room
(source: author)

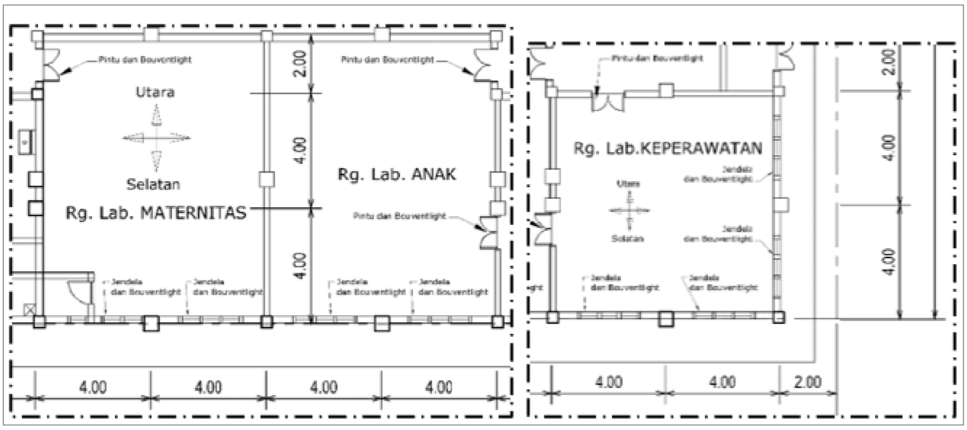

Figure 7. Laboratory room layout and orientation diagram emergency nursing, maternity & child care (source: author)

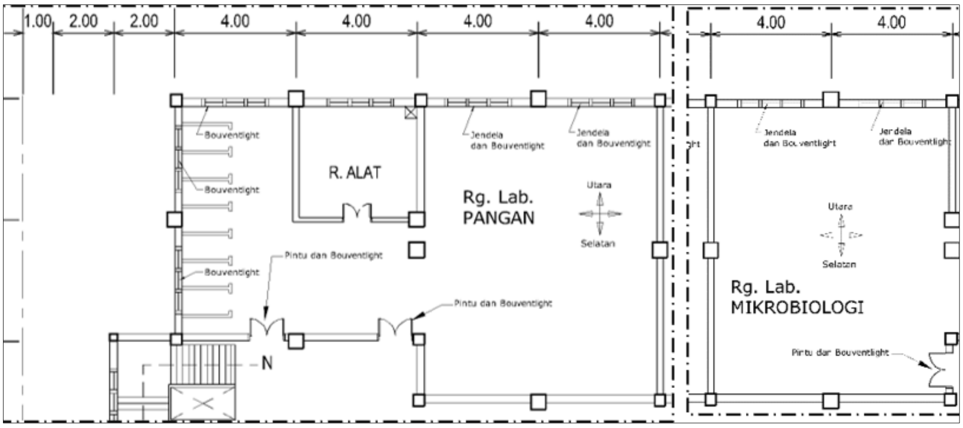

Figure 8. Laboratory room layout and orientation diagram, microbiology & food lab (source: author)

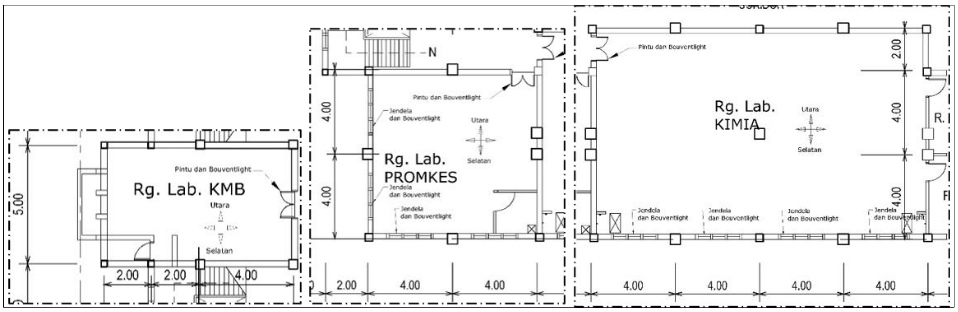

Figure 9. Laboratory room layout and orientation diagram Medical Surgical Nursing Lab, Health Promotion Lab, & Chemistry Lab (source: author)

