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BALANCING AFFORDABILITY AND SUSTAINABILITY: UNVEILING HOMEBUYERS' PREFERENCES FOR GREEN AFFORDABLE HOUSING CRITERIA AND FEATURES

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Abstract

Green Affordable Housing (GAH) embodies a balance between affordability and sustainability in housing development. In Malaysia, the Green Building Index (GBI) outlines green housing criteria across six key areas: energy efficiency, indoor environmental quality, sustainable site planning and management, material and resource efficiency, water efficiency, and innovation. Similarly, the National Housing Policy (NHP) emphasizes affordability through income and housing price criteria. This study aims to align these frameworks by integrating GBI and NHP standards with GAH features identified in prior research. Logistic regression analysis of potential homebuyers' data revealed that 75.8% of respondents are willing to pay a premium for GAH features, with an acceptable cost increment of up to 10%. Top preferences include water-efficient fixtures (62.5%), rainwater harvesting systems (61%), and improved indoor environmental quality, such as low-noise designs (61.7%) and reduced volatile organic compounds (58%). The study highlights that incorporating green features into affordable housing is viable if cost increments remain reasonable, offering guidance for policymakers and developers to create sustainable and affordable housing solutions in Malaysia.

Keywords: Green Affordable Housing, homebuyer preferences, sustainability, affordability, Malaysia.

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INTRODUCTION

The integration of green features into affordable housing (GAH) addresses environmental challenges by creating sustainable living spaces for low- and middle-income families (Ye et al., 2024). While GAH offers environmental and economic benefits, such as lower utility bills and improved health outcomes, balancing sustainability with affordability remains a challenge due to higher upfront costs (Galster, 2020; Yeganeh et al., 2019). Understanding homebuyers' needs is critical, as studies show that while buyers value energy-efficient and green features, affordability is their primary concern, with limited willingness to pay significant premiums (Noiseux & Hostetler, 2010). Identifying cost-effective green features is essential for increasing GAH adoption.

Research highlights that affordability and perceived quality strongly influence purchasing decisions, as seen in Malaysia, where weak policies, high costs, and supply-demand mismatches hinder affordable housing provision (Wong et al., 2024; Daud & Nor, 2018). The M40 group, representing 40% of Malaysia's population, faces affordability gaps due to rising property prices and limited mid-range housing options (Daud & Nor, 2018; Baqutayan, 2014). As a crucial segment of homebuyers, the M40 can benefit from GAH's long-term advantages. This study objectives include (i) to identify key GAH features and (ii) to assess the M40 group's preferences and willingness to pay (WTP), contributing to a tailored green affordable housing model that aligns with their needs (Francis et al., 2023; Zaidi, 2024).

LITERATURE REVIEW

Defining Green Affordable Housing

GAH represents an essential link to social justice, prosperity, and homeowner well-being by combining environmental sustainability with social and economic objectives (Anthony, 2023; Favilukis et al., 2023; Global Green USA, 2007). To justify its costs, GAH requires careful evaluation of cost-effective green features while balancing affordability and sustainability, addressing poverty risks for moderate-income groups, and promoting access to public amenities, healthy neighborhoods, and walkable communities (Silva et al., 2024; Kwofie et al., 2025).

This study defines GAH as integrating green building criteria into affordable housing, targeting Malaysian middle-income groups—40% of the population earning between RM5,250 and RM11,819 monthly (DOSM, 2022)—with a willingness to pay (WTP) for 10% higher costs, ranging from RM120,000 to RM180,000. It also considers households earning RM2,000 to RM8,000 monthly (Rahman et al., 2019; Zulkepli et al., 2017; Mousavi et al., 2013; Aziz et al., 2011; Suhaida et al., 2011), particularly in regions like Johor Bahru, Klang

Valley, and Penang, emphasizing the need for clear implementation strategies aligned with affordability and performance goals (Olanrewaju & Tan, 2018).

GAH Criteria and Features

Six green housing criteria and twenty features identified though a literature review (Table 1), linking broad sustainability principles with practical housing applications. These criteria and features serve as essential guidelines in developing affordable yet eco-friendly homes to foster both cost-effectiveness and improved quality of life for residents.

Table 1: Green Affordable Housing Criteria and Features

Criteria	Features	References
Energy Efficiency	• Heating, ventilation, and air conditioning with energy-efficient systems • Energy-efficient appliances and light fittings • Techniques to reduce solar heat through walls and roofs • Use of solar panels • Building orientation to maximize natural light (north-south orientation)	Fang, Misnan, and Abdul Halim (2024); Igugu et al., 2024; Zulkepli (2020); Olatunde et al. (2024); Simpeh et al. (2022); Bertoldi (2022); El-Azab (2021); Soheilian et al. (2021); Bottarelli et al., (2020); Aggarwal & Molleti (2024); Ziaeemehr et al., (2023); Akinsulire et al. (2024); Maka & Alabid (2022); Wang et al., (2024); Bashir et al. (2024); Sharma & Dongre (2024); UN-Habitat (2024)
Sustainable Site Planning and Management	• Landscaping, especially on the roofs of high-rise buildings • Extensive landscaping throughout the site • Accessibility to public transportation	Ahzahar, Zakaria, and Ismail (2016); Díaz Caselles and Guevara (2024); Zulkepli (2020); Szołomicki (2019); Misni (2017); Ehab et al. (2025); Hussain, M. R. M. (2014); Akinsulire et al. (2024); Silva et al. (2024); Azmoodeh et al. (2020); Howell et al., (2018); Dragu et al. (2025)
Water Efficiency	• Sustainable water management • Rainwater harvesting systems	Flores and Ghisi (2022); Al-Qawasmi et al. (2019); Zulkepli (2020); Madias & Szymkowiak (2022); ; Akinsulire et al. (2024); Sojka et al. (2016); Freni& Liuzzo (2019); Rodrigues et al. (2023)

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Material and Resources	• Use of regional materials to minimize depletion of natural resources • Materials that adopt reduce, reuse, and recycle concepts	Liu (2022); Xiangyu (2024); Zulkepli 2020); Akinsulire et al. (2024); Sánchez Hurtado (2017); Popescu et al. (2024); Shukla et al. (2024); Santos et al. (2024);

Criteria	**Features**	**References**
Material and Resources	• Sustainable construction practices • Good waste management principles • Provision of separate bins and chutes for waste separation	Roslee et al. (2022); Akinsulire et al. (2024); Atta et al. (2021); Silva et al. (2024); Azam (2022); Chen & Lee (2020); Safian (2020)
Indoor Environmental Quality	• Design features that ensure low noise levels, low indoor air pollutants, and high indoor air quality • Minimization of volatile organic compounds (VOCs) • Formaldehyde minimization	Shetaw et al., (2024); Niza, Bueno & Broday (2023); Roslee et al. (2022); Lo et al. (2014); Kurmanbekova et al. (2025); Hashemi & Dungrani (2025); Liu et al. (2024); Alkarimiah et al. (2023); Chaturvedi et al. (2023). Kurmanbekova et al. (2025); Silva et al. (2024).
Innovation	• Environmental ideas to enhance sustainability • Design ideas that promote eco-friendliness	Ahmad (2023); Meena et al. (2022); Gunaselan (2025); Silva et al. (2024); Akinsulire et al. (2024) Gunaselan (2025); Mohamad et al. (2022)

Source: Author (2024)

Homebuyers' Preferences for Green Affordable Housing Criteria and Features

Understanding homebuyers' willingness to pay (WTP) is essential for pricing strategies and developing housing features, as it reflects the maximum buyers are willing to spend (Wang et al., 2024; Mishi & Mwanyepedza, 2023; Breidert et al., 2006). Factors like location, property traits, and disclosure influence WTP, while financial feasibility is key to balancing economic benefits (Mwanyepedza & Mishi, 2024; Azizul & Chuweni, 2024). Research shows buyers are inclined to pay more for green features such as LED lighting and water-saving devices, though affordability and cost-effectiveness remain limiting factors (Yau, 2012; Estep et al., 2013; Ling & Gunawansa, 2011). Affordable housing prioritizes price and income considerations to keep expenses under 30% of income (Crowe & Rowley, 2024; Azmi & Bujang, 2021; Aziz et al., 2011; Hashim, 2010; Global Green USA, 2007). Demand, tied to financial capacity and interest rates, also affects WTP and sustainable housing goals, highlighting the importance of cost-effective solutions (Cervelló-Royo et al., 2021; Węgrzyn & Kania, 2024; Goedertier et al., 2024). While homebuyers value the economic benefits of green

features, their modest WTP underscores the need for affordable and sustainable housing options that align with their financial capabilities.

In summary, the conceptual framework for GAH (Figure 1) integrates affordability considerations namely price, income, and cost—with green building principles, reflected in both criteria (e.g., energy efficiency, water efficiency, sustainable site planning, indoor environmental quality, materials and resources, and innovation) and specific features (e.g., use of solar panels, rainwater harvesting systems, sustainable construction practices, and eco-friendly design ideas). This framework serves to identify comprehensive housing features while analyzing prospective homebuyers' preferences and their willingness to pay for sustainable yet affordable housing solutions.

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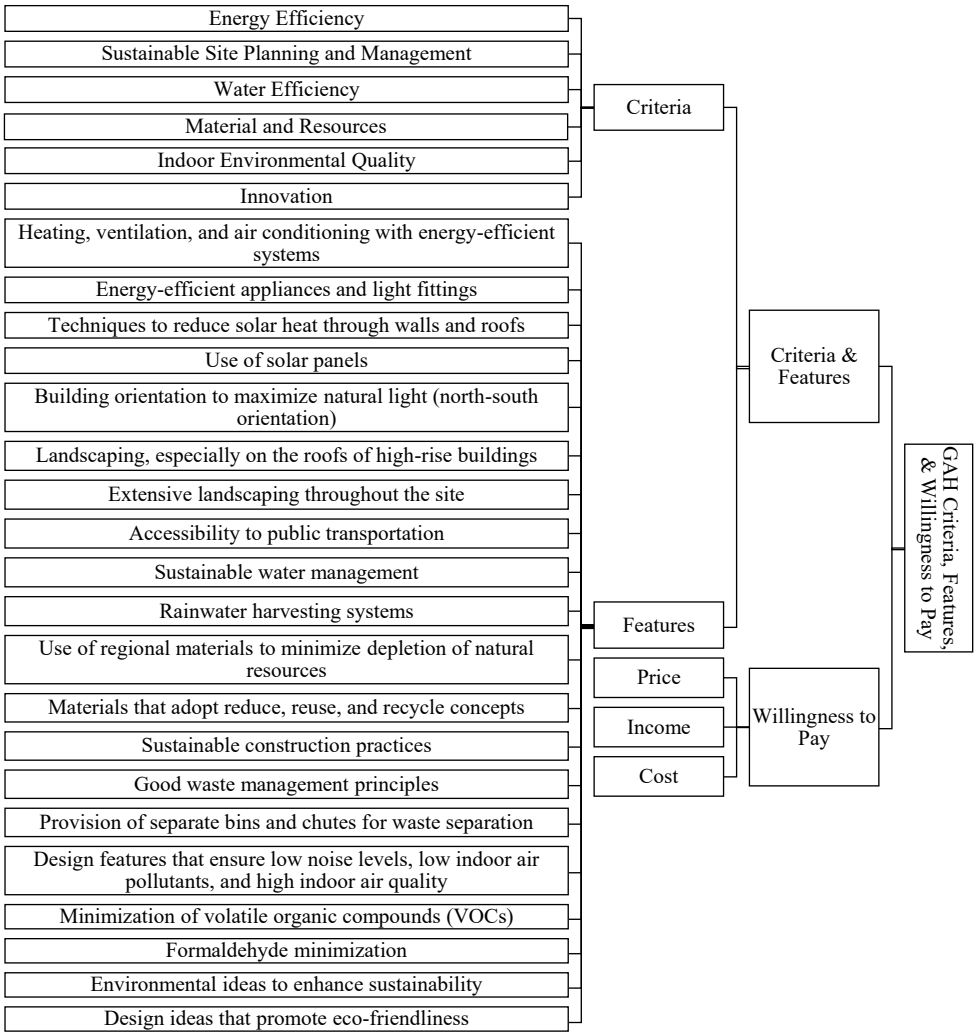


Figure 1: Green Affordable Housing Conceptual Framework
Source: Author (2024)

RESEARCH METHODOLOGY

This study identified GAH criteria and features based on existing literature, considering homebuyers' preferences and willingness to pay. Using a cross-sectional survey design, structured questionnaires were distributed in Johor Bahru, Klang Valley, and Penang, covering respondent profiles and GAH preferences (Cooper, Schindler, & Sharma, 2018, Zikmund et al., 2013).

Following Israel's (1992, 2019) sample size formula, a target of 400 respondents was set, adjusted for population differences across states. To ensure sufficient responses, 300 questionnaires were distributed per state, yielding 600 valid responses with a 100% response rate in Johor Bahru and Penang, and 82% in Klang Valley.

ANALYSIS AND DISCUSSION

Data Analysis

The survey data was analyzed using descriptive and Logistic Regression Analysis to explore respondents' socio-demographic characteristics, knowledge of GAH, and willingness to pay for GAH features. Reliability and validity of the research instrument were ensured through Exploratory Factor Analysis (EFA), identifying patterns among variables and enabling data reduction. Respondents selected GAH features from their perspectives, and cross-tabulation analysis was conducted to assess the incremental cost of GAH criteria and features.

Socio-demographic Profile

The respondent profile illustrated in Table 2 provides a detailed summary of the demographic and socioeconomic profiles of the sample population.

Table 2: Socio-demographic profile of respondents.

Category	Item	Percentage
Gender	Female	55.5
	Male	44.5
Race	Non Bumiputera	12.8
	Bumiputera	87.2
Age	18 – 40 years	76.5
	41 years and above	23.5
Dependent	No dependent	22.8
	Have dependent	77.2
Qualification	School level	37.0
	Graduate level	58.3
	Post graduate level	4.7
Income	RM 5001 and above	29.7
	RM 1001 – RM 5000	70.3
Expenditure	More than RM 1500	65.8
	RM 500 – RM 1500	34.2
Category	**Item**	**Percentage**
Housing Loan	RM 501 and above	69.0
	RM 500 and below	31.0
Occupation	Self employed	8.2
	Government Sector	78.7
	Private Sector	13.2
Knowledge of GAH	No	34.7
	Yes	65.3

Source: Author (2024)

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Reliability Test

A reliability analysis was executed to assess the consistency of the responses obtained. A Cronbach's Alpha value exceeding 0.7 signifies that the data is reliable for further analysis and reporting (Taber, 2018 and Hair et al., 2017). The Cronbach's Alpha value in this research was in the range of 0.930 to 0.970, demonstrating a high level of internal consistency and confirming the reliability of the respondent data.

Exploratory Factor Analysis (EFA)

EFA was used to refine 26 questionnaire items into constructs for independent variables, utilizing SPSS version 27 with varimax rotation (Creswell & Creswell, 2018). The analysis categorized 20 GAH features into six key criteria: energy efficiency, sustainable site and management, water efficiency, material and resources, indoor environmental quality, and innovation.

The EFA results indicate that the six GAH criteria explain 66.67% of the variance and show strong reliability (Cronbach's alpha > 0.966). The 20 items retained were grouped as follows:

(i) Energy Efficiency – 5 items (ii) Sustainable Site and Management – 3 items (iii) Water Efficiency – 2 items (iv) Material and Resources – 5 items (v) Indoor Environmental Quality – 3 items (vi) Innovation – 2 items

These findings align with other GAH rating tools, such as:

i. BREEAM Eco Homes (UK): 8 criteria, 33 features
ii. Green Communities Initiative Criteria (US): 8 criteria, 60 features
iii. Ecocents Living (Australia): 11 criteria, 24 features (Pullen et al., 2009)
iv. Green Building Index Malaysia (GBI): 6 criteria, 39 features

Though not representing GAH Malaysia, GBI served as a basis for its development.

Logistic Regression Analysis

Table 3 presents the logistic regression results, showing that GAH criteria and features significantly influence willingness to pay ($p < .05$). The model meets all key assumptions, with the Omnibus test indicating strong significance ($p < .001$) and explaining 26% to 38.9% of the variation in the dependent variable, based on Cox & Snell and Nagelkerke values.

Table 3: Result for Logistic Regression

	B	S.E	Wald	df	Sig.	Exp (B)
GAH Criteria and Features	1.146	0.096	143.521	1	.000	3.146

Best Model Summary: Omnibus Test ($p < .000$)
-2 Log Likelihood (479.917); Cox and Snell R2 (.260); Nagelkerke R2 (.389)

Source: Author (2024)

Table 4 exhibits the results of the classification of the best model. It shows how well the model predicts group membership. The overall classification accuracy is 75.8%, exceeding the 50% cut off threshold.

Table 4: Predicted vs. Observed Frequencies for GAH Preferences and Willingness to Pay Using Logistic Regression (Cutoff = 0.50)

Observed	Predicted		% Correct
	Not Willing to Pay More (No)	Willing to Pay More (Yes)	
Not Willing to Pay More (No)	0	145	.0
Willing to Pay More (Yes)	0	455	100.0
Overall % correct			75.8

Source: Author (2024)

This classification plot shows the frequency of the willingness to pay for different probabilities and whether there were 'yes' or 'no' categorisation. Figure 2 reveals the graphic guide on how precise the model is and displays how many time the model would predict 'yes' or 'no' outcome based. The outcome from the following graph shows many cases in the right-side area. So, this model identifies that GAH criteria and features significantly influence willingness to pay.

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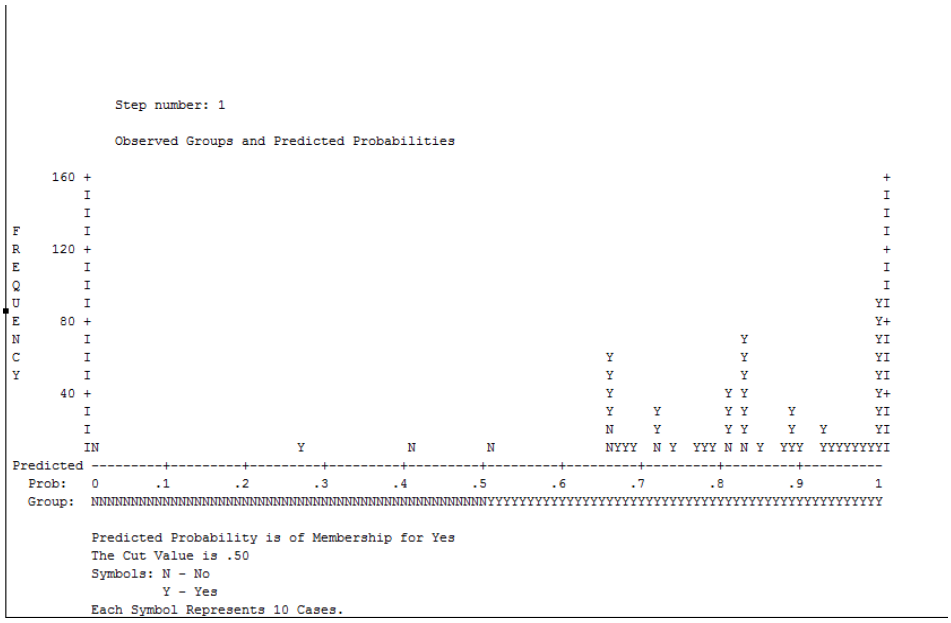


Figure 2: Observed Groups and Predicted Probabilities
Source: Author (2024)

GAH features from Potential Home Buyers' Perspectives

Table 5 highlights potential homebuyers' preferences for GAH features, with high selections for water efficiency criteria like Water Saving Appliances and Fittings (62.5%) and Rainwater Harvesting (61%), as well as indoor environmental quality features such as Low Noise Levels, High Indoor Air Quality (61.7%), Volatile Organic Compounds (58%), and Formaldehyde Minimization (56.7%). These preferences emphasize long-term benefits like lower utility bills, better ventilation, and health-focused living, reflecting buyers' awareness of sustainability and willingness to invest in eco-friendly housing (Liow, 2024; Azizul & Chuweni, 2024). However, findings align with prior studies indicating that buyers prioritize criteria offering direct economic benefits (Zalejska-Jonsson et al., 2020; Estep et al., 2013; Yau, 2012), with affordability constraints showing that Malaysian buyers can only pay less than RM 55 monthly for such features over ten years (Mousavi et al., 2013).

Table 5: GAH features from Potential Home Buyers' Perspectives

	GAH Features	Potential Home Buyers' Willingness to Pay (%)
EE1	Good natural ventilation	53.7
EE2	Energy saving appliances and light fittings	55.5
EE3	Walls and roof fitted with materials that reduce solar heat gain	56.0
EE4	Solar panels	56.8
EE5	North-south orientation	54.3
SM1	Plants and greenery planted on the facade and roof of high-rise buildings	54.5
SM2	Extensive landscaping	56.7
SM3	Public transport accessibility	57.8
WE1	**Water saving appliances and fittings, and low water usage**	**62.5**
WE2	**Rain water harvesting**	**61.0**
MR1	Building installed with regional materials that minimize depletion of natural resources	60.2
MR2	Building installed with materials adopt reduce, reuse and recycle concepts	52.7
MR3	Sustainable construction practices	51.5
MR4	Good waste management principles	53.7
MR5	Provision of separate bins/chutes	55.8
EQ1	**Design with low noise level, low indoor air pollutants and high indoor air quality**	**61.7**
EQ2	**Volatile Organic Compounds**	**58.0**
EQ3	**Formaldehyde Minimisation**	**56.7**
IN1	Environmental idea	59.8
IN2	Green design idea	31.8

Source: Author (2024)

The Incremental Cost for GAH Criteria and Features

Table 6 presents the cross-tabulation results for GAH criteria, including energy efficiency, sustainable site planning, water efficiency, materials, indoor environmental quality, and innovation, showing that over 50% of homebuyers are willing to pay for all six criteria and 20 features within a 10% incremental cost. Developers are ready to adopt these features, but affordability remains crucial, as buyers can only bear up to a 10% increase beyond affordable housing prices (Ibrahim et al., 2013). Studies by Simpeh et al. (2024), Cheam et al. (2023), Mazli and Fauzi (2022), and Swett et al. (2007) reveal limited awareness of green housing, so this study focused on incremental costs buyers are willing to pay. Most respondents (54-56%) prefer up to a 5% cost increase, reflecting interest in sustainability but high cost sensitivity, while 22-25% are willing to pay a 6-10% premium for features like energy efficiency and site management, demonstrating flexibility for added value.