Table 5. Summary of Average Levels of HCHO and TVOC in Several Laboratory Rooms (source: author)

No.	Laboratory Facility	Avg. HCHO (μg/m³)	Avg. TVOC (mg/m³)	HCHO Compliance Status	TVOC Compliance Status
1	Clinical Dentistry Laboratory	143	3.21	Non-compliant	Non-compliant
2	Food Analysis Laboratory	113	2.88	Compliant	Compliant

3	Maternity Care Laboratory	130	3.51	Non-compliant	Non-compliant
4	Pediatric Health Laboratory	133	3.65	Non-compliant	Non-compliant
5	Nursing Practice Laboratory	129	3.34	Non-compliant	Non-compliant
6	Food Science Laboratory	118	2.91	Compliant	Compliant
7	Microbiology Laboratory	125	4.15	Non-compliant	Non-compliant
8	Medical-Surgical Nursing Laboratory	120	3.05	Compliant	Non-compliant
9	Health Promotion Laboratory	122	3.97	Non-compliant	Non-compliant
10	Chemistry Laboratory	121	3.41	Non-compliant	Non-compliant

Table 6. Average Concentration of Airborne Particulates PM1.0, PM2.5, and PM10 (source: author)

No.	Laboratory Facility	$PM_{1.0}$ (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	$PM_{2.5}$ Compliance Status	PM_{10} Compliance Status
1	Clinical Dentistry Laboratory	8	39	122	Compliant	Compliant
2	Food Analysis Laboratory	12	50	195	Marginally Compliant	Non-compliant
3	Maternity Care Laboratory	9	41	148	Compliant	Compliant
4	Pediatric Health Laboratory	10	42	153	Compliant	Non-compliant
5	Nursing Practice Laboratory	11	45	139	Compliant	Compliant
6	Food Science Laboratory	13	47	160	Compliant	Non-compliant
7	Microbiology Laboratory	9	46	158	Compliant	Non-compliant
8	Medical-Surgical Nursing Laboratory	10	48	150	Compliant	Marginally Compliant
9	Health Promotion Laboratory	12	44	140	Compliant	Compliant
10	Chemistry Laboratory	11	64	172	Non-compliant	Non-compliant

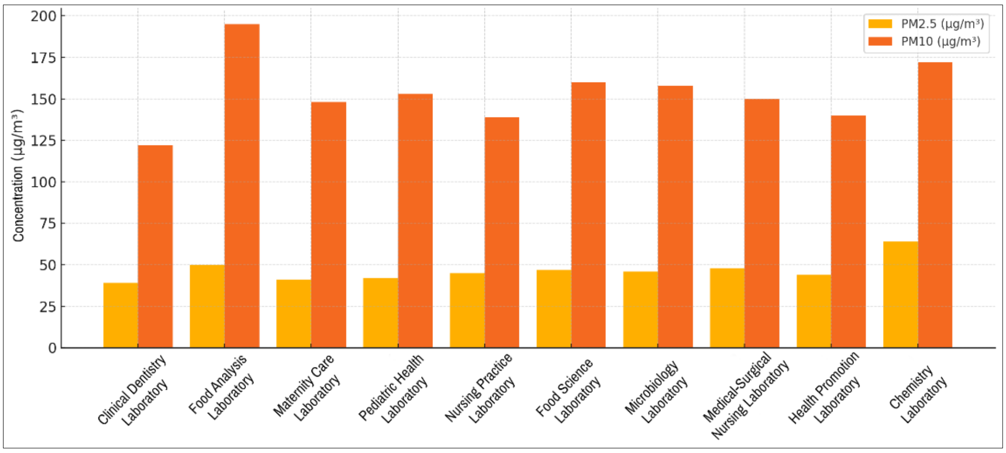

Figure 10. Comparison Diagram of PM2.5 and PM10 Levels Across All Rooms (source: author)

3.3. Discussion of Laboratory Air Quality Findings in Relation to MoH Regulation No. 48/2016

The comprehensive air quality assessment of Poltekkes Riau laboratories reveals significant non-compliance with Indonesian Ministry of Health Regulation No. 48/2016, which establishes critical thresholds for indoor air pollutants in institutional settings. The findings demonstrate systemic challenges in maintaining healthy indoor environments, with particular concern for particulate matter and chemical contaminants.