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Table 6: Percentage of Incremental Cost Potential Homebuyers Willing to Pay

Criteria	0-5 %	6-10%	11-15%	16-20%	21-25%	26-30%
Energy Efficiency	**54.3**	**25.0**	10.3	5.8	2.5	2.0
Sustainable Site and Management	**55.0**	**25.3**	10.2	5.3	2.8	1.3
Water Efficiency	**53.7**	**24.5**	11.5	5.3	2.7	2.2
Material and Resources	**54.2**	**24.7**	10.7	6.2	2.3	1.8
Indoor Environmental Quality	**54.7**	**22.8**	10.3	6.8	3.3	2.0
Innovation	**55.7**	**22.5**	11.2	5.3	2.5	2.8

Source: Author (2024)

CONCLUSION

This study examines potential homebuyers' preferences for green affordable housing (GAH), highlighting that most respondents, aged 18–40 years, married, and employed in the government sector, earn RM1,001–RM5,000 and allocate significant portions of their expenses to housing loans. Respondents demonstrated knowledge of GAH and expressed strong preferences for water efficiency features like water-saving appliances and rainwater harvesting, as well as indoor environmental quality criteria such as low noise levels and high air quality, with more than half willing to pay up to a 10% incremental cost for these features (Piao & Managi, 2023; Kucher et al.,2019). Recommendations include introducing cost-effective green features, targeted marketing campaigns, affordable designs, innovative elements, and policies like tax rebates and subsidies to promote broader GAH adoption while ensuring alignment between sustainability and affordability goals. Future research should address GAH design and construction challenges, include broader geographic samples, and explore qualitative methods or cross-cultural comparisons to better understand the trade-offs between affordability and sustainability in diverse contexts.

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STRATEGY FORMULATION AND SUSTAINABILITY PERFORMANCE IN INDIGENOUS (BUMIPUTERA) CONSTRUCTION COMPANIES IN MALAYSIA: EXAMINING THE MEDIATING ROLE OF STRATEGIC AGILITY

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Abstract

This study examines the mediating role of strategic agility in the relationship between strategy formulation and sustainability performance of Indigenous construction companies in Selangor. Adopting a quantitative design, data were collected through an online survey of G7 Indigenous construction, with 69 responses obtained from random sample of 100 companies registered in the Construction Industry Development Board of Malaysia database. Using SmartPLS 4.0 for Structural Equation Modeling (SEM), the analysis revealed that both strategy formulation and strategic agility significantly improve firm performance. Moreover, strategic agility was found to mediate the positive relationship between strategy formulation and sustainable performance. These findings provide empirical support to the theory of maneuvers and the strategic management literature by examining the relationships between the variables. The findings of this study will encourage Indigenous construction companies to incorporate strategic agility practices into strategy formulation to survive and remain competitive in the challenging environment of the construction industry.

Keywords: Strategic planning; strategy formulation; strategic agility; sustainability performance; Indigenous construction companies

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INTRODUCTION

The construction sector in Malaysia has played a pivotal role in the country's socioeconomic development, particularly through the New Economic Policy (NEP) of 1970, which sought to increase Indigenous (Bumiputera) participation in business. While the number of Indigenous construction companies has grown significantly from 2,049 in 1972 to 66,906 by 2021 (CIDB, 2021), their competitiveness remains questionable. Indigenous companies continue to rely heavily on government contracts and face persistent challenges such as weak financial management, inadequate planning, and high bankruptcy rates (Rahman & Rahmat, 2016). Large-scale projects remain dominated by non-Indigenous construction firms, highlighting the ongoing vulnerability of Indigenous construction companies (Janipha et al., 2021). To enhance competitiveness, such companies must strengthen technical expertise, build robust networks, secure financial resources, and strategically align organizational objectives.

International evidence suggests that Indigenous companies often struggle to sustain competitiveness. For example, Irish-owned companies have lost domestic market share since the 1960s under free trade (O'Malley, 2024), while Indigenous oil and gas companies in Ghana and Ivory Coast face capital mobilization challenges (Adjei & Ackah, 2023). These cases emphasize the significance of strategic planning and agility for organizational survival in highly competitive and dynamic environments. Although strategic planning is often associated with improved organizational performance, research findings remain mixed, with some studies reporting positive effects while others find negligible or even negative outcomes (Jayawarna & Dissanayake, 2019). Scholars increasingly argue that strategic planning must be complemented by strategic agility-the ability to anticipate, adapt, and reconfigure resources in response to environmental change (Roberts & Stockport, 2009). To remain viable, companies must adopt adaptable strategies that address globalization, technological advancements, workforce mobility, and accelerated knowledge transfer (Chen et al., 2010)

Despite the growing recognition of strategic agility, limited empirical research has examined its interaction with strategic planning and sustainability performance, particularly among Indigenous construction companies in Malaysia. Balancing structured planning with agility remains an unresolved challenge in both theory and practice. While strategic planning offers structure, agility provides adaptability. Yet, the mechanism through which these two constructs jointly influence sustainability outcomes remain underexplored. Furthermore, existing research highlights gaps in stakeholder engagement during strategy formulation (Desta, 2019) and in understanding the contextual realities faced by Indigenous construction companies in volatile markets (Balatbat et al., 2011; Yesil & Kaya, 2013).

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This study addresses these gaps by investigating the relationship between strategic planning, strategic agility, and corporate sustainability performance among Indigenous construction companies in Malaysia, focusing on G7 Indigenous construction companies in Selangor. This context is significant given Selangor's concentration of high-tier Indigenous companies and its central role in Malaysia's construction industry. By integrating insights from strategic management, contingency theory, and sustainability research, this study provides new perspectives on how Indigenous construction companies can balance formalized planning with adaptive agility to improve long-term performance.

The remaining of this paper is structured as follows. The next sections review the relevant literature and develops research framework. The methodology of the empirical study is then outlined, followed by the presentation of results. The paper concludes with a discussion of findings, implications, and recommendations for both theory and practice.

LITERATURE REVIEW

Research Model

Grounded in contingency theory, this study proposed that strategic agility mediates the relationship between strategy formulation and sustainability performance (Figure 1). Contingency theory is a well-recognized framework in strategic management literature, widely applied to explain variations in organizational performance (Ho, 2016; Wilden et al., 2013). The theory posits that an organization's performance is contingent upon the alignment of its strategy with structural and contextual factors such as organizational culture, management style, and problem-solving approaches (Wilden et al.,2013). Within this framework, strategy formulation is conceptualized as a critical element of the broader strategic planning process, while strategic agility provides a more holistic understanding of how organizations translate strategic intent into performance outcomes. Accordingly, this study investigates the direct relationship between strategy formulation and sustainability performance, while also theorizing that strategic agility serves as a mediator in this relationship. This conceptualization advances current understanding by integrating planning and adaptability as complementary mechanism that jointly enhance sustainability-oriented performance.

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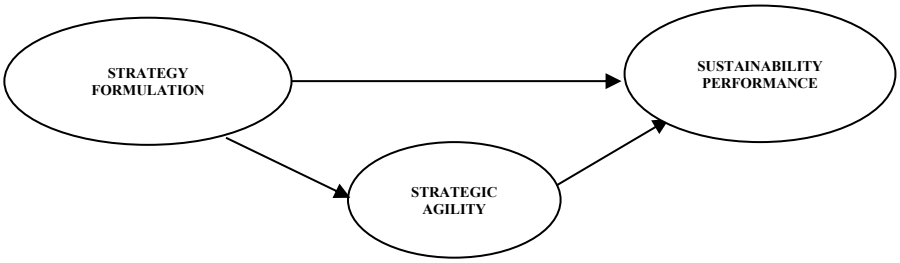


Figure 1: Research Framework

Strategic Planning

Strategic planning is a long-established process that helps organization sustain operations and enhance competitiveness (Aminu Umar et al., 2020; Chaudhry et al., 2012). It is considered essential for effective management organizational success (Tarifi, 2021; Al-Ghrairee, 2021). To be effective, strategic plans must be simple, practical, and flexible enough to adapt to uncertainties and environmental changes (Arend et al.,2017). Fundamentally, strategic planning involves formulating, implementing, and evaluating decisions that collectively guide an organization towards its long-term goals (Gurel & Tat, 2017).

Strategy Formulation

Strategy formulation is a process by which organizations define their business scope, set objectives, and determine the methods to achieve them (Meier, 2010). It generally begins with environmental analysis to guide the development of action plans that enhance competitiveness (Král & Královú, 2016). Effective strategy formulation is essential for improving performance and sustaining growth (Nwachukwu et al., 2018). A sound strategy must align with organizational resources, industry conditions, and situational demands to ensure relevance and success (Kimanthi, 2015).

Strategic Agility

Strategic agility refers to an organization's ability to continuously adapt and refine its strategic direction in response to evolving goals and dynamic environmental conditions. Although definitions vary, three core capabilities are widely recognized: strategic sensitivity, resources fluidity, and leadership unity (Doz & Kosonen, 2008). In the construction industry, where volatility and competition are high, companies require adaptive strategies for survival. Earlier studies emphasized the importance of clear strategic goals (Mulcahy, 1990), and the adoption of long-term planning in the 1990s (Betts & Ofori, 1992), though the implementation has often been limited due to its complexity and cost. Industry volatility continues to threaten companies, with bankruptcy remaining a common

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challenge (Omar & Azmi, 2015). In Malaysia, despite government efforts to support Indigenous entrepreneurship, growth of Indigenous companies has lagged behind overall economic expansion (Ramli et al., 2017). Accordingly, construction companies must adopt strategic agility practices to remain competitive and resilient in uncertain markets.

Indigenous Construction Companies

In Malaysia, construction companies are categorized as either Indigenous or non-Indigenous. To qualify as Indigenous, a business must have at least 51% Malays or other Bumiputera groups, with the majority of its workforce also comprising Indigenous employees (Rahman & Rahmat, 2016). Non-Indigenous firms are owned by individuals from other ethnic groups. Regardless of ownership, all construction companies operating in Malaysia must register with the Construction Industry Development Board (CIDB), which regulates their paid-up capital and bidding capacity (Mustafa Kamal et al., 2012). Registered contractors are assigned grades ranging from G1 to G7, reflecting their financial strength and capacity to undertake projects of varying size. A company's organizational structure is closely tied to its registration grade, which determines its bidding eligibility and overall competitiveness. As firms expand their financial resources, they may apply for higher grades, enabling them to compete for larger projects. According to CIDB classifications, construction small and medium - sized enterprises (SMEs) are categorized as small-sized (G1 to G3), medium-sized (G4 and G5), and large-sized (G6 and G7).

Sustainability Performance

Firm performance refers to the outcomes achieved relative to internal and external objectives, encompassing both financial and non-financial measures (Njeri, 2017). Financial indicators include return on investment (ROI), profit margin, and capital ratios, while non-financial indicators involved productivity, growth, and customer satisfaction. In contrast, sustainability performance extends beyond traditional measures by integrating the triple bottom line-economic, environmental, and social dimension (Elkington, 1998; Amrollahi et al., 2014; Nguyen et al., 2018; Amin et al., 2019). It reflects an organization's capacity to address risks and responsibilities while creating long-term value across these three dimensions (Amin et al., 2019).

Strategy Formulation and Sustainability Performance of Indigenous Construction Companies

Organizational strategy formulation is crucial for establishing both long-term and short-term goals, aligning objectives with actions, and ensuring competitiveness. Strategic planning provides a structured process for creating, implementing, and

managing strategies to achieve organization's goals within a defined timeframe. Previous studies highlight its positive and significant impact on organizational performance (Skokan, 2013; Babafemi, 2015; Gomera, 2018). However, critics argue that traditional strategic planning can be rigid and less effective in dynamic environments that flexibility, creativity, and rapid response (Weber & Tarba, 2014). In the construction sector, strategy formulation is particularly important for navigating turbulence and sustaining competitiveness (Langford & Male, 2001; Amrollahi & Rowlands, 2017). Thus, Indigenous construction companies must treat strategy formulation as a critical starting point for effective strategic planning.

Nonetheless, strategic planning alone may not guarantee improved performance (Abuzaid, 2018; Hartmann & Stillings, 2015). Companies must adapt quickly to environmental changes, as flexibility is essential for long-term survival (Gotcher, 1977). Empirical evidence shows that organizations with formalized strategic planning process outperform those without (Hakimpoor, 2014). Similarly, Arasa & K'Obonyo (2012) emphasized the importance of formulating, implementing, monitoring, and evaluating strategies to enhance organizational outcomes. Based on these arguments, this study proposes the following hypothesis:

H_1 – Strategy formulation positively influences sustainability performance of Indigenous (Bumiputera) construction companies in Selangor.
H_2 – Strategy formulation positively influences strategic agility of Indigenous (Bumiputera) construction companies in Selangor.
H_3 – Strategic agility positively influences the sustainability performance of Indigenous (Bumiputera) construction companies in Selangor.
H_4 – Strategic agility mediates the relationship between strategy formulation and the sustainability performance of the Indigenous (Bumiputera) construction companies in Selangor.

RESEARCH METHODOLOGY

This study employed a quantitative research design using document analysis and survey data collected via questionnaires distributed between 2022-2023. The population consisted of 855 grade G7 Indigenous construction companies officially registered in Selangor. Grade G7 denotes large-scale companies with paid up capital exceeding RM750,000.00 and unrestricted tendering capacity. The focus on Indigenous construction companies was based on their limited economic participation (EPU, 2018), their significant presence in the construction sector, and ongoing sustainability challenges (Rahman & Rahmat, 2016; Ayub & Eman, 2006). Companies were randomly selected from the CIDB's Centralized Information Management System (CIMS), and participation was voluntary.

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The sample size was determined using G-Power 3.1 statistical power analysis (Cohen, 1992), with 66 respondents required. Ultimately, 69 responses were obtained. This aligns with Chuan's (2006) recommendations to apply statistical power analysis to ensure confidence in study results.

The study began with a literature review emphasizing Contingency Theory and strategic agility, leading to the development of metrics and dimensions for empirical analysis. Measurement items were adapted from established works (El-Mobayed, 2006; Cegarra-Navarro et al., 2016; Nafei, 2016; Thompson et al., 2020). Sustainability performance was assessed through Elkington's Triple Bottom Line framework, using the multi-dimensional scales from Manaff (2019), and Asha'Ari (2020). Responses were captured using a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). Data were analyzed using Partial Least Square Structural Equation Modeling (PLS-SEM) with SmartPLS 4, covering descriptive statistics, measurement and structural model evaluation, and hypothesis testing.

ANALYSIS AND RESULTS

From 69 valid responses (69% response rate), 53.6% were CEOs, 17.4 % were Senior Managers, and 29.0% were department managers, ensuring respondents were qualified to represent their companies. Most had over six years of tenure (85.5%), and 68.1% of companies had operated more than 15 years, indicating experienced leadership and established organizations. The demographic profile is presented in Table 1.

Table 1: Respondent's demography for the study

Category	Items	Frequency	Percentage (%)
Designation	CEO	37	53,6
	Senior Manager	12	17.4
	Manager	20	29.0
Highest educational qualification	PhD	12	17.4
	Masters	19	27.5
	Bachelor's Degree	38	55.1
Number of years in the construction industry	Less than 5 years	3	4.3
	5-10 years	14	20.3
	11 – 15 years	22	31.9
	More than 15 years	30	43.5
Number of years working in the company	Less than 1 years	3	3.7
	1- 5 years	7	10.8
	6 - 10 years	16	23.1
	More than 10 years	43	62.4
Company establishment	Less than 5 years	1	1.7
	5-10 years	4	5.2
	11 – 15 years	17	25.0

Category	Items	Frequency	Percentage (%)
	More than 15 years	47	68.1
Company business structure	Sole proprietorship	12	17.4
	Public listed	8	11.6
	Private limited	49	71.0
Type of business	Building Construction (B)	18	26.1
	Mechanical engineering (ME)	10	14.5
	Civil Engineering Construction (CE)	34	49.3
	Facilities (F)	7	10.1

Source: Author's survey

Measurement Model Analysis

As shown in Table 2, all variables demonstrated adequate validity, with average variance extracted (AVE) values exceeding 0.5. Reliability was also confirmed, as Cronbach's α and composite reliability values were above 0.7. Although some variables display loadings below 0.7, they were retained since the AVE values exceed the 0.6 threshold, meeting acceptable standards (Byrne, 2016). Discriminant validity was also achieved. As presented in Table 3, the square roots of AVE values exceeded the inter-construct correlations, thereby satisfying the Fornell-Larcker criterion.

Table 2: Results of Reliability and Convergent Validity Tests

Descriptive	Cronbach's α	C Reliability	AVE	Loading	p-values	Conclusion
Strategic Formulation	**0.922**	**0.935**	**0.616**			**Reliable**
SF1				0.788	< 0.001*	Valid
SF2				0.812	< 0.001*	Valid
SF3				0.777	< 0.001*	Valid
SF4				0.746	< 0.001*	Valid
SF5				0.777	< 0.001*	Valid
SF6				0.840	< 0.001*	Valid
SF7				0.852	< 0.001*	Valid
SF8				0.716	< 0.001*	Valid
SF9				0.748	< 0.001*	Valid
Strategic Agility	**0.751**	**0.855**	**0.666**			**Reliable**
SA 1				0.871	< 0.001*	Valid
SA 2				0.896	< 0.001*	Valid
SA 3				0.660	< 0.001*	Valid
Sustainable Performance	**0.918**	**0.929**	**0.505**			**Reliable**
CSP1				0.714	<0.001*	Valid
CSP2				0.706	<0.001*	Valid
CSP3				0.659	<0.001*	Valid
CSP4				0.711	<0.001*	Valid
CSP5				0.651	<0.001*	Valid

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Descriptive	Cronbach's α	C Reliability	AVE	Loading	p-values	Conclusion
CSP6				0.827	<0.001*	Valid
CSP7				0.823	<0.001*	Valid
CSP8				0.643	<0.001*	Valid
CSP9				0.674	<0.001*	Valid
CSP10				0.629	<0.001*	Valid
CSP11				0.762	<0.001*	Valid
CSP12				0.671	<0.001*	Valid
CSP13				0.731	<0.001*	Valid

*Note: * Indicates significant at 1% level of significance*
Source: Author's analysis

Table 3: Discriminant Validity (Fornell-Larcker Criterion)

	Strategic Agility	Strategy Formulation	Sustainable Performance
Strategic Agility	0.816		
Strategy Formulation	0.656	0.785	
Sustainable Performance	0.604	0.692	0.71

Source: Author's calculation

Structural Model Analysis

The structural model was assessed using collinearity diagnostics, coefficient of determination (R^2), Standardized Root Means Square Residual (SRMR), Chi-square, and Normed Fit Index (NFI). Following Hair et al., (2011), collinearity was tested using variance inflation factor (VIF) with a threshold value of 5. As shown in Table 4, all constructs recorded VIF values between 1.000 and 1.754, well below 5, indicating no collinear issues.

Table 4: Results of Collinear Test

	VIF
Strategic _Agility -> Sustainability _Performance	1.754
Strategy _Formulation -> Strategic _Agility	1
Strategy _Formulation -> Sustainability _Performance	1.754

Source: Author's calculation

The R^2 indicates the variance of an endogenous variable due to its exogenous connections. Hair et al. (2016) categorized an R^2 value of 0.75 as indicative of substantial predictive accuracy, an R^2 value of 0.5 as representative of moderate predictive accuracy, and an R^2 value of 0.25 as a low level of predictive accuracy, From the analysis, the values of R^2 in Table 5 are below 0.75, suggesting a moderate level of predictive accuracy (Chin, 1998).

Table 5: Coefficient of Determination (R^2) Results

Dependent Variable	R^2
Sustainability _Performance	0.519
Strategic _Agility	0.43

Source: Author's calculation

Table 6 demonstrates that all the values fall within an acceptable range, indicating that the research model exhibits a strong fit (Hair et al., 2016). The results further corroborated the hypothesis that strategic agility mediates the relationship between strategy formulation and the sustainable performance of Indigenous construction companies in Selangor.

Table 6: Model of Goodness Fit

Parameter	Value	Criterion	Conclusion
SRMR	0.188	< 0.08	Moderate
Chi-square	851.877	> 7.37	Good
NFI	0.504	> 0.9	Moderate

Source: Author's calculation

Hypothesis Testing

The structural model examined the direct relationships among the variables. The hypothesis testing results in Table 7 revealed that the hypothesis was supported by the empirical data with its T value greater than or equal to 1.64 and P value below the acceptable significant level of 0.1 (Hair et al., 2016).

Table 7: Hypothesis Testing Results

	Path Coefficient	Std. Dev. (STDEV)	T value	P value	Conclusion
H_1 - Strategy formulation positively influences sustainability performance of Indigenous (Bumiputera) construction companies in Selangor.	0.52	0.11	4.727	<0.001	Supported
H_2 - Strategy formulation positively influences strategic agility of Indigenous (Bumiputera) construction companies in Selangor.	0.656	0.073	8.976	<0.001	Supported

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	Path Coefficient	Std. Dev. (STDEV)	T value	P value	Conclusion
H_3 - Strategic agility positively influences the sustainability performance of Indigenous (Bumiputera) construction companies in Selangor.	0.264	0.121	2.182	0.015	Supported
H_4 – Strategic agility mediates the relationship between strategy formulation and the sustainability performance of the Indigenous (Bumiputera) construction companies in Selangor.	0.173	0.089	1.947	0.026	Supported
Note: * indicates significant at 10% level of significance (one-tailed).					

Source: Author's calculation

DISCUSSION

The results obtained in this study revealed that strategy formulation has a positive effect on the sustainability performance of Indigenous construction companies (β=0.52, t=4.727, p<0.001) and strategic agility (β=0.656, t=8.976, p<0.001). Thus, H1 and H2 were supported. These findings are in line with many literatures that shows favourable correlation between strategic planning and performance (Glaister et al., 2008; Arasa & K'Obonyo, 2012; Skokan, 2013; Babafemi, 2015; Gomera, 2018; Kabeyi, 2019; Nzewi & Mgbemena, 2016; Asil et al., 2019). For the third hypothesis H3, the study shows that strategic agility practices have a positive effect on the sustainability performance of Indigenous construction companies (β=0.264, t=2.182, p<0.01). Therefore, H3 was supported. Previous research has consistently reported similar results, suggesting a positive correlation between company performance and strategic agility (Claver-Cortés et al., 2007; Kornelius et al., 2021). The result of this study also confirms that strategic agility practices mediate the relationship between strategy formulation and the sustainability performance of the Indigenous construction companies in Selangor. This is due to the fact that the indirect path (Strategy Formulation→ Strategic Agility → Sustainability Performance) is significant (β=0.173, p<0.01). Thus, H4 was supported. This result is consistent with numerous other studies that have shown that strategic agility practices serve as a mediator for the impact of strategic planning specifically strategy formulation on company performance (Dibrell et al., 2014; Gabrielsson et al., 2018; Kornelius et al., 2021).

CONCLUSION

The study intended to establish a link between strategy formulation and sustainable performance among Indigenous construction companies in Selangor as well as the impact of strategic agility on this relationship. Findings highlight the importance of integrating strategic agility into strategy formulation to enhance resilience, competitiveness, and sustainability performance in a volatile business environment. The unique contribution of this research is to draw attention to the need to incorporate strategic agility into the strategy formulation process in order to achieve sustainability performance. Consistent with prior reserach (Nwezi & Mgbemena, 2016; Asil & Farahmand, 2019; Dubey et al., 2019; Kornelius et al., 2021), these results confirm that strategic agility improves company performance. This baseline study examines how strategy formulation and strategic agility affects sustainability performance of Indigenous construction companies in Malaysia. The study contributes to both theory and practice by emphasizing the necessity of agile strategic planning for Indigenous construction companies, offering insights for managers and policymakers seeking to strengthen sustainable industrialization and resilient infrastructure in Malaysia.

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EXPLORING PLACE ATTACHMENT IN HERITAGE TOURISM: A CASE STUDY OF BAGANSIAPIAPI CHINATOWN, INDONESIA

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Abstract

This article aimed to explore place attachment in Bagansiapiapi, focusing on the cultural heritage surrounding Chinatown. The goal is to preserve the uniqueness of local cultural heritage to enhance the attractiveness of sustainable heritage tourism and improve the economy and well-being of the local community. 193 residents and 193 tourists were stratified and randomly completed the questionnaire. The twelve key informants were purposive sampling selected by semi-structured interviews and observation at the research location by photo documentation. Place attachment is influenced by historical, belief, cultural, and social factors significant. Bagansiapiapi Chinatown demonstrates a strong sense of place attachment by focusing on two key aspects: emotional attachment and memories experience. These findings are expected to contribute to sustainable heritage tourism preservation in Bagansiapiapi and promote cultural heritage as a tourist attraction aligned with the sustainable cities and the welfare of the local communities. This study provides an innovative method for preserving cultural heritage for tourism stakeholders. It focuses on place attachment established by cultural heritage and applied as a reference for sustainable development by practitioners in various sectors, including tourism planners and government officials. This research examines the relationship between place attachment and cultural heritage tourism in Bagansiapiapi. It analyzes how cultural heritage influences the identity of the Chinese community and offers strategies for sustainable tourism development to enhance economic growth while preserving cultural heritage.

Keywords: Place Attachment, Heritage Tourism, Bagansiapiapi Chinatown, Cultural Heritage, Historical Buildings

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INTRODUCTION

Heritage tourism has emerged as a key sector in global tourism, with cultural and historical destination significance playing a crucial role in attracting visitors (Timothy, 2020). This type of tourism reflects the desire to engage with the past while connecting with the present of a destination, fostering an appreciation for its traditions, culture, and history (Park et al., 2019). The success is fundamentally dependent on the sustainability of heritage tourism and the concept of place attachment, which influences the behavior of visitors and the preservation of local cultural and environmental values (Ajuhari et al., 2023; Avifah et al., 2022). As tourism continues to evolve, place attachment offers insights into how residents and tourists interact with heritage sites, contributing to the growth of sustainable tourism and cultural heritage preservation.

Studies on place attachment in heritage tourism have shown its important role in influencing tourist behavior and site sustainability. For example, studies in Melaka and George Town have shown that cultural motivation increases place attachment, especially affective attachment, and place dependence, increasing tourists' desire to recommend places (Latiff et al., 2020). In addition, the sustainability of intangible cultural heritage in George Town and Melaka has been associated with strong connections between people and places, characterized by a sense of loss, justice, and purpose among local communities (Nian et al., 2019). Similarly, in Bagansiapiapi's Chinatown, understanding the nuances of place attachment can offer valuable insights into how residents and visitors form relationships with the heritage site, contributing to both the preservation of cultural identity and the promotion of tourism.

This research examines place attachment in heritage tourism in Bagansiapiapi Chinatown, a location rich in cultural and historical heritage. Meanwhile, there have been limited studies on how heritage tourism has the potential to influence place attachment and contribute to the preservation of cultural heritage as a tourist attraction to enhance the economic growth of the local community. This study aims to explore various aspects of place attachment in Bagansiapiapi Chinatown and identify the factors that strengthen this attachment. Specifically, it will identify factors that influence strong place attachment and analyze how such attachment can support sustainability and enhance the attractiveness of heritage tourism in the region.

LITERATURE REVIEW

Place Attachment

Place attachment reflects a strong emotional connection to a location and contributes significantly to a sense of belonging and personal fulfillment (Alcindor et al., 2021; Mandal et al., 2023; Sari et al., 2018). Research has shown that place attachment influences personal experiences, perceptions of a place, residential status, memories, lifestyle, and overall quality of life (Novianti et al.,

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2018). The place attachment dimension includes four main aspects: place dependence, place identity, social bonds, and affective attachment. The historic bridge is both a physical infrastructure and an emotional, and cultural emblem that enhances communal cohesion (Yao & Rasidi, 2024). These factors collectively help to define the relationship individuals have with the meaning of a place.

Cultural variations also play a role in shaping place attachment. For example, family connections in Spain are central to forming place attachments. This bond fosters solidarity across both intergenerational and intragenerational relationships, highlighting the importance of familial ties in creating emotional links to places (Lebrusán & Gómez, 2022). Memories are another critical element of place attachment, with nostalgia as a valuable lens through which past relationships with places are examined. Nostalgia emphasizes the emotional significance of these memories, enabling individuals to relive their past experiences and integrate them into their present lives, thereby deepening their attachment to a place (Chen & Dwyer, 2018).

Historic places, in particular, play a key role in fostering place attachment through their ability to evoke meaningful memories and emotions. For instance, in Edinburgh, Scotland, historic environments offer opportunities to reflect on past lives with feelings of pleasure, satisfaction, pride, and admiration. These experiences often enhance happiness, pride, and self-esteem, as individuals draw on positive memories and moments associated with living in or visiting such places (Irani et al., 2023; Wang, 2023). Additionally, changes in the physical and visual aspects of a place can amplify place attachment by evoking stories and memories tied to its history.

The formation of place attachment relies not solely on individual emotional experiences but also on the social and historical dimensions of a place. Social interactions and communal bonds within a place contribute to a collective sense of belonging and identity (Madgin et al., 2016). Place attachment focuses on two main aspects: emotional attachment and experience memories. This place attachment contributes to the preservation of sustainable heritage tourism is essential in Bagansiapiapi, as well as promoting cultural heritage as a tourist attraction to improve the welfare of the local community.

Heritage Tourism

Heritage reflects the past but remains essential in contemporary contexts by connecting communities to their history and culture. An important aspect of heritage tourism management is the concept of place attachment, which describes the emotional bond individuals form with a location, enhancing the meanings and experiences they derive (Graham & Ashworth, 2005). Heritage tourism provides a spatial experience that intertwines tangible and intangible elements, fostering a connection between visitors and heritage. It aligns with the place attachment

concept, where emotional ties to a location enrich tourist experiences (Poria & Ashworth, 2009).

Heritage tourism fulfills visitors' desire to engage with representations of a place's historical and cultural narratives, creating profound and memorable experiences through connections with cultural and historical elements (Park et al., 2019). The combination of tangible and intangible cultural heritage is fundamental to culture-based interpretation and the preservation of local values, which are central to the heritage tourism experience (Santa & Tiatco, 2019). Unique characteristics of a heritage site significantly shape visitors' emotional connections to the place, which, in turn, enhances the depth of their tourism experience (Lin & Rasoolimanesh, 2023). Moreover, preserving cultural traditions and their associated values and meanings is crucial in supporting place attachment through intergenerational transmission (Lee et al., 2018; Ruan et al., 2024). Cultural heritage contributes significantly to creating meaningful tourism experiences. The interplay between tangible and intangible heritage elements, place attachment, and cultural preservation efforts highlights the importance of maintaining cultural values for future generations.

RESEARCH METHODOLOGY

The study was carried out in Bagansiapiapi Chinatown (Figure 1), located in Rokan Hilir Regency, Riau Province, Indonesia. The location is an attractive tourist destination due to the Bakar Tongkang Festival. The festival is a part of the national 100 events calendar (Ginting et al., 2022).

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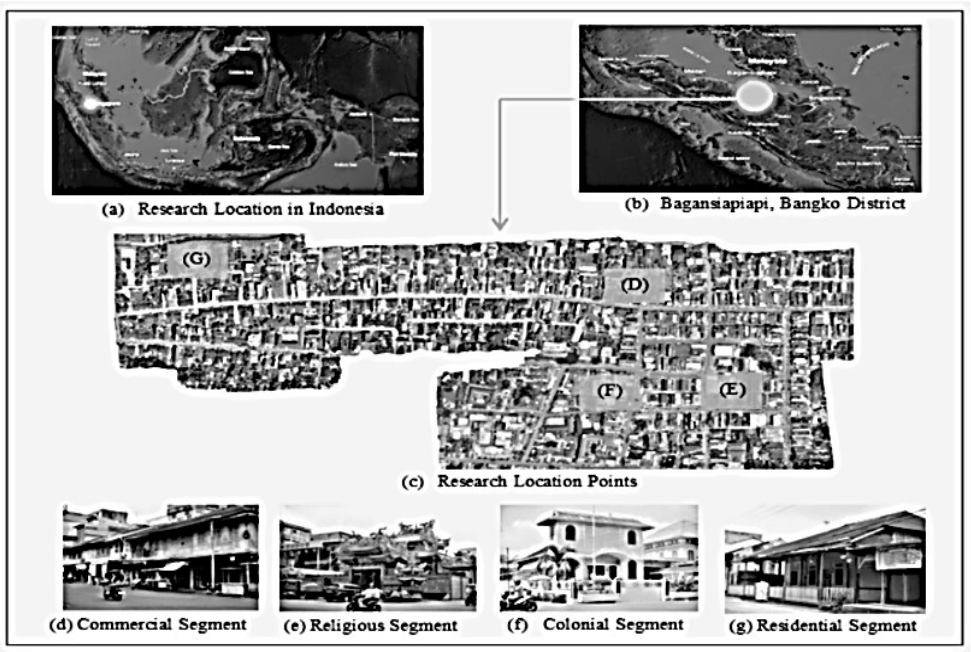


Figure 1: Research Area
Source: Google Earth (a-b) Author's Analysis (c-g)

The location is based on four criteria: heritage area, uniqueness, activities, and tourist attraction (Aleksandrova & Aigina, 2017; Jahan, 2019; Nugroho & Hardilla, 2020; Zhao, 2021). This study focuses on locations divided into four streets: Jalan Perniagaan-Commercial (PK), Jalan Kelenteng (KL), Jalan Merdeka (MK), and Jalan Perniagaan-Residential (PM). The segments are divided based on the main functions and daily activities.

This research uses mixed methods that combine quantitative and qualitative approaches to gain an in-depth understanding of the phenomenon based on relevant experiences and information (Creswell, 2010; Jin et al., 2020). In the quantitative approach, a questionnaire with a 5-point Likert scale was used to measure respondents' perceptions, with high reliability and validity (Sari et al., 2018). The sample used stratified random sampling and the Cochran Method to determine the sample size (Sugiyono, 2019), with 386 respondents consisting of residents and tourists. The qualitative approach involved observation and semi-structured interviews with 12 key informants, including government officials, community members, entrepreneurs, academics, residents, and tourists, who were selected based on their roles in tourism planning and heritage site protection. Data triangulation is employed to enhance evidence from multiple approaches, including theoretical triangulation that combines multiple perspectives to broaden understanding of phenomena (Creswell & Clark, 2017; Flick, 2018).

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ANALYSIS AND DISCUSSION

Based on the analysis of the distributed questionnaire results (Figure 2), Jalan Perniagaan (PK) shows that respondents are satisfied with the uniqueness of the Ing Hok Kiong Temple (4.17) in the KL segment and enjoy the atmosphere created (4.18) on Jalan Kelenteng and Jalan Perniagaan, resulting in a high overall average (4.17). While also showing an emotional attachment between individuals and the physical form of the building as well as the atmosphere in the area. Almost the same as PK, Jalan Kelenteng (KL) clearly shows that respondents are pleased with the uniqueness of the building (4.22) Ing Hok Kiong Temple and enjoy the atmosphere (4.06) on Jalan Kelenteng and Jalan Perniagaan, with an overall average score (4.14). Although slightly lower than PK, these findings still indicate a good appreciation for the visual elements and atmosphere, even though the level of emotional attachment is not as strong as in PK. Meanwhile, respondents on Jalan Merdeka (MK) gave an average rating of the uniqueness of the building (3.01) as ordinary with Ing Hok Kiong Temple and the atmosphere in the area of Jalan Kelenteng and Jalan Perniagaan (2.88), resulting in the lowest average score (2.95). These results indicate that the MK segment has a low level of emotional attachment because this segment serves a governmental or office function. These findings are supported statement by a cultural heritage expert: "Emotional attachment to an area is greatly influenced by its social function in people's lives. Areas with social functions, such as housing, commercial centers, or community interaction spaces, tend to create strong emotional bonds because they are often part of daily activities and community experiences."

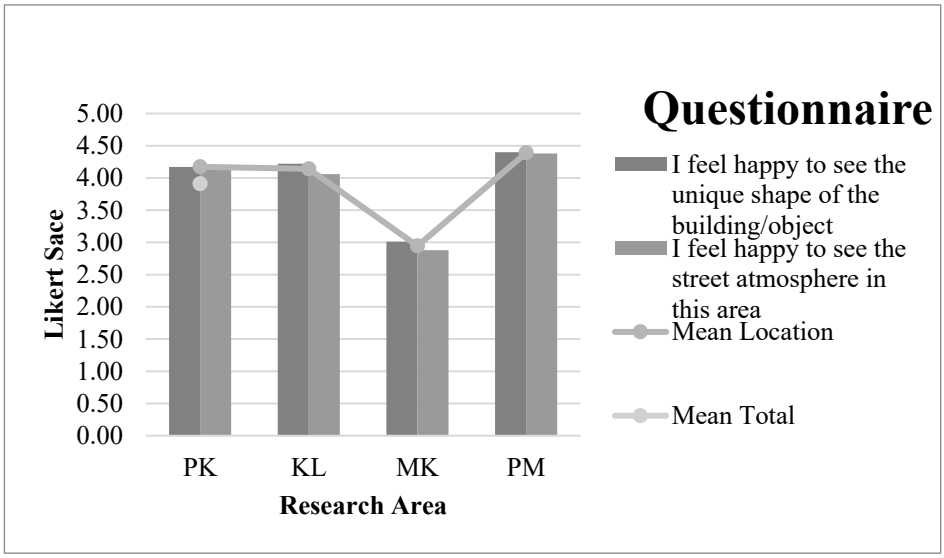


Figure 2: Aspect of Feelings (Emotional Attachment) in Tangible Heritage (Building)
Source: Author's Analysis (2024)

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On Jalan Perniagaan-Residential (PM), respondents strongly agreed with their feelings of pleasure in seeing the uniqueness of the Ing Hok Kiong Temple (4.40) and the atmosphere of the Jalan Kelenteng and Jalan Perniagaan (4.38), showing the highest cumulative average (4.39). These findings indicate that PM is the area with the highest appreciation compared to other segments. The uniqueness of the building design and the street atmosphere are the main factors that strengthen the emotional attachment between the respondents and this area. This finding was supported by the statement of the Head of Tourism, Arts, Culture, Youth, and Sports, who said: "The Bagansiapiapi Chinatown has a unique and comfortable experience for visitors. One of the main attractions is the atmosphere that preserved the authenticity and depth of Chinese culture, which has existed for a long time. Visitors can feel the calm atmosphere, even though in the city center. The unique architecture of the old Chinese shophouses, with their traditional designs, generates for many people a fascinating sensation and evokes memories."

To summarise, Bagansiapiapi Chinatown's visually unique elements such as Chinese architecture and the presence of cultural landmarks contribute to the creation of strong emotional attachments. It is reflected in the high average score (3.91) which indicates the level of emotional attachment of the residents to the area. Urban landscapes, especially historic buildings, have a significant impact on forming individuals' emotional attachment to a place. The unique visual characteristics and historical value of urban landmarks create a sense of place identity and strengthen social connections among residents. As a result, this emotional attachment can contribute to an increased sense of belonging, community attachment, and individual well-being, especially in historical areas (Fard & Paydar, 2024; Zhang et al., 2024). In areas abundant in historical or cultural significance, the uniqueness of place perception often influences the formation of profoundly emotional attachment. These attachments tend to develop through repeated experiences and close interactions with the place, strengthening an individual's connection with their environment (Li et al., 2023).

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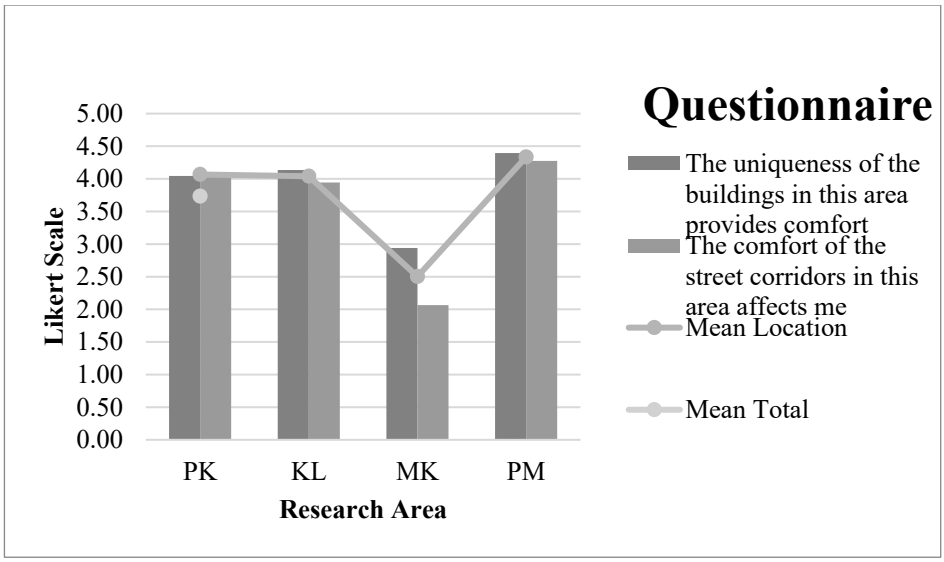


Figure 3: Aspect of Comfort (Emotional Attachment) in Tangible Heritage (Building)
Source: Author's Analysis (2024)

Questionnaire statement Figure 3, respondents on Jalan Perniagaan (PK) agree that the uniqueness of the Ing Hok Kiong Temple provides a fairly high level of comfort (4.05). Additionally, the comfort of the Jalan Kelenteng and Jalan Perniagaan corridors also has a strong influence on visitors (4.09). Overall, PK has a high average (4.07), reflecting a positive perception from visitors. The same results were found in KL, with respondents agreeing that the uniqueness of the Ing Hok Kiong Temple provides comfort (4.14), and the comfort of the Jalan Kelenteng and Jalan Perniagaan corridors influences visitors (3.95). With a high average (4.04) but slightly lower than PK, this still indicates a good perception of the comfort and uniqueness of the area.