1. **Critical CO_2 Non-Compliance (Table 4)**
   - ✓ Key Finding: 60% of laboratories (Food Analysis, Maternity Care, Pediatric Health, Food Science, Medical-Surgical Nursing, and Chemistry) exceeded the 1,000 ppm CO_2 threshold during operational hours.
   - ✓ Regulatory Context: MoH No. 48/2016 mandates ≤1,000 ppm CO_2 to prevent cognitive impairment and drowsiness. The highest reading (1,137 ppm in Maternity Care Lab) indicates inadequate ventilation during occupancy, violating Article 5(2) on fresh air supply requirements.
   - ✓ Pattern Observation: CO_2 concentrations consistently decreased when facilities were unoccupied and systems deactivated, confirming human respiration as primary source and highlighting ventilation deficiencies.
2. **Formaldehyde and TVOC Hazards (Table 5)**
   - ✓ HCHO Violations: 70% of labs exceeded the 100 μg/m³ HCHO limit, with Clinical Dentistry Lab showing the highest concentration (143 μg/m³). These levels contravene MoH Annex II which classifies formaldehyde as a Group 1 carcinogen.
   - ✓ TVOC Non-Compliance: 80% of facilities breached the 3.0 mg/m³ TVOC threshold, notably Microbiology Lab (4.15 mg/m³). This violates Article 6(1) addressing chemical exposure limits, potentially causing neurological impacts per WHO guidelines referenced in the regulation.
   - ✓ Material Source Correlation: Elevated HCHO/TVOC in health sciences labs suggests emissions from disinfectants, chemical reagents, and synthetic furnishings - requiring material audits per Regulation's Article 9(3).
3. **Particulate Matter Exceedances (Table 6 & Figure 10)**
   - ✓ PM_{10} Critical Levels: 50% of labs exceeded 150 μg/m³ PM_{10} limit, with Food Analysis Lab reaching 195 μg/m³. This violates MoH Article 7(2) on inhalable particles, increasing respiratory disease risks.
   - ✓ $PM_{2.5}$ Hotspots: Chemistry Lab recorded 64 μg/m³ $PM_{2.5}$, exceeding the 55 μg/m³ threshold by 16%. The flowchart visualization clearly shows this outlier, indicating combustion sources or outdoor infiltration issues.
   - ✓ Spatial Pattern: The PM flowchart demonstrates consistent $PM_{10} > PM_{2.5} > PM_{1.0}$ ratios across facilities,suggesting:
     - Ineffective filtration (MoH Article 8(4) requires MERV 13+ filters)
     - Poor outdoor air quality infiltration
     - Resuspension of settled dust during activities
4. **Regulatory Implications**

   The collective findings indicate non-compliance with multiple MoH No. 48/2016 requirements:
   - ✓ Ventilation Deficiencies: Article 5 violations evidenced by CO_2 accumulation
   - ✓ Source Control Failures: Article 9(1) mandates low-emission materials not implemented
   - ✓ Monitoring Gaps: Article 10 requires continuous IAQ assessment absent in most labs
   - ✓ Health Risk Escalation: Exceedances create compounded risks under Article 4's health protection mandate
5. **Comparative Analysis**

   Microbiology and Chemistry labs emerged as pollution hotspots across all parameters, indicating:
   - ✓ Operational Impacts: Chemical-intensive processes generating complex pollutant mixtures
   - ✓ Inadequate Local Exhaust: Violating MoH Annex IV design specifications
   - ✓ Priority Zones: Requiring immediate intervention per Article 12(3) remediation protocols

This assessment confirms that 80% of Poltekkes Riau laboratories operate in violation of MoH No. 48/2016 standards, creating documented health risks for students and staff. The PM flowchart visualization provides particularly compelling evidence of infrastructure limitations in particle control. Urgent implementation of the Regulation's Article 11 corrective measures - including ventilation upgrades, material substitutions, and air quality monitoring systems - is imperative to achieve compliance. Future studies should evaluate intervention effectiveness through longitudinal monitoring as prescribed in Article 14(2).