Consequently, respondents in MK averaged the uniqueness of the buildings (2.97) and disagreed on the comfort aspect of the street corridor (2.07). The result is a disagreed overall average (2.50). It indicated that MK's situation does not provide a strong level of comfort for visitors. This finding is supported by the statement of the Community Leader, who said: "The Chinatown on Jalan Merdeka has significant historical value as an important part of Chinese cultural identity. However, comfort still needs to be improved because some historical buildings function as private residences. For example, sidewalks and lighting are still limited, reducing the attractiveness for visitors and tourists." However, the respondents strongly agree that the uniqueness of the Ing Hok Kiong Temple, which provides comfort (4.40), as well as the comfort of the Jalan Kelenteng and Jalan Perniagaan corridors, influences visitors (4.28). This results in the highest

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overall average (4.34). This value indicates that PM has a higher appeal compared to other street corridors.

The unique visual character of the buildings and the comfort of the environment in Bagansiapiapi Chinatown have an important role in creating a positive impression and emotional attachment for visitors (3.74). Research shows that aesthetic elements, especially historical or cultural visual attractiveness, contribute to a sense of nostalgia and emotional attachment, which affects an individual's attachment to the place. This emotional attachment is closely related to the material features of the environment and the resulting social atmosphere (Friesinger et al., 2022; Meng et al., 2024). In addition, improvements in MK areas have to enhance the area's attractiveness by increasing visitor satisfaction and strengthening their emotional attachment to the location. Therefore, it might increase the area's attractiveness as a tourist destination (Meng et al., 2024).

Table 1: Aspect of Sensory Visual (Memory Experiences) in Tangible Heritage (Building).

Statements	PK		KL		KL		KL		TOTAL	
	F	P (%)	F	P (%)	F	P (%)	F	P (%)	F	P (%)
Temple Roof	35	9.07	47	12.18	11	2.85	28	7.25	121	31.35
Ing Hok Kiong Temple	26	6.74	26	6.74	31	8.03	21	5.44	104	26.94
Bank Bagan (Bank BRI)	11	2.85	7	1.81	9	2.33	7	1.81	34	8.81
Row of Houses	5	1.30	3	0.78	4	1.04	0	0.00	12	3.11
Chinese Shophouses	1	0.26	0	0.00	0	0.00	2	0.52	3	0.78
Chinese Houses	1	0.26	3	0.78	0	0.00	2	0.52	6	1.55
Water Tanks	0	0.00	1	0.26	1	0.26	3	0.78	5	1.30
lanterns	3	0.78	3	0.78	11	2.85	8	2.07	25	6.48
Bakar Tongkang Procession	11	2.85	5	1.30	27	6.99	25	6.48	68	17.62
Flag	3	0.78	3	0.78	2	0.52	0	0.00	8	2.07
Total Respondents	96	24.87	98	25.39	96	24.87	96	24.87	386	100

Source: Author's Analysis (2024)

According to Table 1, respondents agreed that the most dominant visual element is the temple roof (31.35%). Respondents identified that the main factor of the elements affected their memories. It indicates that the distinctive ornaments, colors, and roof shapes provide significance in building visual identity and attachment to the place. As a heritage building, Ing Hok Kiong Temple has a strong visual attraction (26.94%), confirming that its architectural aspects and historical value contribute to the emotional attachment of visitors. In addition, cultural processions of Bakar Tongkang received considerable attention (17.62%). It has a strong visual representation that evokes collective memories and creates emotional attractiveness. Other buildings, namely Chinese shophouses and Bagan Madjoe Bank (Bank BRI), had less influence on respondents' visual memories (8.81% and 0.78%). It shows that although they have historical value, the visual appeal of the two buildings tends to be less prominent compared to more iconic elements. Lanterns, as decorative elements, also play a significant role (6.48%) in strengthening the atmosphere of Chinese culture. The visualization of lanterns provides an authentic atmosphere that supports the creation of an emotional attachment to the place. The Ing Hok Kiong Temple in Bagansiapiapi has a main gate with three doors, one on the right and one on the left side, and the main door in the center consists of two red door leaves. Above the gate, the roof is adorned with ornaments in the form of dragons and deities. At the ends of the roof, are decorations of dragons, phoenixes, or other mythological creatures that symbolize luck, protection, and prosperity (Figure 4).



Figure 4: Ing Hok Kiong Temple and Roof Ornament of the Ing Hok Kiong temple
Source: Author's Analysis (2024)

In summary, visual elements of the temple roof, Ing Hok Kiong temple, and the Bakar Tongkang ritual procession play a key role in forming experiential memories that foster visitors' attachment to the place. These elements demonstrate the importance of combining visual, symbolic, and emotional aspects in heritage buildings to support cultural tourism. These elements can enhance the attachment that makes visitors want to return (Madgin & Lesh, 2021).

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Table 2: Aspect of Sensory Auditory (Memory Experiences) in Tangible Heritage (Landscape)

Statements	PK		KL		KL		KL		TOTAL	
	F	P (%)	F	P (%)	F	P (%)	F	P (%)	F	P (%)
Fireworks	51	13.21	50	12.95	29	7.51	52	13.47	182	47.15
Vehicles	5	1.30	2	0.52	0	0.00	7	1.81	14	3.63
Human Activities (Cooking, Talking)	10	2.59	16	4.15	23	5.96	19	4.92	68	17.62
Musical Instruments	12	3.11	3	0.78	35	9.07	6	1.55	56	14.51
Bell	16	4.15	11	2.85	6	1.55	6	1.55	39	10.10
Swallow Sound	2	0.52	16	4.15	3	0.78	6	1.55	27	6.99
Total Respondents	96	24.87	98	25.39	96	24.87	96	24.87	386	100

Source: Author's Analysis (2024)

Based on the analysis of the distributed questionnaires (Table 2) along the PK, KL, MK, and PM Street corridors, the sound of fireworks (47.15%) is the element that has the highest percentage. Fireworks displayed with various shapes and colors spark joy and nostalgia, especially during the Lunar New Year along Jalan Perniagaan (Figure 5).



Figure 5: Fireworks illuminate the sky of Bagansiapiapi City on the night of the Chinese New Year or Imlek
Source: Author's Analysis (2024)

It shows that the distinctive characteristics of fireworks, such as explosions or bangs, significantly affect the auditory experience and memories. The sound of musical instruments (14.51%) also stands out as an important element, reflecting the role of traditional instrument sounds in creating a unique and memorable atmosphere. Furthermore, the sounds of cooking or talking in human activities (17.62%) contribute to a dynamic social atmosphere, generate a sense of community connection, and enhance the street corridor. The sound of bells (10.10%) is distinctive as religious activities representative of local culture rooted in local traditions. Meanwhile, the sound of swallows (6.99%) contributes to a calm natural atmosphere and balances the other sound elements in the street corridor. Following the key informant of Tourism Academician Universitas Riau's statement: "Memories of listening to the sound of fireworks at night illuminated during Chinese New Year and Cap Go Meh celebrations around the Ing Hok Kiong temple or flying tang lung make the atmosphere happy."

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In summary, uniqueness and infrequent sound elements, fireworks, bells, and musical instruments tend to be more memorable and contribute significantly to the formation of memories of visitors' experiences. The diversity of auditory elements, including natural and cultural sounds, and human activities, creates a holistic experience that makes the street corridor more interesting and memorable (Degnen, 2016).

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CONCLUSION

Place attachment in Bagansiapiapi Chinatown was influenced by historical, religious, cultural, and social factors. A strong emotional bond between the residents and the place is a relationship through unique visual elements and historical value inherent in iconic buildings such as the Ing Hok Kiong Temple and cultural activities like the Bakar Tongkang Festival. These factors strongly play an important role in shaping emotional attachment and memory experiences and strengthen visitors' attachment to the place. This research also reveals that place attachment is closely related to the cultural experiences associated with the heritage. Visual elements, such as temple roofs and traditional celebrations, along with distinctive auditory elements like fireworks and musical instruments, enrich the tourist experience, making it more impressive and evoking a sense of nostalgia. It contributes to the identity of the Chinese community in Bagansiapiapi and strengthens social ties among residents.

This research highlights the exploration of place attachment to cultural heritage in shaping the identity of the Chinese community in Bagansiapiapi, demonstrating how preservation can lead to sustainable tourism development. It has focused on enhancing visitor satisfaction through the promotion of cultural heritage as a tourist attraction, Bagansiapiapi can continue to strengthen its emotional and social connections with visitors, contributing to the well-being of the local community and economic growth.

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THE ECONOMICS Vs SUSTAINABILITY IN ECOTOURISM SITES PLANNING AND DEVELOPMENT: LESSONS LEARNED FROM THE IMPACT OF LANTEBUNG MANGROVE FOREST ECOTOURISM ON THE COMMUNITY'S SUSTAINABLE LIVELIHOOD

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Abstract

The study evaluates the Lantebung Mangrove Ecotourism Area (LMEA), managed by the Tourism Awareness Group (TAG), focusing on its economic contribution and potential to promote community awareness for ecosystem sustainability as part of the Sustainable Development Goals (SDGs). 187 respondents were interviewed and scored the human, social, natural, physical, and financial capital indicators of TAG individuals to create a pentagonal asset framework. The findings indicate that TAG LMEA has significant natural and social capital due to its ecological tourism potential and stakeholder support. The natural capital score was 2.52 (high), and the social capital score was 2.37 (high). In contrast, the measured values for human capital (1.63), physical capital (1.51), and financial capital (1.63) are insufficient. The study demonstrates a reciprocal relationship between financial and human capital, wherein community engagement fosters growth and participation in LMEA governance. Stakeholder trust is affected by human and social capital, necessitating government regulation of the "Build-Operate-Takeover" paradigm to protect vulnerable people from the adverse impacts of financial capital. Due to their limited knowledge, a "collaborator" component is essential to aid TAG in overseeing green tourism enterprises.

Keywords: Sustainable Livelihood, Ecotourism, Sustainable Tourism Policy

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INTRODUCTION

Sustainability is now an integral concept in the tourism industry, shaping development strategies worldwide. In Indonesia's 2030 Sustainable Development Goals strategy, tourism is highlighted as a key driver of welfare and environmental sustainability (UNDP, 2024). The sector significantly contributes to the national economy, employing 12.7 million people in 2020, which accounted for over 10% of the workforce (NDPA, 2021). By 2030, tourism is projected to contribute 5.13% to GDP and attract 23.18 million international tourists. Under the National Long-Term Development Plan (RPJPN), Indonesia aims to become a Golden Indonesia by 2045, targeting a per capita income above USD 23,000, requiring the achievement of the SDGs by 2030 (NDPA, 2023). This vision emphasises social reform, economic growth, good governance, rule of law, stability, and diplomacy (Akbar et al., 2024). Accelerating tourism initiatives is essential to support economic, environmental, social, and cultural development as part of these national goals.

Makassar, South Sulawesi's capital, is a popular Indonesian tourist destination for its history and culture. The Lantebung Mangrove Forest Ecotourism Area (LMEA) is a growing tourist attraction, an economic resource, and a natural defence against coastal erosion and climate change (Akram, 2024; Moussa et al., 2024). The Tourism Awareness Group-Pokdarwis (TAG), a varied economic, social, and cultural community organization, manages LMEA and represents a vulnerable group in need of help and progress. This method is essential to balancing the community's economic access to conservation programs with LMEA's green tourism impact on the local economy. In biodiversity-rich but economically poor locations, local communities depend heavily on natural resources for income (Dawson et al., 2021).

There has been substantial research into the development of mangrove forests as tourist attractions (Dalimunthe et al., 2023), as well as the measurement of community livelihoods (Mallick et al., 2021). Nevertheless, research examining the potential of mangrove forests as a community asset and economic resource, which could influence the sustainability of their livelihoods, remains very limited. This research posits that if the community identifies itself as integral to the preservation of the mangrove forest ecosystem, it will enhance their well-being, thereby fostering a mutually beneficial relationship between the community and environmental conservation (Petriello, 2024; Qin et al., 2024).
This research seeks to evaluate the LMEA as a green tourism destination by examining its role as a contributor to the economy of the community, which can foster collective awareness for the sustainability of the regional ecosystem in a mutually beneficial manner. The analysis employed the Pentagonal Asset framework, a well-established tool for assessing the sustainability potential of a region. This research outcome will provide a significant reference for the

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government, especially for the city of Makassar, in developing and executing enhanced policies, programs, and strategies to promote green and sustainable tourism destinations, thus aiding in the attainment of the SDGs.

LITERATURE REVIEW

Green Tourism and Sustainable Development Goals

Tourism is a fast-growing industry with major economic, social, and national impacts. Travel and tourism made up 9.1% of global GDP in 2023, up 23.2% from 2022 and down 4.1% from 2019. The sector added 27 million jobs, representing a 9.1% increase from 2022 and a 1.4% decrease from 2019. In 2023, domestic visitor expenditure rose 18.1%, exceeding 2019. Although foreign visitor expenditure rose 33.1% in 2023, it slipped 14.4% below 2019 levels (WTTC, 2023). Tourism is important for employment creation and foreign exchange gains (Zhao, 2023) as well as improving transportation infrastructure (Yanchao et al., 2023). It promotes social globalization, economic expansion, and prosperity (Alamineh, 2023). The tourism industry needs to rethink how to use innovation to create long-term recovery plans (Chiawo et al., 2023); improve educational programs to get people involved and help them work together to create the best ecotourism (Habibulloev et al., 2024); and use eco-friendly practices to help the world reach its sustainable development goals. People may confuse green tourism and ecotourism to mean rural tourism or ecotourism, both of which are environmentally conscious. Due to environmental concerns, tourism growth, and the necessity for careful management have evolved (Al-Sakkaf et al., 2024; Raza et al., 2024).

Environmental economics promotes green tourism and sustainable growth by viewing sustainable deterioration as a business failure. Environmental concerns and visitors' preferences for green tourism strongly influence ecologically responsible tourism behaviour (Tafsirun et al., 2024). The relationship between tourism and ecosystem conservation and restoration is also important. A viable environment for future tourists requires sustainable tourism activities. Cultural landscapes, resources, and customs can boost visitor satisfaction and stimulate repeat trips (Kızıldağ & Yıldız, 2024). Satisfied tourists may not behave properly, requiring a more deliberate approach (Borthakur & Kondasani, 2024). Travelers choose sustainable tourism destinations found that tourists prefer sustainable sites (Kyriakaki & Kleinaki, 2021). The largest tourism and hospitality corporations can help execute the SDGs. Tourism is a big polluter, say critics. Tourism authorities and the government could reduce this impact by passing eco-friendly laws (Wania et al., 2024).

Green Tourism Policy: A Global Perspective

While presenting obstacles to environmental preservation, green tourism is turning the green economy into a feasible area for economic expansion (Toubes & Araújo-Vila, 2022). Sustainable tourist management depends on effective regulation, yet many developing countries continue to have weaker legal systems than industrialized ones. In addition to taking proactive steps to mitigate negative environmental, social, and cultural impacts, sustainable tourism requires a nuanced understanding of social costs and benefits (Baena & Cerviño, 2024).

Globally, green tourism supports the human right to a sustainable, safe, and healthy environment that includes public health, decent housing, and spiritual prosperity. International cooperation, multi-level governance, resource allocation, and regulation should be the main focuses of green tourism policy. National frameworks, from economic facilitation policies to environmental protection acts and tourism laws, aim to promote cross-sector cooperation, safeguard ecosystems, and reward green projects; however, enforcement and policy clarity frequently continue to be major obstacles (Thang & Thanh, 2023). Numerous nations have implemented a range of tactics to encourage green tourism, such as eco-destination development, clean-green practices, blue-economy plans, sustainable sports, regenerative tourism, tourist decarbonization, and community-based tourism. Many strategies are used to improve quality and sustainability in tourism, including green certification, strategic marketing, innovation incentives, and educational initiatives (Tran & Xuan, 2021; UNWTO, 2023).

Azmadi et al. (2023), for instance, looked into digital smart-tourism applications, notably QR-code integration on the KL QR Trail. They discovered that visitors' established habits and sustainability attitudes greatly increase their happiness and behavioral intention toward smart-eco activities. Azinuddin et al. (2022) assessed overtourism, perceived man-made threats, and revisit intents in Malaysia's heritage environment, demonstrating how unchecked tourism pressures might undermine conservation objectives. For sustainability and social acceptance, Mohd Rasdi et al. (2022) discovered that local community involvement in responsible tourism is essential. Additionally, Shehab et al. (2023) investigated how socioeconomic disparities impact community support for tourism and how destination image branding influences resilience and retention in frameworks for sustainable tourism.

Green tourism significantly drives economic growth within the green economy but also creates challenges for environmental conservation, making effective regulation vital for sustainable tourism management (Toubes & Araújo-Vila, 2022). In Indonesia, although the government has prioritised green tourism governance through laws such as the Tourism Law 2009, Environmental Protection Law 2009, and Job Creation Law 2023, its regulatory frameworks

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remain weaker compared to developed nations (Thang & Thanh, 2023). Achieving sustainable tourism requires balancing social costs and benefits while mitigating negative environmental, social, and cultural impacts (Baena & Cerviño, 2024). The 1945 Indonesian Constitution recognises green tourism as part of the right to a safe and healthy environment, including housing, healthcare, and prosperity rights. Therefore, policies should focus on regulation, governance, resource allocation, and international cooperation. Indonesia's Ministry of Tourism promotes initiatives such as regenerative tourism, decarbonisation, sustainable sports, blue ocean strategies, clean and green practices, tourist villages, and super priority destinations through green certification, strategic marketing, innovation, and education (Tran & Xuan, 2021; UNWTO, 2023).

For green tourism to succeed, human, ecological, cultural, financial, and technological resources must be managed efficiently based on sustainability and conservation principles (Ramírez et al., 2024). Governance should emphasise coordination, transparency, accountability, and collaboration within the tourism penta-helix—government, private sector, academia, communities, and media—to foster innovation, empower locals, protect intellectual property, and preserve cultural and environmental diversity (Andrades, 2024; Dushkova & Ivlieva, 2024). Effective governance also requires active stakeholder participation and green investments to optimise resource use and ensure equitable benefits. Collaborative governance is crucial for enhancing community ownership, encouraging responsibility for environmental preservation and cultural diversity, and supporting innovation and empowerment in environmental management, thereby making tourism economically viable, socially inclusive, and environmentally sustainable for long-term development (Dushkova & Ivlieva, 2024).

The Sustainable Livelihood (SL) Framework

Current discussions about poverty and sustainable development are increasingly emphasizing the interconnected themes of vulnerability, social protection, and livelihoods. This movement has been accompanied by a variety of techniques, all of which focus on studying conditions and evaluating the possible effects of project interventions. The livelihoods framework includes the skills, assets (both physical and social), and tactics that individuals and communities use to ensure their existence. Sustainability is the ability of individuals or groups to withstand and handle stress or crises while maintaining or developing their existing and future abilities and resources—all without depleting their natural resource base (Mondal & Palit, 2022; Yletyinen et al., 2024).

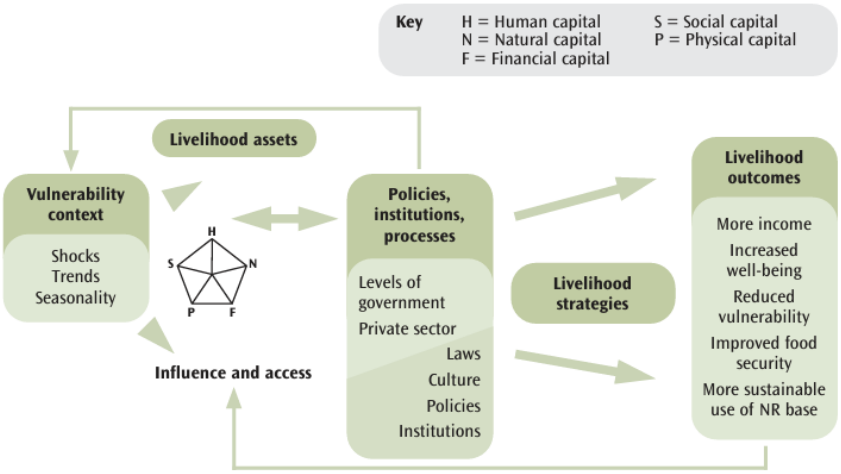


Figure 1: DFID's Sustainable Livelihoods Framework
Source: UNDP (2017).

Sustainable livelihoods (SL) strategies are used to organise information and analysis for assessing development projects, with flexibility being their main characteristic rather than a rigid methodology (Natarajan et al., 2022; Diehl & Bose, 2023). This study adopts an SL model framework encompassing three core components: (1) context, which includes external factors contributing to the hardships faced by poor communities; (2) assets and capabilities, referring to the resources available for their survival; and (3) policies, institutions, and processes that regulate access to these resources and shape livelihood choices. Natarajan et al. (2022) introduced a revised SL model that builds upon and addresses critiques of the DFID Sustainable Livelihoods Framework, aligning it with contemporary development perspectives. The updated framework emphasises understanding vulnerability in specific settings, creating livelihood protection plans, and assessing human, social, natural, physical, and financial capital to ensure comprehensive planning and implementation (UNDP, 2017).

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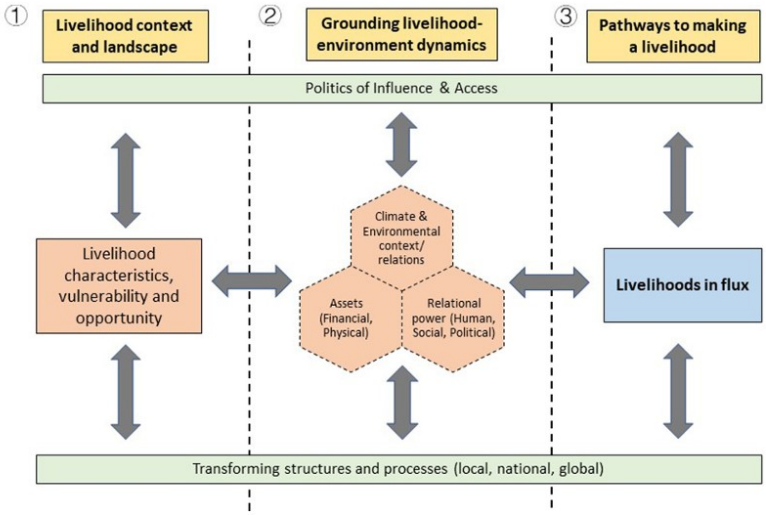


Figure 2: Sustainable Livelihoods Framework for the 21st Century
Source: Natarajan et al. (2022)

RESEARCH METHODOLOGY

The research was conducted at the LMEA, located in Bira Village, Tamalanrea district, Makassar City, South Sulawesi Province, Indonesia. This village is the largest in the Tamalanrea sub-district, including an area of 9.2 km², which constitutes 29.08% of the entire area of the sub-district.

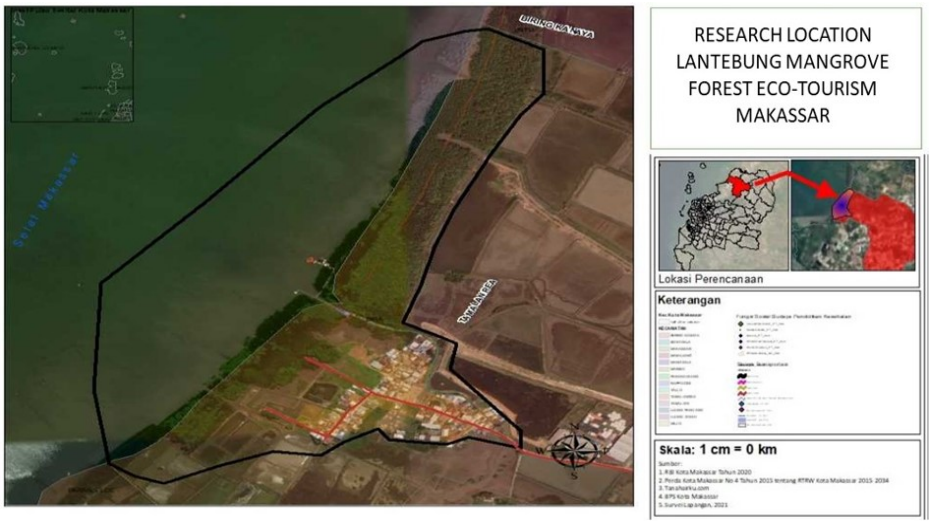


Figure 3: Research Location
Source: Authors' research data (2024)

In 2023, Bira village had a population of 13,669, comprising 6,853 males and 6,816 females, yielding a ratio of 100.54% and a population density of 1,476.13 individuals per square kilometre. The primary vocations of the inhabitants in the Lantebung region include fishermen, aqua-culturists, labourers, artisans, and various other professions.

This research utilizes both primary and secondary data. Primary data was collected via comprehensive interviews with 187 participants, including 8 members of TAG LMEA, 36 individuals from the local community around LMEA, 6 local government leaders, 14 academics, 27 community members, 5 entrepreneurs, 6 media personnel, and 85 visitors. Secondary data was obtained from many sources, including journals, textbooks, statistical data, and findings from previous studies or papers relevant to the research objectives. Data was collected by observation, interviews, and document analysis.

A descriptive analysis was conducted to evaluate the livelihoods of the populations in the LMEA. The pentagonal asset model was employed to examine the livelihood assets of individuals. This model delineates five unique attributes of the assets that individuals possess or may acquire to fulfil their essential survival needs. The indicative evaluation results were classified into three categories: high, moderate, and low, to assess the state of each asset indicator. The asset indicators were evaluated using the interval scoring system, with intervals spanning from 1 to 3 (Low: 1.00 to 1.66, Moderate: 1.67 to 2.33, and High: 2.34 to 3.00).

Table 1: Indicators of Pentagonal Assets and Measurement Scales of the TAG- LMEA

Asset Type	NO	INDICATORS
Human Capital	1	Educational level
	2	Green business experience
	3	Green business Skills
	4	Family Health of
	5	Involvement on green activities
Physical Capital	1	Condition of accessibilities
	2	Diversity of green attractions
	3	Variety of green activities
	4	Availability of green accommodation
	5	Availability of green amenities
	6	Overall appearance as a green destination
Natural Capital	1	Land Availability
	2	Land ownership
	3	Biodiversity
	4	Preserving the ecosystem
	5	Planning and development policies
	6	Designation and function
	7	Availability of water and sanitation facilities
Social Capital	1	Harmonization of communities

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	2	Trust among the stakeholders
	3	Participation/ involvement
	4	Collaboration among the stakeholders
	5	Cultural activities
	6	Recognition and awards
Financial Capital	1	Business development
	2	Sources of income
	3	Investment
	4	Availability of natural resources
	5	Business innovation and creativity

Source: Researchers' data analysis (2024)

ANALYSIS AND DISCUSSION

Livelihood Assets

Livelihood assets consist of various components, including human, physical, natural, social, and financial capital. An individual, community, or society owns or publicly manages assets or capital in the LMEA, which enables them to sustain their livelihood. Improving the resource potential allows evaluating its impact on the community's livelihoods and income, which subsequently provides benefits for meeting their needs and enhancing their well-being.

Human Capital

This study assesses five human capital factors: education, green business experience, skills, family health, and community green activity. These features show community members' strengths and traits (Tjahjadi et al., 2022; Ma et al., 2021). The analysis found a poor average human capital score of 1.63. This suggests the LMEA must prioritize human capital upgrades due to its limited capacity. The majority of TAG members in LMEA have only completed elementary to secondary education, resulting in their low educational attainment (1.52).

The community's green business experience indicator is low (1.47), mostly because green tourism is a new business model. Reduced community awareness leads to insufficient experience. The community can make mangrove coffee, batik with mangrove dye, and crab-nut crackers, according to the moderate (1.95) rating of green business competencies. Skills training programs are supported by local government and higher education. Their abilities and knowledge have improved after this course. TAG's moderate family health score of 2.21 indicates the LMEA is disease-free and safe. Most TAG family members have mild health difficulties. People also think this area is disaster-proof; however, the 2022 Makassar floods were a major tragedy. Each human capital aspect's scores are shown in Figure 4.

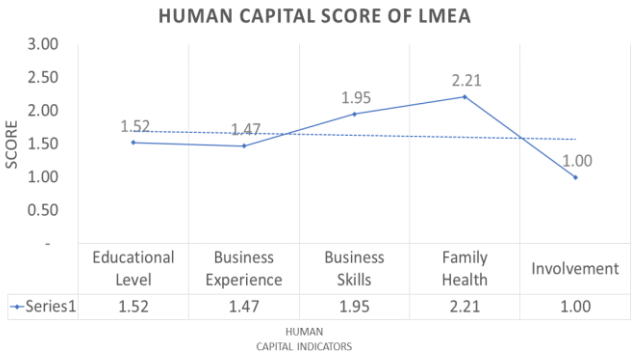


Figure 4: Human Capital of the TAG - LMEA Community
Source: Research data analysis (2024)

Physical Capital

Physical capital includes the infrastructure and structures that bolster the LMEA's status as a green tourism destination and affect local communities in achieving their livelihood objectives. This physical capital acts as a significant asset to enhance income and deliver services for creative communities to meet their needs. Figure 5 displays comprehensive metrics for each physical capital indicator.

The main road to the property and internal trails and boardwalks are moderately maintained by the LMEA (2.12). This signifies that concrete and asphalt principal roadways are in good condition. The narrow and degraded residential access roads to the LMEA site and the overly restricted neighbouring boardwalk access fail to meet visitor safety and comfort standards. The green attraction potential rating is 2.57 (high), indicating that the LMEA offers natural vistas, sunrises, sunsets, birdwatching, and cultural events. Green activities scored 1.53, indicating that tourist options are limited by a lack of facilities like fishing or boating equipment. A low green lodging score (0.51) is due to the absence of restaurants and cottages, or rooms for travellers seeking relaxation or overnight stays in the gorgeous mangrove forest area. Parking spots, identity gates and signage, information centres, restrooms, rubbish bins, and clean water were scarce and poor, resulting in a low availability rating of 0.57. The LMEA's modest aesthetic assessment of 1.75 suggests poor design and development, despite its green tourism potential. The boardwalk's bright colours hurt its green tourism image. Many indicators show that the LMEA's physical resources have a low grade of 1.51, suggesting that improving them is essential to attract tourists and enhance economic activity in the area.

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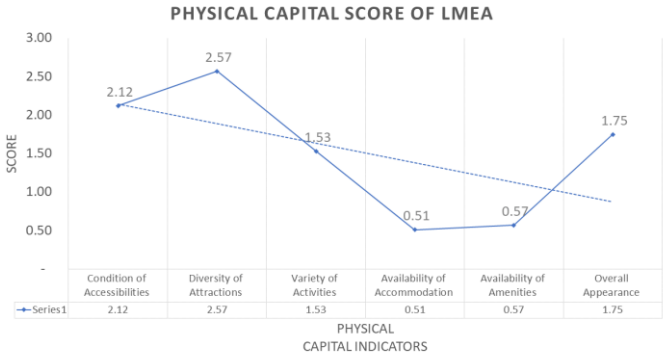


Figure 5: Physical Capital of the TAG - LMEA Community
Source: Research data analysis (2024)

Natural Capital

Local communities' survival depends on natural capital in agriculture, fishing, forestry, and tourism. Sustainable resource management can reduce poverty and boost wealth. Land availability, biodiversity, ecosystem conservation, planning, and water and sanitation service accessibility are utilized to assess natural capital potential. Local communities can fight poverty and achieve enduring prosperity by sustainably managing these resources (Damania et al., 2023). The LMEA scored natural capital 2.52. This means the area is vital to the ecology, the economy, disaster mitigation, and Makassar's carbon sink. Figure 6 summarizes all of the natural capital measure scores.

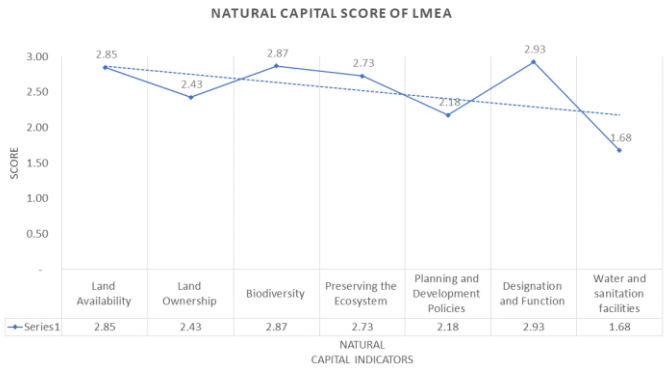


Figure 6: Natural Capital of the TAG - LMEA Community
Source: Research data analysis (2024)

Studies show the LMEA, which got 2.85, has 30 hectares. Community ownership exceeds 87% of LMEA-adjacent land. State sovereignty over the LMEA as a coastal border zone is allowed, but communities lack management capabilities. Despite a 2.43 score drop, this feature remains great. The LMEA has several mangrove species, maritime biota, and coastal and mangrove forest animals. The regional biodiversity index is 2.87. The LMEA ecological preservation target is met. All tourism partners plan and plant mangroves sustainably. Their 2.75 (high) score indicates tenacity despite substrate and waste management challenges. LMEA is a green tourism destination in Makassar city's regional regulation, but it lacks a master plan for regional development, earning a moderate score of 2.18 in the planning and development policies category. The LMEA has a categorization and functional indicator score of 2.93 (high) because it prevents floods and tidal disasters, mitigates coastal erosion, and provides green space for carbon absorption. The protracted dry season in Makassar makes it difficult for residents to get drinkable water. Poor environmental sanitation contributes to a concerning water and sanitation facilities indicator score of 1.68 (moderate), indicating restricted availability.

Social Capital

Social capital includes the norms, habits, networks, and cultures vital for improving connections within the community. It is essential for cultivating relationships among individuals, interest groups, society, and diverse stakeholders, creating a penta-helix of collaboration. Social capital, characterized by the structure and quality of social ties, arises as a significant result of social interactions, providing various advantages to individuals, social groups, and society at large (Sánchez-Arrieta et al., 2021; Tsounis & Xanthopoulou, 2024).

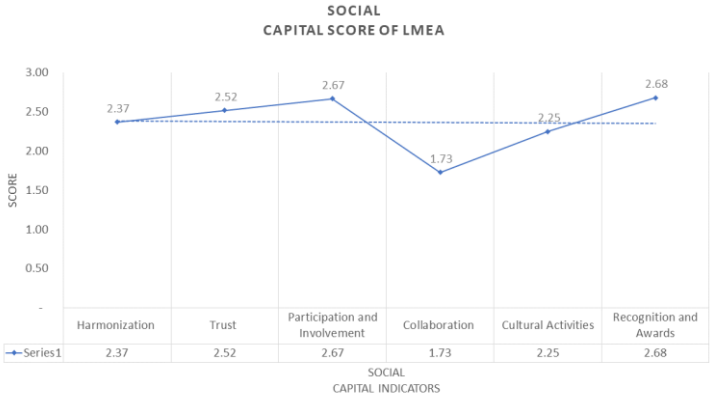


Figure 7: Social Capital of the TAG - LMEA Community
Source: Research data analysis (2024)

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Indicators of collaboration among stakeholders reflect a modest level (1.73). Notwithstanding the robust elements of trust, relationships, and engagement, it appears that the majority of participation efforts function autonomously, devoid of coherence with one another or the LMEA development plan. This scenario pertains to the concept of collaborative governance, necessitating a "collaborator" to consolidate all stakeholders under a unified program and set of activities. Community involvement in cultural activities, essential for tourism, is restricted and frequently transient. Common cultural activities include religious events, Independence Day celebrations, batik-making with dyes derived from mangroves, and the manufacture of mangrove coffee (2.25). The LMEA's social capital is rated highly (2.37) across all criteria, indicating its favourable condition.

Financial Capital

Monetary resources, including financial capital, are crucial for local communities to achieve their livelihood goals. These resources, both flowing and existing, are essential for consumption and production, enabling individuals to implement various livelihood strategies (Lu et al., 2023; Azumah, 2023). The specific scores of every financial capital indicator measure are displayed in Figure 8.

TAG business development scores 1.35, which is low. Business creativity and innovation metrics score 1.56, also low. This is because TAG relies on entry fees as its main revenue source. Food and drink sales, fishing, and housing services are other tourism-related income sources that have not been studied. LMEA is moderate in income source measurement at 1.77. About 38% of the local people make a living fishing in the mangrove forest. Most LMEA residents work in manufacturing. LMEA facilities have only been developed with government backing and company social responsibility contributions. No external investment has accelerated LMEA's tourism destination transformation, resulting in a poor indicator score of 1.26. The remaining four indicators are disappointing because mangrove forest natural resources have great potential (2.37). This means the area is bountiful and can boost LMEA business growth, creativity, and innovation.

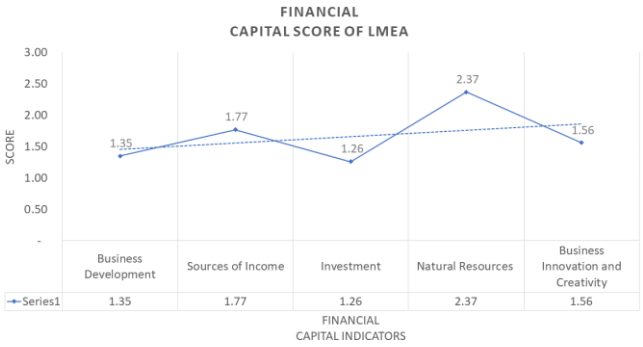


Figure 8: Financial Capital of the TAG - LMEA Community
Source: Research data analysis (2024)

Pentagonal Assets

The Sustainable Livelihoods Approach gives a structure and a list of important features that characterize people's livelihoods and explains how these aspects interconnect. The key components of this framework comprise the context of vulnerability, the assets of livelihood, the structures and processes, the strategies of livelihood, and the outcomes of livelihood. A livelihood is deemed sustainable if it can endure and recover from adversities while preserving or enhancing its capabilities and resources both presently and in the future, without depleting the underlying natural resources.

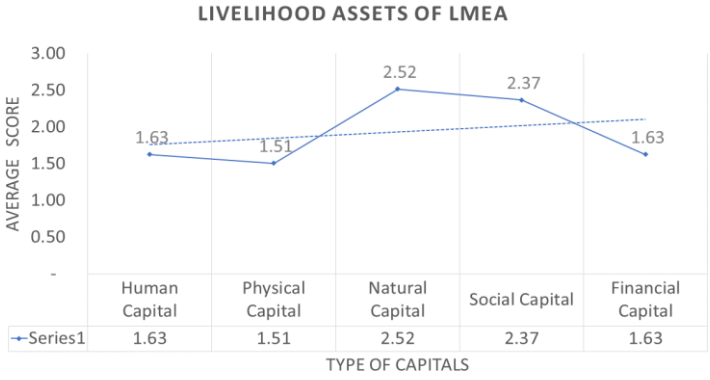


Figure 9: Livelihood Asset of the TAG - LMEA Community
Source: Research data analysis (2024)

For LMEA livelihoods to survive, community resources must be accessible. Each person has five asset categories. An individual's assets may

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change. Variations may rise or decrease relative to previous possessions. Individual activities, societal changes, and environmental processes can cause these variances. Figure 9 shows TAG LMEA livelihood asset status. An asymmetrical pentagonal assets diagram in Figure 10 shows the TAG LMEA's livelihood assets and unequal access to the five asset types. The Pentagon's large divergence from the ideal illustrates this. Figure 10 shows two categories of communal livelihood assets. Human, physical, and financial capital are the least developed, whereas natural and social capital are abundant.

Human capital—skills, knowledge, and experience in green tourism—is essential to realizing LMEA as a green and sustainable livelihood source. Physical capital, such as infrastructure and sustainable tourism, enables varied LMEA livelihood strategies. Natural capital in LMEA includes household and family participation in mangrove ecotourism and resource collection for subsistence and income. TAG people and families' social capital—networks, group connections, and trust relationships—increases tourism and community revenue. Financial capital available to TAG individuals and households, including external investment sources from outside LMEA, supports business potential and innovation as livelihood or additional income routes. In alignment with the SDGs' goals of eradicating poverty, promoting decent work and economic growth, developing sustainable cities and communities, preserving life below water and on land, and fostering partnerships, this dynamic creates mutually beneficial interdependencies that create a sustainable environment and ecosystem in a thriving society.

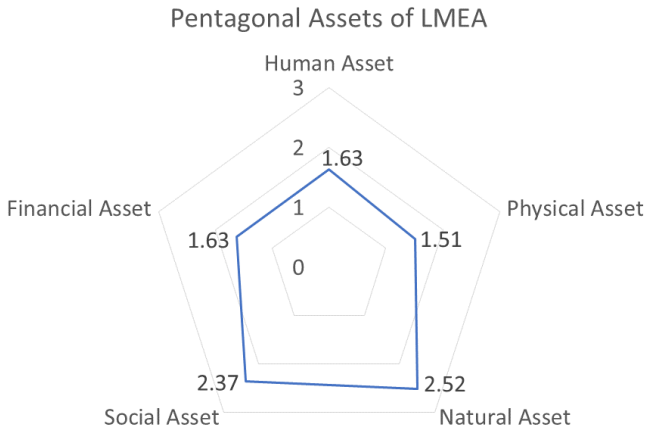


Figure 10: Pentagonal Assets of The TAG LMEA
Source: Research data (2024)

CONCLUSION

The TAG LMEA's asset situation is poor, with uneven access to various assets and significant disparity in community ownership. While natural and social capital have high levels due to ecological potential and tourism connections, human, physical, and financial capital levels are inadequate. Low educational attainment among TAG members negatively impacts skills, innovation, and creativity in establishing LMEA businesses. Local factories employ most individuals who do not rely on income. LMEA, with its natural capital and biodiversity, has potential for green tourism, but its governance is hindered by 87% of TAG members, who lack experience and high school education, and lack the necessary skills, training, and innovation to fully realize its potential.

Government support is crucial for building public infrastructure, especially in the LMEA region, including enhancing access roads and constructing boardwalks. Establishing tourism amenities like parking lots, signage, and facilities will enhance comfort, safety, visitor engagement, and revenue potential for the local community and TAG. A collective consciousness among all stakeholders is essential to establish LMEA as a "subject" rather than an "object" in the advancement of green tourism. To promote green tourism in LMEA, stakeholders must collaborate, focusing on economic, social, and cultural benefits. This will help local communities contribute to the area's sustainability, as neighbouring towns may use it negatively, potentially compromising its condition due to economic demands. External investors are crucial for regional development, but the government must oversee the "Build-Operate-Takeover" model to protect vulnerable communities from financial capital's adverse effects, as ownership may be usurped, leading to displacement and marginalization.