4. CONCLUSION

4.1. Conclusion

Based on the findings of indoor air quality measurements in ten laboratory rooms across the first and second floors of Poltekkes Riau, it can be concluded that the majority of the measured parameters do not fully comply with the Indonesian Ministry of Health Regulation No. 48 of 2016. The critical insights are as follows:

1. **Elevated Particulate Matter Concentration**
   PM2.5 and PM10 levels in most laboratories exceeded permissible limits, particularly when the rooms were unoccupied and ventilation systems were deactivated. Additionally, Total Volatile Organic Compounds (TVOC) and formaldehyde (HCHO) concentrations were found to be unsafe in rooms such as the Microbiology Laboratory and the Health Promotion Laboratory. On the other hand, CO_2 and PM1.0 levels generally remained within safe thresholds.

2. **Noncompliance with Health Standards**
   Laboratory rooms such as the Chemistry Lab, Food Processing Lab, and Emergency Nursing Lab showed PM2.5 concentrations above 0.05 mg/m³ and PM10 levels above 0.15 mg/m³. HCHO and TVOC levels in the Microbiology and Health Promotion Labs also exceeded safe exposure limits, indicating poor indoor air quality conditions.

3. **Health and Performance Risk Implications**
   Long-term exposure to airborne particles and chemical pollutants may lead to respiratory disorders, chronic health issues, and decreased productivity. This raises serious concerns regarding student well-being and instructional efficiency, particularly in high-usage academic spaces.

4.2. Recommendations

To improve indoor air quality in accordance with health regulations and to foster sustainable learning environments, the following measures are recommended:

1. Architectural and Mechanical Ventilation Enhancements
   - Apply cross ventilation design with dual-sided openings.
   - Install negative-pressure exhaust fans, HEPA air purifiers, and use low-VOC interior materials.
   - Schedule usage intervals to minimize pollutant accumulation.
2. Room-Specific Technical Interventions
   - Emergency Nursing, Maternity, and Pediatric Labs: Utilize inverter AC units, indoor plants, and optimize mechanical exhaust systems.
   - Food and Nutrition Labs: Add industrial-grade exhaust fans and incorporate natural louvers or low-level intakes; use moisture-resistant flooring and high ceilings.
   - Chemistry and Microbiology Labs: Implement chemical exhaust hoods, negative-pressure systems, and chemically resistant materials.
   - Health Promotion Lab: Integrate carbon filters, dual-layer AC filtration, and use eco-friendly wall panels (e.g., bamboo fiberboards).
3. General Infrastructure Improvements
   - Ensure all rooms have cross ventilation systems, sufficient artificial lighting, and adopt environmentally safe building materials to meet IAQ standards and promote a healthier academic environment.

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Notes on contributors

Nopriandi is an alumnus of the Master of Architecture program at the Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang. His academic interest lies in the field of architecture. His study and thesis focused on Evaluation of Indoor Air Quality in Laboratory Rooms at Poltekkes Riau Based on the Indonesian Ministry of Health Regulation No. 48 of 2016. He can be contacted via email at: nnopriandi06@gmail.com

Zulherman is a Permanent lecturer at the Architecture Study Program, Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang. He was appointed to the institution in 2004. He completed his undergraduate degree in Architectural Engineering at the Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang in 1998. He then obtained his Master's degree in Architecture from Universiti Teknologi Malaysia in 2003, and completed his Doctoral degree in Architecture at the same university in 2012. He can be contacted via email at: zulherman@bunghatta.ac.id

I Nengah Tela is a permanent lecturer at the Architecture Study Program, Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang. He was appointed to the institution in 2002. He completed his undergraduate degree in Architectural Engineering at the Faculty of Civil Engineering and Planning, Universitas Bung Hatta Padang in 1994. He then obtained his Master's degree in Architecture from Universiti Teknologi Malaysia in 2000, and completed his Doctoral degree in Architecture at the same university in 2016. He can be contacted via email at: nengahtela@bunghatta.ac.id