Theoretical Implication

To reduce tourism expansion and promote local livelihoods, development and conservation must be combined. This requires public-private collaboration, local conservation participation, proper funding, and education. Prioritizing human assets for households near natural areas is crucial for sustainable livelihoods. Local government policies should focus on mangrove conservation, governance enhancement, investment policy, and community empowerment. These policies should involve boundary zones, collaborative efforts, community empowerment, and economic capacity enhancement. The "build-operate-takeover" approach promotes mutually beneficial business management and development while ensuring intellectual property rights and geographical identity are protected.

ACKNOWLEDGEMENT

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DETERMINING FACTORS DURING THE PROJECT LIFE CYCLE ON HIGH-RISE BUILDING PROJECT PERFORMANCE IN INDONESIA

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Abstract

Infrastructure is a basic human need that supports all daily activities. In order to advocate for government programs in providing quality infrastructure, it is necessary to implement projects that achieve good performance. One way to meet this objective is to focus on the project life cycle process. Currently, there are still deviations in project development management during the project life cycle phase that lead to delayed projects, losses, and so on. This study aims to find the determining factors that cause poor project performance, especially in high-rise building projects. The study used qualitative analysis to process data from various library sources. Additionally, data processing was performed using SPSS version 24.0, with a total of 18 respondents (pilot testing). The results identified 5 highest determining factors, namely incremental (incr), preparation (prep), behaviour (beha), iterative (iter), and briefing (brie) in each of the project life cycle phases.

Keywords: Project Life Cycle, Project Performance, High-rise Building Project

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INTRODUCTION

Indonesia is a well-documented country where much of the population consumes domestic goods and services, including architectural services, consulting engineers, economic consultants, building materials, financial services, legal consultants, construction equipment, and transportation and communications. These services prove the substantial contribution of the building industry across Indonesia. Accordingly, the contributions of this aspect are apparent in the total value of construction and building work, which makes up a great percentage of the total Gross Domestic Product (GDP). The Indonesian construction industry works in various sectors, such as residential and non-residential construction, as well as those that relate to agricultural or irrigation structures, infrastructure (roads, bridges, ports, electricity, gas, water, and communications), and others (Raftery et al., 2023). Nowadays, governmental projects are significant, with most of them focusing on office and housing construction (Riantini et al., 2017). The construction work on high-rise buildings is likely to be associated with three significant issues: work injuries, hazardous material exposure, and health-related complications. The possible accidents that may afflict the high-rise construction workers include: (1) falling off a ladder or scaffold or failing to wear personal protective equipment; (2) being hit by construction vehicles, such as cranes, forklifts, or backhoes; (3) being electrocuted due to undefined electrical systems with exposed cables; and (4) becoming the target of falling material in the workplace. Other critical issues, such as a lack of human resources, poor infrastructure and facilities, failure to translate academic knowledge into practice, fierce arguments between various project members, and inability to perform construction work contracts, are also of concern.

LITERATURE REVIEW

Project Life Cycle

Organizational process assets refer to documented plans, processes, policies, procedures, and knowledge bases belonging to the executing organization. Such assets may be artifacts, practices, or knowledge, including that which is common or exists in one or more of the organizations involved in the project and is useful for the purpose of executing or managing the project. These process assets are documented strategies and frameworks, plans, schedules, and other resources, including stipulations, policies, procedures, and knowledge bases tailored to and employed by the executing organization (PMI, 2017). Organizational processes and procedures for executing project work include, but are not limited to: (1) Initiation; (2) Planning; (3) Execution; (4) Control and Monitoring; and (5) Closing.

When it comes to projects related to the topic of interest, there are a lot of differences in the nature of projects and the actual way of performing the business. In simpler terms, there is no single answer that can serve as a solution

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to all problems. To summarize, as can be observed in the custom solution project, it is essential to outline a project life cycle that is better suited to the project than the standard project life cycles. It is during this stage that the acronym stating all of the existing five types of methodology in circulation becomes critical, namely predictive, iterative, incremental, agile, and hybrid (PMI, 2017; Teoh et al., 2021). For example, the same custom solution that is being assessed can be transported to the end user instead of creating tens to hundreds of assessments for that purpose in the projected life cycle of a predictive project (Teoh et al., 2021).

The project life cycle is a concept of phases that are fundamental and should be successfully gone through by a project from its initiation to its closing (PMI, 2017). According to the data collected in 2008 from the Project Management Institute (PMI) of the United States and Association for Project Management (APM) of the United Kingdom, a general project life cycle commonly contains the following five phases: Initiating, Planning, Executing, Control & Monitoring, and Closing (Wang & Chen, 2023).

Project Performance

In regard to the performance aspect, each company should engage a project manager and their team with experience in performing the work appropriately, which is not limited to time performance, cost impact, and quality aspects. However, the control of health, safety, and the environment is a prescription that has to be complied with for the mastery of occupational health. In terms of enforcing regulations, which include requirements stated in the contract of work and several other regulations, the project manager's role can be instrumental in ensuring the project's successful performance (Mairizal et al., 2020; Adriadi et al., 2024).

As indicated in the study by Syamil et al. (2021), it was discovered that the majority of the Project Managament practitioners in Indonesian projects are users or customers of the projects being undertaken, and that the areas of project schedule, cost, human resources, and risk management performance are variables that actually affect customer satisfaction in a significantly positive manner. Contrary to expectations, project schedule, communication, and stakeholder management performance do not significantly influence overall customer satisfaction (Yuslim et al., 2023).

According to Ladika and Sanggoro (2024), if stakeholders wish to make a direct contribution to any modelling condition, they should possess as many project interests as possible. Referring to the project analytical framework discussed earlier, it is clear that competence always has a positive impact on the results of project performance. Hence, the improvement in the competence of stakeholders, under any modelling condition, can foster positive improvement in the project performance results, without negation.

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In project management, a variety of research has been conducted to identify the competency aspects that can be used or observed in successful or highly rated project managers (Sirau et al., 2024). Such research entails the collection of data from project management practitioners. In addition, although most of the reviews focus on contexts from experience and literature, occasionally it is also possible to encounter attractive papers that are rich in empirical evidence or, ideally, theoretical and model clarifications (Mairizal, 2020; Adriadi et al., 2024).

High-Rise Building

According to Adriadi et al. (2024), a high-rise building is an infrastructure that has a high structure, such as residential areas, apartments, and offices. However, a building can only be considered in this category if it meets several characteristics. These include meeting the minimum height of 23 meters, with elevators and a strong structure.

Many studies from the literature provide a distinct definition of high-rise buildings. Nonetheless, most of them only mention a single characteristic of high structures. Apart from that, even though high-rise buildings are widely discussed in terms of the design of their structural strength due to wind loads, earthquake loads, and others, there has been no accurate and definitive definition of the infrastructure (Adriadi et.al. 2024).

Furthermore, based on a study in the research by Adriadi et al. (2024), the definition of a tall building can be found in Law of the Republic of Indonesia No. 28 of 2002 concerning buildings, Article 1. Here, the definition given is the physical structure of the construction result that is closely related to the place, above and/or under the ground, and/or water, used by human beings for certain activities, placement or dwelling purposes, worship, commercial, social, cultural, and specific purposes. According to Article 1, the general function of a building is differentiated into several aspects.

Another opinion from Effendi et al. (2021) stated that high-rise buildings in big cities are very important for business, economic, educational, housing, and entertainment activities, especially in the current era. The transition from horizontal to vertical buildings occurs because of the scarcity of land in the city. This has led to the development of different types of large buildings and skyscrapers. Therefore, the issue is more than a question of meeting the need for space, but rather the search for technology in areas that underpin the construction of high-rise buildings, including structures, mechanics, electricity, and materials used. esides, the rapid rate of innovations in the construction industry has also contributed to the development of different high-rise building architectural designs, including their functionality during operation and maintenance to meet the objectives of being eco-friendly, efficient, and effective. At present, the environmental impacts have become challenges that require a universal approach

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to minimize the negative outcomes in comparison with the past. Due to these obstacles, the design of high-rise buildings has become a rather difficult process.

According to Astarini & Utomo (2020), as a concept, Performance-Based Building Design (PBBD) calls for strategic emphasis in terms of integration in building design from the viewpoint of performance specifications. PBBD gives an approach in the design process in the form of a thinking approach, more concerned with the usage of users/occupants. The first is the occupancy-related group, which includes indoor environmental quality, visual comfort, accessibility, acoustical comfort, building quality, and maintainability; the second is total management of energy loads and building sustainability and business processes; the third is integration with other design consultants and building operations; and the fourth is risk of loss, including structural safety and fire safety.

Construction management is also anticipated to assist the contractors in avoiding project delays arising from a change of design. Construction management, as a consulting company for owners, has to prepare the abilities and deliberate all of the owner's input, then oversee and enable the consultants in integrating them into the design (Kaming & Saputra, 2013; Salim & Sujana, 2020). In addition, construction management must bring the issue of convenience into play because it acts as an interface between consultants and contractors. The second factor that is considered to be the main reason for project delays is the insufficient level of planning and controlling, both of which are cognate activities in construction project management.

Project management is a form of management that deals with the coordination of a set of activities to achieve a project goal. Data from the research study established that contractor project teams in Indonesia are currently not well-equipped in construction management. Moreover, planning is affected by the time required for material acquisition, the time when workers are likely to be needed in a project, and the time when equipment must be hired. Hence, contractor project teams need to grow accustomed to preparing detailed working plans, such as risk and risk response descriptions (Salim & Sujana, 2020).

In a study, Chicoca & Utomo (2019) conclusively identified a significant correlation between cost drivers and project cost performance in Surabaya. Seven cost components were considered and classified according to their importance and potential effect. Due to its high ranking, the model postulated that the property market and construction industry play the most influential role, followed by property characteristics, socio-economic factors, and project component cost factors. The last of the seven factors that was considered, and therefore the least significant, was the regulatory factor. In terms of significance, the project stakeholder factor had the most influential impact, followed by the property market and construction industry, project characteristic factors, and project component cost factors.

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Project Performance Summary

Several factors of project performance during project life cycles are discussed in Table 1.

Table 1: Several performance factors of the project life cycle

	Initiating (X1)	**Planning (X2)**	**Executing (X3)**	**Control & Monitoring (X4)**	**Closing (X5)**
PMI (2017)	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid
Teoh et.al. (2021)	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid	predictive, iterative, incremental, agile, hybrid	iterative, incremental,
(APM, 2019);	contextual, technical, behavioural	contextual, technical, behavioural	contextual, technical, behavioural	contextual, technical, behavioural	contextual, technical, behavioural
(Wang & Chen, 2023)	preparation, briefing	design, coordination, technical	manufacturing, construction	manufacturing, construction	handover
Mairizal et.al. (2020)	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal
Edrizal et.al. (2020)	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal
Mairizal et.al. (2023)	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal
Adriadi et.al. (2024)	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal	knowledge, technical, personal
Syamil et.al. (2021)	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management
Astarini & Utomo (2020)	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management

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	Initiating (X1)	**Planning (X2)**	**Executing (X3)**	**Control & Monitoring (X4)**	**Closing (X5)**
Salim & Sujana (2020)	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management	project schedule, cost, human resources, risk management
(Ladika & Anggoro, 2024)	stakeholder, competence	stakeholder, competence	stakeholder, competence	stakeholder, competence	stakeholder, competence
Chicoca & Utomo (2019)	stakeholder, cost	stakeholder, cost	stakeholder, cost	stakeholder, cost	stakeholder, cost
Total factors	**19**	**19**	**19**	**19**	**15**

RESEARCH METHODOLOGY

The current study is a descriptive analysis in which the research method used was aimed at identifying variables that affect the project life cycle and, in turn, the performance of high-rise building projects in Indonesia. The methodological steps used and factors selected during the project life cycle that affected performance are presented in Figure 1 and Table 1.

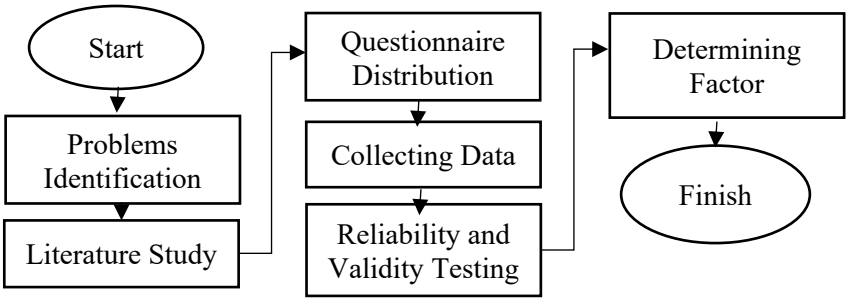


Figure 1. Research Methodology

After ratification was carried out for all factors in Table 1, a total of 17 factors in the life cycle across 5 phases were obtained from a pilot test on 18 respondents (n+1). These data were obtained from a high-rise building contractor company using the purposive sampling method.

A total of 18 professionals from the construction management field who managed high-rise building projects for more than twenty years participated in the survey. The questionnaire displayed 17 factors through descriptive and qualitative questions to the participants.

ANALYSIS AND DISCUSSION

The study started its analysis section by validating reliability scores with alpha values > 0.70 and validity standards that exceed r-table values. Pearson and coefficient characteristics: r-table = 0.4000 according to Pearson's Product Moment with a significance level of 0.05. The results of the SPSS data analysis showed a minimum r-count result = 0.348 (contextual), and the factor is deemed ineffective. For the reliability test, the Cronbach Alpha value ranged from 0.948 to 0.954 (Table 2). In addition, the highest mean calculation result was 4.5556 (incremental), and the lowest mean was 4.0000 (competence).

Table 2: Item Statistics

Sub-factors	Mean	Std. Deviation	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted	N
pred	4.2222	.64676	18	.753	.951
iter	4.3333	.68599	18	.627	.953
incr	4.5556	.61570	18	.530	.954
agil	4.1111	.58298	18	.866	.949
hybr	4.1111	.75840	18	.868	.948
cont	3.5556	.78382	18	.348	.958
tech	4.1667	.61835	18	.853	.949
beha	4.3889	.77754	18	.742	.951
prep	4.5000	.70711	18	.770	.950
brie	4.3333	.97014	18	.736	.952
know	4.2778	.89479	18	.878	.948
pers	4.1667	.70711	18	.870	.949
sche	4.2778	.66911	18	.926	.948
cost	4.2222	.64676	18	.841	.949
risk	3.7778	.64676	18	.441	.956
stak	4.1111	.58298	18	.753	.951
comp	4.0000	.76696	18	.627	.953

After examining the results of the factor analysis, the 17 performance factors that determine and have an impact during the project life phase were sorted, as shown in Table 3.

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Table 3: Item Statistics (ranking)

Sub-factors	Mean	Std. Deviation	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted	N
incr	4.5556	.61570	18	.530	.954
prep	4.5000	.70711	18	.770	.950
beha	4.3889	.77754	18	.742	.951
brie	4.3333	.97014	18	.736	.952
iter	4.3333	.68599	18	.627	.953
know	4.2778	.89479	18	.878	.948
sche	4.2778	.66911	18	.926	.948
cost	4.2222	.64676	18	.841	.949
pred	4.2222	.64676	18	.753	.951
pers	4.1667	.70711	18	.870	.949
tech	4.1667	.61835	18	.853	.949
hybr	4.1111	.75840	18	.868	.948
agil	4.1111	.58298	18	.866	.949
stak	4.1111	.58298	18	.753	.951
comp	4.0000	.76696	18	.627	.953
risk	3.7778	.64676	18	.441	.956
cont	3.5556	.78382	18	.348	.958

According to PMI (2017), the project life cycle is a model of stages that a particular project passes through in its total life span. The project life cycle gives a general approach that can be followed while implementing the project in the management stage. It follows the basic form of the framework, which applies irrespective of the items or type of project work that is at play. Such phases may be linear, cyclic, or concurrent. All project initiatives can be placed within the framework of a generalized life cycle.

Furthermore, PMI (2017) explains that the project life cycle can be predictive or adaptive. In this regard, there is generally one phase or several phases related to the development of products, services, or results. As a whole, these phases are called the development life cycle, and it can be predictive, iterative, incremental, adaptive, or a combination of the four.

Table 3 shows the results that identify incremental (incr) as the dominant factor affecting project performance due to its first-ranking status. The preparation factor (prep) held the second position, following the first-ranking determinant. The behavioural factor (beha) held the position of the third strongest determinant according to the results. The acquisition of briefing (brie) was positioned as the fourth most important factor, and iterative (iter) stood as the fifth. High-rise construction projects must use these seventeen factors as fundamental references during their five project phases.

CONCLUSION

The results of the discussion above, if viewed as the 5 highest determining factors in sequence from the project life cycle factors, are incremental (incr), preparation (prep), behaviour (beha), briefing (brie), and iterative (iter). Due to limited writing opportunities and space, this research will be continued in a more detailed direction with more clearly visible data processing stages.

The research will proceed in detail with better visible processing stages because of restricted space and opportunity. Other researchers should investigate the project team's potential competencies, since these factors determine overall performance.

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CURRENT STATE OF CIRCULAR ECONOMY PRACTICES IN MALAYSIA'S CONSTRUCTION INDUSTRY

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Abstract

Despite growing interest in sustainable construction, the adoption of Circular Economy (CE) principles in Malaysia remains limited due to various challenges, including regulatory gaps, lack of awareness and economic constraints. By contrast, the CE framework aims to reduce waste and maximise resources by closing material loops, aligning with global efforts toward sustainable development. This paper examines the current adoption of CE in Malaysia's construction sector. A questionnaire survey was randomly distributed to 250 contractors ranging from G1 to G7. The data were analysed using the Statistical Package for the Social Sciences (SPSS), applying reliability tests and factor analysis to rank the significant results systematically. The results showed that reversible and dismantled connection methods are the most effective CE strategies, allowing for greater flexibility and sustainability. However, a lack of understanding and awareness about rapidly evolving technologies and practices emerged as a key obstacle. To address this, the paper recommends updating guidelines on dismantling structures and reusing materials, providing clearer standards to support more sustainable construction approaches, which have not been sufficiently explored in previous research. These insights can help to drive improvements in CE practices for policymakers and construction industry stakeholders, encourage meaningful progress, and advance long-term sustainability in Malaysia's building sector.

Keywords: Circular Economy, Malaysia, Construction, Contractors

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INTRODUCTION

A significant portion of construction and demolition (C&D) waste ends up in landfills, creating a range of environmental, social, and economic challenges, including the loss of land space, resource depletion, and pollution (Ilmi et al., 2024). Despite Malaysia's growing emphasis on green and sustainable building practices (Yadegaridehkordi et al., 2020), there is still a pressing need to understand and enhance how industry players view and implement Circular Economy (CE) concepts in local development (Mustaffa et al., 2021). CE emphasize the reuse, repair, and recycling of construction materials to improve sustainability, aligning with global policies to decrease environmental impact and preserve natural resources (Akhimien et al., 2021; Norouzi et al., 2021).

Implementing CE principles in construction mainly involves cutting down on on-site waste and using materials that can be reused or recycled (Salleh et al., 2022). However, the industry still faces several hurdles, such as a shift in mindset, limited support within organisations, outdated procurement models, consumer behaviour challenges, poor collaboration, inadequate government backing, and intense competition centred on low bids. In a study by Ahmed et al. (2023), it was found that most of the leading players—organisational managers, clients, consultants, and contractors have only a small understanding of CE, with a few consultants showing moderate experience. Additionally, the sector's reliance on a linear model makes it challenging to adopt circular methods—particularly when many stakeholders are still learning about these principles and their benefits. CE draws on ideas from various fields, such as economic ecosystems, the 3Rs, cleaner production, and cradle-to-cradle design (Norouzi et al., 2021).

In light of these issues, this paper explores how CE concepts are used in the construction industry. The main goals are to analyse current practices, pinpoint obstacles, and recommend ways to increase sustainability by prioritizing material reuse, repair, and recycling—thereby reducing environmental impact and improving resource efficiency.

LITERATURE REVIEW

Circular Economy Practices to be Adopted in Construction

The construction industry currently faces significant challenges in managing its waste, calling for a more sustainable approach. One way to address this issue is by applying Circular Economy (CE) principles, such as "design for disassembly." Disassembly involves systematically removing individual building components like wall cladding, non-structural panels, flooring, and interior finishes—so that these parts can be reused or repurposed in new constructions (Dams et al., 2021).

A key tool in this process is the Disassembly and Deconstruction Analytics System (D-DAS), which uses information modelling to support sustainability at a building's end-of-life stage. By promoting thoughtful material

selection from the start, D-DAS helps reduce waste and align with CE goals of minimising new materials through smarter resource use and reuse (Akanbi et al., 2019).

Further reinforcing CE principles is the concept of "design out waste," which involves creating lighter structures that rely on fewer materials (Diemer et al., 2022). This lowers costs and energy demands and minimises environmental impact across the entire building lifecycle. Factoring in disassembly from the beginning encourages ongoing reuse and recycling of materials, ultimately boosting a building's overall sustainability (Mattaraia et al., 2021). Additionally, integrating lean production methods like just-in-time (JIT) processes and design for disassembly into the manufacturing chain helps curb material waste (Minunno et al., 2018). Circular Modular Construction Projects (MCPs), which emphasise sustainable material choices, waste reduction, and resource recovery, also reflect these CE ideals by keeping resources in a continuous loop (Wuni & Shen, 2022).

Another core strategy for advancing CE in the built environment involves carefully selecting materials and components to fit into a closed-loop system (Rahla et al., 2021). While current standards often focus on recycled content and recyclability, inventive approaches are needed to expand the circularity (Rahla et al., 2021). New rules setting targets for reuse and recycling could significantly boost circularity by incentivising creative ways to reclaim and repurpose construction and demolition waste (Ghaffar et al., 2020). For example, turning debris into recycled aggregates can help establish a closed-loop cycle in multiple building projects (Maury-Ramírez et al., 2022). Another promising route is to enhance the quality of secondary materials, including through upcycling, so they meet the same performance requirements as raw materials, allowing for repeated reuse and recycling which strengthening the circular economy's core principles (Ma et al., 2023).

The Barriers Faced by Construction Organisations in Implementing Circular Economy Principles in Malaysia

A lack of awareness, understanding, and insight within the construction industry remains as a key obstacle to embracing Circular Economy (CE) concepts (Munaro et al., 2020; Wuni, 2022), further reflected in the limited technical expertise and stakeholder familiarity with circular materials and architectures (Marek & Krejza, 2024). A significant part of the problem stems from limited CE expertise, technical know-how, and practical experience, compounded by insufficient stakeholder awareness of circular materials, products, services, and initiatives. In particular, gaps in knowledge about building design, especially around material quantities, quality, and availability, hinder the use of reusable components. Without reliable information on existing structures and materials, making informed decisions and implementing CE technologies becomes difficult. An additional challenge is the lack of robust data on the origin and supply of

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reused materials, which can lead to inefficiencies across the supply chain (AlJaber et al., 2023; Groenewald, 2024).

Insufficient CE training programs for contractors may also discourage the adoption of environmentally friendly methods in construction projects. The innate complexity of building projects, including multi-layered systems, steel-reinforced concrete components, concealed joints, and design modifications over time, further complicates the integration of circular practices.

Identifying how to reuse recyclable components, particularly steel, can be complex, with common design difficulties such as the scale of building materials, jointing procedures hindering disassembly, and intricate material composition. Challenges also arise in detaching bricks, especially when mixed with Ordinary Portland Cement, and recycling reinforced concrete components. The complexity of building data management further complicates efficient life cycle assessment (LCA) during the end-of-life phase due to missing or incorrect data during the design phase (AlJaber et al., 2023).

Construction organisations also grapple with the lack of standardisation assurance, making monitoring and comparing performance challenging. Circular practices necessitate standardised materials and explicit rules, but their absence complicates the assessment of circularity in buildings. Trust concerns may also arise without recognised certifications for circular products, impacting stakeholders' confidence in the long-term reliability of reused or recycled materials. Understanding materials' origin, lifespan, and traceability is crucial for accurate appraisal and reliable reuse or recycling, which is challenging without proper traceability. A lack of standardised methods and tools impedes incorporating strategic sustainability into the construction sector. Design for Disassembly (DfD) faces challenges due to a lack of tools compatible with Building Information Modelling (BIM), with sensors and radio-frequency identification identified as essential digital instruments for identifying reused parts (Munaro & Tavares, 2023).

Solutions for Best Practices Circular Economy Implementation for Construction Organisations in Malaysia

Facilitating the transition to CE necessitates a robust focus on awareness and research and development (R&D). Various governmental parties should champion enterprises to engage in R&D & Innovation, fostering collaborations between research centres, universities, and businesses. Joint efforts and networks are vital forums for exchanging knowledge, experiences, and best practices. At the same time, case studies contextualise business models, establishing credibility and trust in circular methods (Munaro & Tavares, 2023b). CE education and training programs are pivotal for equipping stakeholders with the necessary skills, and academic research contributes to new methods, technologies, and policies for CE adoption, providing evidence for policymakers. Raising awareness about CE

practices can be accomplished through workshops, seminars, conferences, and media channels. Campaigns also play a crucial role in developing fundamental understanding and encouraging stakeholders to embrace circular practices, amplifying the positive impact of CE on businesses and the environment (AlJaber et al., 2023). A well-defined roadmap that engages all stakeholders and construction experts is vital for encouraging the broader use of recycled materials in the building sector (Osei-Tutu et al., 2022). To address the economic barriers that often limit the marketability of reused materials, awareness forums can highlight the financial and environmental advantages these materials offer, helping to counter their relatively low market value. Increasing landfill disposal fees also discourages unnecessary waste, nudging the industry toward resource reuse (Osei-Tutu et al., 2022). When these awareness efforts are coupled with updated legislation and supportive funding measures, they can effectively tackle economic concerns, enhance public perception, and pave the way for a more circular and sustainable construction industry (AlJaber et al., 2023).

From a practical standpoint, contractors can bridge skill gaps by leveraging advanced technologies like Building Information Modeling (BIM). BIM's digital project management capabilities streamline the reuse of complex building elements and improve planning for waste management. Meanwhile, ongoing innovation in circular construction tools ensures that repurposed materials meet established quality standards. Another promising strategy is to create building guidelines that facilitate deconstruction and material reuse, thereby boosting market acceptance of reclaimed components. Revising regulations to allow the use of such materials in new projects further reinforces their legitimacy. These design guidelines also serve an educational role, clarifying key CE ideas and demonstrating how to apply them in practice—ultimately strengthening professionals' confidence in circular methods. Lastly, ensuring reclaimed materials carry appropriate certifications boosts trust and increases their likelihood of being adopted in construction projects, especially where safety is paramount (AlJaber et al., 2023; Osei-Tutu et al., 2022).

METHODOLOGY

A questionnaire survey was developed through Google Forms and designed based on a summarisation of the extensive literature review. The online questionnaire survey involved the types of circular economy practices that can be adapted in construction, barriers faced by construction organisations and proposed solutions for best practices in Circular Economy implementation for construction organisations in Malaysia. While past studies often rely on qualitative reviews or case studies, the questionnaire survey in this study is designed and randomly distributed to construction contractors in grades G1– G7, providing statistically validated insights. This methodological advancement offers a more structured and data-driven assessment of the CE transition challenges, setting this study

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apart from earlier works. The targeted study area is in Johor and Kuala Lumpur only, and the Krejcie Morgan approach was utilised to choose 250 samples from Johor and Kuala Lumpur-based organisations. Kuala Lumpur was selected due to its status as Malaysia's capital, serving as the construction hub with large-scale infrastructure projects and high contractor engagement. On the other hand, Johor is experiencing rapid urban development and cross-border construction investments, making it a key area for studying CE adoption. The questionnaire has three sections that involve Likert scale questions based on a level of agreement of 1-5 points. Section A's questions are designed to identify the types of circular economy practices that can be adapted to construction. In Section B, the respondents are questioned on investigating barriers construction organisations face to transition from linear to circular economy to accomplish the second objective of this study. Finally, in Section C, the respondents are asked to propose solutions for best practices in circular economy implementations for construction organisations in Malaysia.

The data collected from the online questionnaire survey was analysed using the software Statistical Package for the Social Science (SPSS). To ensure data reliability and validity, the analysis involved three key steps (1) Cronbach's Alpha for internal consistency, (2) KMO and Bartlett's test for sampling adequacy, and (3) Factor Analysis for identifying the type of CE, barriers and solutions for best practice CE. The Cronbach's alpha coefficient test α used to measure the internal consistency to assess the reliability of the data for further analyses. Cronbach's alpha coefficient ranges from 0 to +1. An acceptable value of Cronbach's alpha is 0.7, while 0.8 indicates a very good internal consistency.

To evaluate the level of agreement for each criterion, Factor Analysis (FA) was employed to identify and assess the most influential criteria. Hence, this study differs from previous research by employing Factor Analysis to assess and rank barriers to CE adoption systematically. FA is a statistical method used to compute subsets of variables, serving as a traditional and widely recognised approach for analysing data involving multiple factors. It simplifies a large dataset into smaller, more meaningful components without altering its fundamental structure. In this study, FA was conducted using Principal Component Analysis (PCA), which generates Factor Loading (FL) values for each factor (i.e., sub-criteria) in the form of a rotated matrix. The rotation of factors helps clarify relationships between variables, distinguishing high relationships from low ones while maintaining the structure. A varimax rotation method was applied to obtain the FL values for each sub-criterion, where higher FL values indicate the most influential factors. According to previous studies, FL coefficient values between 0.5 and 0.69 are considered significant, while values between 0.7 and 1 are deemed very substantial.

Conducting FA involves several preliminary steps to ensure data suitability. First, the correlation matrix must be tested for significance to confirm

the variables are appropriate for factoring. Bartlett's Sphericity test, based on Chi-square, is performed for this purpose, with a value of 0.005 or less, which is considered satisfactory. Next, the Kaiser-Meyer-Olkin (KMO) test is conducted in SPSS to examine data adequacy. The KMO value ranges from 0 to 1, with values closer to 1 indicating a more considerable common variance, making the data suitable for FA. A value of 0.5 is typically regarded as acceptable to proceed with the analysis.

RESULTS AND DISCUSSION

Types of Circular Economy Practices That Can Be Adapted in Construction

Factor Analysis is used to analyse the results of types of circular economy practices that can be adapted to construction. Figure 1 shows that "Reversible and Disassembled Connections" (T-C1), with an FL value of 0.844, is the top-ranked practice, emphasising its ability to facilitate deconstruction and material reuse for future projects. These findings align with Dams et al. (2021), who emphasise that reversible construction methods extend building lifespan by allowing dissembled components to be repurposed, reducing demolition waste and promoting sustainability. Furthermore, this result is supported by Wuni & Shen (2022), who highlight that Circular Modular Construction Projects (MCPs) play a crucial role in preserving natural resources, optimizing material efficiency and maintaining building components in continuous use cycles. This reinforces the argument that modular and reversible construction methods contribute significantly to the sustainability of the built environment by reducing material wastage and enhancing circularity in construction practices.

Following closely is "Creation of Information Modelling" (T-C2) with FL value of 0.829. This refers to the integration of digital tools such as Building Information Modelling (BIM) to improve construction resources. BIM enhances material tracking, enables predictive maintenance and supports disassembly planning by providing real-time insights into the building's components, ensuring that materials can be efficiently reused or repurposed after demolition. Similarly, "Modular or Prefabricated Component" (T-A3) also shares an FL value of 0.829. Prefabrication aligns with circular modular construction principles, which aim to minimise material waste while maximizing efficiency in production and installation. Modular construction not only accelerates project timelines but also reduces the demand for raw materials, making it a viable approach for sustainable construction practices. Next, "Systematic Dismantling" (T-A6) ranks third with an FL value of 0.725 and is rated as the third potential circular economy practice to be adopted. In Circular Economy models, Benachio et al. (2020) emphasise the significance of methodically deconstructing end-of-life building materials, changing them into valuable resources that serve as material banks for new construction.

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Besides, Practices related to material selection, including "Emphasizing the Use of Recycled Materials and Promoting Recyclability" (T-B1) and "Quality of Secondary Materials" (T-B2), are also highly rated, with similar FL values of 0.694. The effectiveness of these strategies depends on regulatory policies that mandate recycling targets encouraging resource recovery from construction and demolition waste (Ghaffar et al., 2020). Other notable practices include "Remanufacturing" (T-A5)," Reused of Salvaged Materials" (T-A4) and "Structures with Reduced Material Input" (T-A1) with a similar FL value of 0.654 also being found to be potential practices to be adapted in construction. This shows that respondents perceive these approaches as equally promising and practical for implementation in the construction industry. In contrast, their effectiveness and suitability for incorporation into construction processes align with circular economy principles.

Lastly, "Lean Production Optimising the manufacturing chain for scrap and raw materials" (T-A2), with a value of 0.644, ranked as the least potential circular economy practice. This ranking indicates that, while Lean Production is recognised for its ability to optimise resource use and reduce waste in manufacturing chains, it may face perceived challenges or be less immediately applicable in circular economy practices tailored specifically for construction. Further investigation and understanding of these problems may aid in the refinement of its execution and perception within the industry.

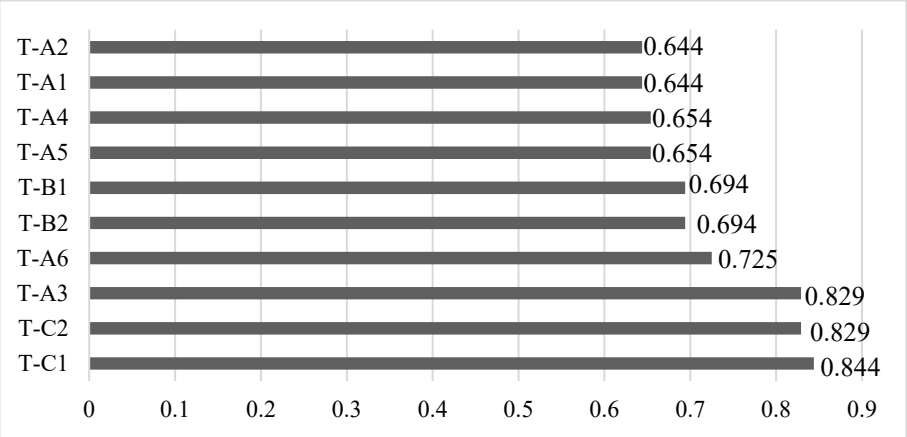


Figure 1: Type of Circular Economy

Barriers Faced by Construction Organisations When Transitioning from A Linear to A Circular Economy Practice.

Figure 2 illustrates the barriers construction organisations face. "Insufficient Comprehension and Insight" (B-A2), holds the highest factor loading (FL = 0.854). Based on findings from Munaro et al. (2020), this challenge stems from

insufficient awareness, comprehension, and insight regarding the Circular Economy in the building industry. As a result, many professionals struggle to grasp the long-term benefits of circular practices, leading to hesitation in adopting CE-based construction methods and resistance to shifting from traditional linear models. The second largest barrier, shared by all four factors, suggests that "economic aids and marketability" (range from B-B1 to B-B4) substantially impact the implementation of Circular Economy Principles, with an FL value of 0.784. This agrees with Guerra and Leite's (2021b) study, which highlighted budget, schedule, and regulations as significant barriers. The high initial cost of CE technologies, such as material recovery systems and modular construction techniques, often discourages adoption, especially among smaller contractors. Additionally, the lack of strong financial incentives, such as tax benefits or subsidies, makes it difficult for companies to justify the transition to circular method. "Inadequate of Information in Building Design" (B-A3) with an FL of 0.745 ranked as the third factor impacting the transition from a linear to a circular economy practice. This indicates that the absence of data on the number, quality, and availability of building materials and components causes a fundamental barrier to their reuse.

Four additional barriers which is "Unfamiliarity of Circular Economy Concept" (B-A1), "Inadequate Knowledge in Building Design" (B-A4), "Inadequate Knowledge on Current Structure and Materials" (B-A5) and "Lack of Standardization Assurance" (B-C2) each hold an FL value of 0.742, reflecting broad industry recognition of these challenges, though they are considered slightly less pressing than the top-ranked barriers.

The least significant barriers faced by construction organisations are "Lack of Data Accessibility and Origins of Reused Materials" (B-A6) and "Lack of Availability of Training Programs for Contractors" (B-C1). The first point emphasises the difficulty in obtaining and validating the source and quality of recycled materials, which affects project planning and execution. The last point indicates a lack of learning resources and skills development opportunities for contractors, which may limit their ability to adopt new techniques and technology.

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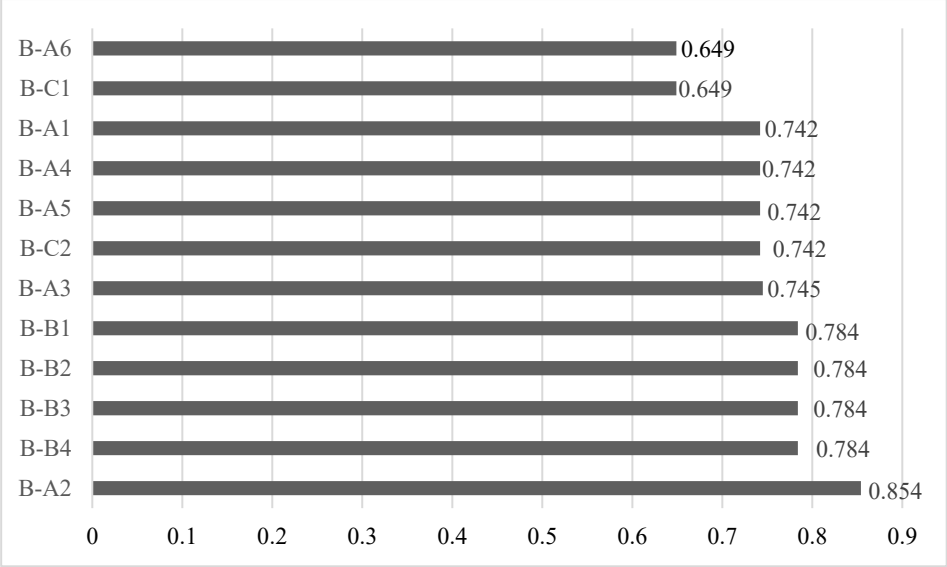


Figure 2: Barriers Faced by Construction Organisation for Circular Economy

Solutions for Best Practices Circular Economy Implementation for Construction Organizations in Malaysia

Figure 3 shows the data analyzed using Factor Analysis on the Solutions for Best Practices Circular Economy Implementation for Construction Organizations in Malaysia. The most highly ranked solution is "Establishment of Updated Guidelines: Deconstructing Structures and Reusing Materials" (S-B2), as the best solution with an FL value of 0.748. Design guidelines alleviate the lack of understanding of CE by acting as instructional materials that clarify CE ideas and show how they may be implemented realistically in building projects. Updating the present regulations for new construction to allow reused materials in new construction projects will broaden the market acceptability of recovered materials (Osei-Tutu et al., 2022).

"Education and Training Programs" (S-A3) follows closely with an FL value of 0.743 is also a significant solution as implementing CE education and training programs may provide stakeholders with the necessary skills to execute CE principles. The third highest ranked solutions are "Advance Technology Implementation" (S-B1) and "Innovation in Circular Building Tools (S-B3), with a same FL value of 0.644. Advanced technology such as BIM can successfully cope with building complexity by digitizing information that stakeholders may access throughout the project's life cycle, and thus, with such information, disassembly or probable reuse of a complicated building structure becomes a more plausible alternative (AlJaber et al., 2023).

Ranking fourth, with an FL value of 0.615, are "Joint Efforts and Networks" (S-A2), "Legislative Actions" (S-C2)" and "Economic Incentives" (S-C4). These findings suggest that a combination of awareness forums, legislative actions and financial support mechanisms is essential to address economic barriers and promote the public perception of recycled materials in construction, encouraging a more sustainable and circular construction industry. Moreover, by cutting prices and enhancing the attraction of circular structures, economic incentives can substantially impact modifying consumer behaviour (AlJaber et al., 2023). Furthermore, all interested parties and construction experts must be included in developing a roadmap to encourage using recycled materials in the building sector (Osei-Tutu et al., 2022).

Besides, "Large Amount of Research and Development" (S-A1) and "Campaign on Fundamental Knowledge of Circular Economy Practice" (S-A5) are both ranked fifth in the data with an FL value of 0.542. Case studies are also required to contextualize business models and establish credibility and trust in circular methods (Munaro & Tavares, 2023b). Apart from that, Campaigns, by definition, aid in developing fundamental knowledge of CE and its advantages, pushing stakeholders to embrace circular practices and boost the beneficial impact of CE on the surroundings (AlJaber et al., 2023).

"Awareness Forums" (S-C1), as part of the Economic and Marketability solutions, ranked sixth in the data with an FL value of 0.509. This suggests that awareness forums are recognized as a helpful solution for improving economic viability and marketability in the construction industry. They are viewed as less crucial than other options. Next, according to the respondents, "Workshops, Seminars Conferences, Social Media and Print Media", with an FL value of 0.503, is considered the second lowest option for solution for best practices circular economy implementation for construction organizations. This could be due to issues like limited reach, engagement difficulties, or the perceived impact of different platforms in producing significant change in the industry.

Lastly, the "Financial Support Mechanism" (S-C3) is considered the lowest viable solution in this study, with an FL value of 3.94. This indicates that respondents perceive financial support mechanisms as less effective or less prioritized than other solutions for implementing best practices in the circular economy within construction organizations.

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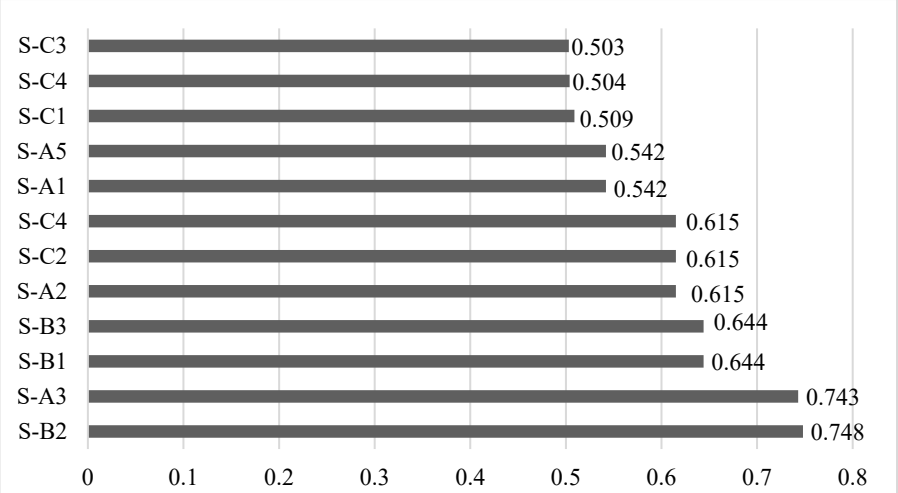


Figure 3: Solutions for Best Practices Circular Economy Implementation

CONCLUSION AND RECOMMENDATION

Malaysia's construction sector is at a pivotal juncture, requiring long-term strategies that reduce environmental impacts while improving resource efficiency. This paper sheds light on the state of circular economy (CE) practices in the industry, fulfilling key goals: identifying which CE approaches can be adapted to construction, examining barriers that organizations face when shifting from a linear to a circular model, and providing best-practice solutions for CE implementation.

A standout finding was that "Reversible and Disassembled Connection" emerged as the most promising CE practice, thanks to its emphasis on easily dismantling building components for reuse. In contrast to conventional linear methods—where materials are often thrown away—this approach preserves material value and conserves new resources by allowing parts to be reintroduced elsewhere. Yet the study also revealed that "Insufficient Comprehension and Insight" is the main hurdle to fully embracing CE. This underscores the need for robust awareness and training programs so that stakeholders can become more comfortable with CE techniques and justify their investment.

Looking ahead, "Establishment of Updated Guidelines: Deconstructing Structures and Reusing Materials" stands out as an essential recommendation for industry-wide best practices. By introducing clear standards and incentives—such as procurement procedures that integrate CE criteria, regulatory certifications, and shared best-practice initiatives—stakeholders will be better positioned to adopt circular approaches.

In conclusion, this paper recommends broadening the range of stakeholders involved, increasing educational outreach, and updating regulatory

frameworks to speed up CE acceptance in Malaysia's construction industry. Featuring real-world case studies of successful CE adoption could help address the current gaps in understanding. Additionally, integrating CE benchmarks into procurement and fostering active knowledge-sharing will create a more supportive environment for the adoption of circular practices.

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DISCLOSURE STATEMENT

The authors declare that there is **no conflict of interest** related to this research.

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ISSUES ON IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE (AI) IN INDONESIA CONSTRUCTION PROJECTS

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Abstract

Facing the acceleration of infrastructure development in the recent decade, the Indonesia Construction Industry keeps innovating by adopting technology. It is linear with the current development from Industry 4.0 to Society 5.0. The use of Artificial Intelligence (AI) to manage construction project works is a reflection of Society 5.0's requirements. This paper aims to discuss the supply and demand, awareness, commitment, policy, and also readiness level of human resources based on AI tools in construction projects. Several subfields of AI can be adopted, such as machine learning, knowledge-based systems, computer vision, robotics, natural language processing, automated planning and scheduling, and optimization. Machine learning is the most frequently used that can be applied to planning, construction, monitoring evaluation, and also operation maintenance. Aside from their benefits, AI subfields also have limitations in construction, such as machine learning from streaming data, dealing with high-dimensional data, scalability of models, and distributed computing. A critical review of the available literature is being compared with site surveys on construction projects related to AI applications such as activity monitoring, risk management, resource, and waste optimization. This study provides insights into key AI applications as they apply to construction-specific challenges, as well as the readiness to realize the benefit of AI in the construction industry. The goal of this research is to optimize issues in AI applications throughout the whole lifecycle of the actual complex project.

Keywords: Artificial Intelligence, AI applications, machine learning, construction industry, optimization

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INTRODUCTION

The transformation of construction projects from traditional to modern construction along with the use of information technology are the current trends. This is because effective and punctual analysis and tracking of labor activities is an important contribution to increasing productivity and safety on construction sites (Yang et al., 2019). Construction workers are facing high ergonomic risks that can harm their welfare and productivity. Therefore, it is important to assess ergonomic risks accurately. Observations, sensors, and depth cameras are the three main posture data collection methods, but they face the challenges of low accuracy, inconvenience, and unsuitability for outdoor environments (Yang et al., 2019). Research related to employee assessment by integrating technology and machine intelligence began 10 years ago, and several related studies (Antwi-Afari et al., 2020, 2022; T. Cheng et al., 2013a; Guo et al., 2017; Jebelli et al., 2018, 2019; Kurien et al., 2018; Luo et al., 2018a; Shakerian et al., 2021; Valero et al., 2017; X. Wang & Zhu, 2021) have been carried out.

Several studies related to employee assessment with the assistance of technology continue to develop. Generally, researchers try to utilize technology as a tool that makes it easier to monitor the performance of construction workers. Sensors, algorithms, and artificial intelligence are used to monitor worker activities throughout the day (Z. Yang et al., 2019a). In addition, the dynamic and complex work environment in construction projects means that workers' fatigue status tends to have a more serious impact on their performance compared to other sectors. A sustainable management of fatigue levels for construction workers is essential to improve safety management in projects (Xing et al., 2020).

Figure 1 showed an implementation of AI in the construction stage. Workers observation using sensor and camera to monitor worker’s behaviour to evaluate the site layouts. Job-site layout provisions are made to put temporary site offices, heavy equipment locations, storage and workshop areas, access points and safety areas (Small & Baqer, 2016). Since construction workers will perform manual labor and repetitive activities, an assessment of the ever-changing activities and movements of workers is needed to measure individual productivity as input to improve their performance on construction projects (Cho, 2020). A manual productivity data collection was carried out using daily reports from monitoring project achievements. Every day, the quantity surveyor (QS) will observe the time, cost, and progress of the work to be evaluated using the work plan that has been prepared. Using this manual method will take time and there is also a possibility of high human error factor from QS in the field.

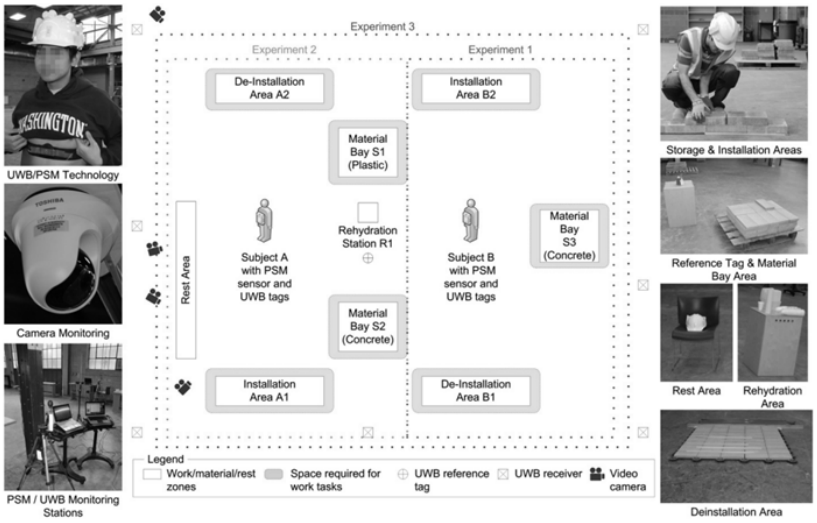


Figure 1: Examples of Worker Observations with the Use of Sensors and Use of Worker Behavior References
Source: (Wong, 2019)

Furthermore, algorithms for job classification can also be used to predict construction worker productivity. This assessment method utilizes a deep learning algorithm to classify time series data from worker inertia measurements (Jacobsen et al., 2023). However, the majority of construction workers' assessments with the help of information technology and machine intelligence lead to mitigation in reducing work accidents. Thus, the assessment of construction workers to increase productivity is rarely carried out. Several productivity assessments with the help of information technology and machine intelligence are carried out by assessing the activities of heavy equipment used on projects (Bai et al., 2021; Chen et al., 2020; Sabillon et al., 2020; D. Wang et al., 2022).

BACKGROUND PROBLEM

Based on the Government AI Readiness Index 2023, Indonesia is ranked 42nd out of 193 surveyed with a total score of 61,03 from 3 (three) evaluation dimensions, such as the government pillar, technology sector pillar, and data infrastructure pillar. This survey was developed based on government public sector performance. In the meantime, there has not been any evaluation regarding the performance of AI used at construction project sites in the construction sector. Several on site data showed that AI's implementation in the construction site start from planning until operation and maintenance. An example from the developed country, Virtual Reality (VR) has begun to be used to evaluate worker performance in construction projects. Documentation of worker movement shots

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at the project location was then assessed for ergonomic risks which later became the input in developing the project layout (Wong, 2019). This was done to increase work efficiency so that unnecessary repetition of movements and effective distances in the project layout could be optimized. The urgency of using automated technology to assess the performance of construction workers is high, considering that development is increasing massively. This study provides insights into key AI applications as they apply to construction-specific challenges, as well as the readiness to realize the benefit of AI in the construction industry. The extensive adoption of AI is experiencing a rapid digital transformation in the construction industry. The goal of this research is to optimize issues in AI applications throughout the whole lifecycle of the actual complex project. This research outcome contributes to opportunities, challenges, and threats to implementing AI in Indonesia's construction industry.

LITERATURE

Figure 2 showed manual productivity data collection is done using daily reports of project achievement monitoring results. Every day the quantity surveyor (QS) will observe the achievement of time, cost, and work progress to be evaluated later with the work plan that has been prepared. The use of this manual method will take time and there is also a high human error factor from the QS in the field. The transformation of construction projects from traditional to intelligent construction and the use of information technology is a current trend. This is done because effective and timely analysis and tracking of labor activities is an important contribution to improving productivity and safety on construction sites (Yang et al., 2019).

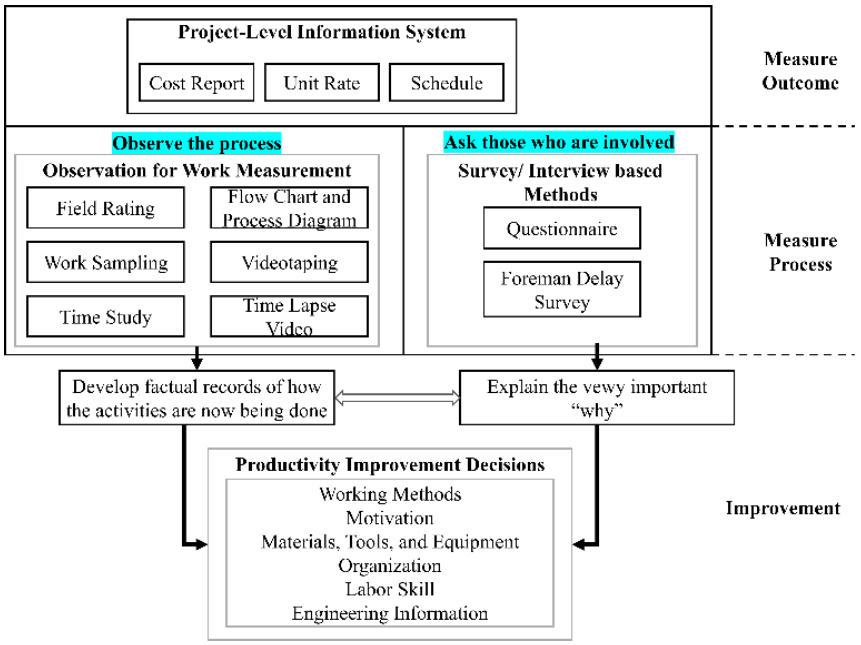


Figure 2 Traditional Productivity Data Collection Methods
Source: (de Araújo et al., 2021)

Studies on automatic models for recognizing construction worker movements were conducted using the Long Short-Term Memory (LSTM) network designed to learn sequential information. The LSTM network can recognize worker movements from motion sensor data by measuring the inherent inertia of each worker (Kinam Kim1 and Yong K. Cho, 2021). Observing worker movements via Internet of Things (IoT)-based cameras is often linked to the need for Occupational Safety and Health management to be able to control worker ergonomics. The use of Smart Work Packaging (SWP) in construction HSE applications is usually carried out to monitor construction worker fatigue factors, which then create safety warnings (Li et al., 2021). In addition, the work safety monitoring model was also carried out by predicting the level of severity based on images and video clips determined through visual data of workers' body posture, use of personal protective equipment, workers' interactions with tools and materials, construction activities being carried out, and the presence of dangers in the surrounding workplace (Tang & Golparvar-Fard, 2021).

Construction labor requires heavy work which easily makes workers exhausted (Jiang et al., 2015). When they are exhausted, workers' ability to do physical work tends to decrease, along with their awareness of safety, which can trigger dangerous behavior that might lead to accidents. Therefore, fatigue is considered a negative factor in Occupational Safety and Health as one of the main causes of behavior in construction workers (Anwer et al., 2021). In the

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construction industry, the lack of a comprehensive framework, standards, and independent task types to produce serial productivity estimation models is a challenge. The proposed model cannot be replicated for all types of projects and it requires time and effort to adapt to new project conditions (Sadatnya et al., 2023). When studied comprehensively, the successful prediction of models used in labor productivity must be supported by algorithmic learning from previous relevant research about the use of ML in construction project case studies (Adebowale & Agumba, 2021). The key success to use machine learning is the algorithms. Research from Ja'far, et.al (2021) identified the most selected algorithm used for cost prediction is Random Forest (RS) that has less error that others. Because the accurate cost estimation is a critical aspect of successful construction projects (Salleh, 2023).

Artificial intelligence, often called AI, is revolutionizing the manufacturing, retail, telecommunications, and construction industries. The construction industry faces many challenges which cause its productivity levels to be lower when compared to manufacturing (Abioye et al., 2021). The lack of digitalization and technology adoption in the construction industry is also associated with cost inefficiencies, project delays, poor quality performance, uninformed decision-making, and low productivity and work safety. AI is a significantly beneficial tool. With the help of algorithms, AI can help solve construction life cycle problems like showed in the Figure 3 (Oluleye et al., 2023). Recognition of various activities can used CCTV to monitor the worker productivity in the construction site.

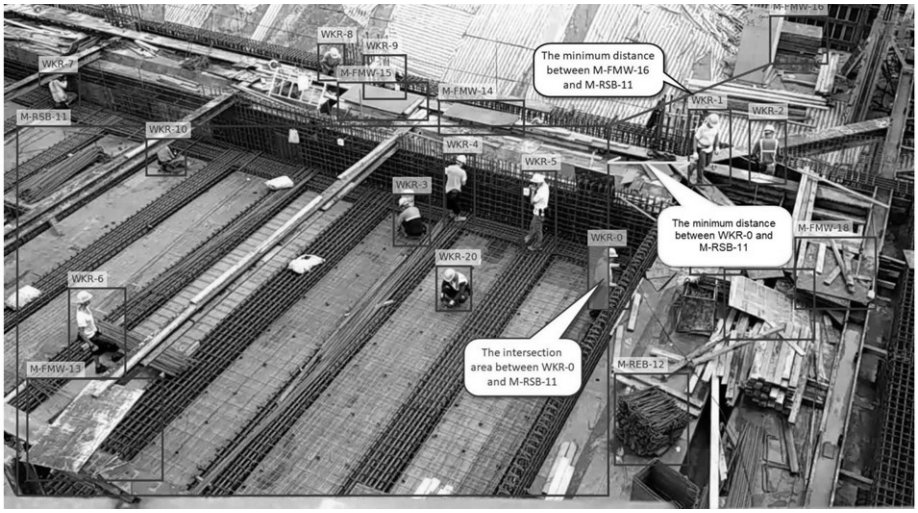


Figure 3: Recognition of Various Activities in Construction Projects via Object Relevance Networks Using Convolutional Neural Networks
Source: (Luo et al., 2018)

In the context of Industry 4.0, the construction industry continues to innovate towards digitalization and intelligence to realize major improvements in automation, productivity, and reliability (Zhang et al., 2021). The emergence of AI will certainly have implications for social, ethical, policy, legal, and even human resources. Apart from the need for digitalization to speed up construction work, it was revealed that the use of AI also poses a risk to the transition from using manual workers to technology. Even in developed countries, the risk of automation in reducing manual workers reaches 51-52% (Nazareno & Schiff, 2021).

RESEARCH METHODOLOGY

This research used a questionnaire to evaluate the construction project readiness levels. The variable was constructed based on the pillars of the government AI Readiness Index and the Construction Industry 4.0 Readiness Index (CI4.ORI). There are three pillars related to the government AI Readiness Index, namely the technology sector, data, and infrastructure. Meanwhile, in CI4.ORI, there are five pillars used to assess the level of readiness to implement Industry 4.0 in the construction industry, which are management and organization, human resources and culture, products and services, technology, and onsite and offsite operations. Both the Government AI Readiness Index and Construction Industry Readiness Index 4.0 (CI4.0RI) determined the research variables. Subsequently, those pillars were combined with an updated implementation in the construction project. The detailed variable is shown in Table 3 along with the research results.

Each of the indicators was evaluated using four scale levels related to the readiness level. Research data was collected through an online questionnaire using Google Forms. The pilot survey was designed before the distribution of the main questionnaire. The respondents were contractors, consultants, and stakeholders related to the construction industry. In total, 75 samples contributed to this research. The respondent has at least 5 (five) years of working experience in the construction industry. The basic questions of this questionnaire asked about the company's level of readiness in implementing AI, which included 43 questions using a level scale from 0 to 4, which ranges from whether they are ready or not to whether it has been implemented already.

The result of the evaluation phase was later verified using the Spider Web Method. The Spider Web method was developed by Bernstein in 1986 as a qualitative technique in the field of management to produce decision-making. In general, spider web methods tend to adopt a four-stage process:

1) Problem recognition;
2) Strategy development;
3) Execution of action plans; and
4) Implementation.

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The Spider Web diagram was used to map the results of the readiness level of construction industry players based on the average value of each pillar. Based on the average value, the results of the overall readiness level of each pillar were divided into five categories, with level 0 indicating unreadiness and level 4 indicating complete implementation. Those five pillars were broken down into indicators and sub-indicators (see Table 1).

Table 1: Level Scale

Index	Level	Description	
0,0 < Mean ≤ 0,8	Level 0	Not Ready	Not supported yet
0,8 < Mean ≤ 1,6	Level 1	Early Readiness	Have a plan to transform to Industry 4.0
1,6 < Mean ≤ 2,4	Level 2	Medium Readiness	Start transforming to Industry 4.0
2,4 < Mean ≤ 3,2	Level 3	Ready	Transformed to Industry 4.0
3,2 < Mean ≤ 4,0	Level 4	Already Applied	Already implemented all Industry 4.0

RESULTS AND DISCUSSION

Society 5.0 requires three main abilities such as creativity, critical thinking, communication, and collaboration (Yulianto, 2021). The adoption of Society 5.0 has several rules in the construction industry:

1) Creativity in the construction industry is actualized through various innovations in project implementation such as methods, equipment, and increased productivity.
2) The use of intelligent technology with the concept of Machine Learning and Deep Learning in the implementation of the project continues to develop as a reflection of critical thinking in the construction industry.
3) Using Building Information Modelling as a tool for communication and collaboration between project parties is one of the steps of readiness level construction industry for Society 5.0.

The literature review showed that there are 4 (four) types of AI used in the construction industry, such as machine learning, Building Information Modelling (BIM), computer applications, and statistics. Machine learning is frequently used to detect and classify human activities using wearable inertial measurement units (IMUs). An algorithm is needed to determine the object and it can also be used for direct assessment tools. As for BIM, it is frequently used for drawing and calculating construction objects and it needs software to translate into industry foundation classes (IFC) format. Recently, BIM has been used to assess cost and time in construction projects. While machine learning started to be used as an assessment tool at the beginning of 2018 to identify activity recognition that connects to productivity analysis, BIM was used in advance of machine learning but it focused more on drawing and estimating. Based on the recent condition of a construction project, manual assessment is not

recommended because it cannot show the comprehensive and tracking results of the worker's assessment.

The construction industry in most countries accounts for the highest share of employment. Indonesia, as a developing country, has approximately 203,403 construction companies, from small to large scale. Data for 2020 states that the number of construction workers in Indonesia reached 1,133,290 people (BPS, 2021). The average growth trend in the construction sector workforce is 2.38%, so it is projected that in 2023, the construction sector can absorb 8,769,798 workers. The large number of workers and high labor wages cause labor costs in construction projects to be large. Additionally, project delays due to lost labor productivity can result in additional costs. Therefore, human resource management is necessary to increase worker productivity in construction projects (Gurmu & Ongkowijoyo, 2020). Based on (Risnu et al., 2016), two stages in construction projects have been carried out with the assistance of AI, namely the planning and execution stages.

Table 2: AI Implementation in Construction Projects.

Planning Phase	AI Implementation	Execution Phase	AI Implementation
Design Planning	PMCS Tools: Cost Estimating	Quality Control	CAE: Structural Modeling
	Billing & Payment System Tools	Progress Monitoring	PMCS Tools: Scheduling
Engineering Design	PMCS Tools: Cost Estimating		
	Billing & Payment System Tools		
Risk Planning	PMCS Tools: Cost Estimating		
	Billing & Payment System Tools		

Several AI implementations have been performed in construction projects. Survey technology that implements AI is often found in construction projects. Generally, AI is implemented to speed up surveys, especially for hard-to-reach project locations. Based on the results of the questionnaire evaluation, it was found that the technology infrastructure variable is in the first place with a value of 3.301. This shows that the technology infrastructure has been implemented comprehensively in construction projects. The human resource development variable, the level of BIM implementation, and the AI implementation policy came after technology infrastructure, respectively. It was revealed that these variables were ready but had not been implemented comprehensively. The last variable, the AI implementation policy, was carried out through the construction and post-construction stages, which were categorized as the planning stage of transformation in the construction industry.

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This is a common concern because the evaluation results revealed that the policy and preparation of technology infrastructure have led to the implementation of AI in the construction industry but have not been able to be fully applied yet in construction projects.

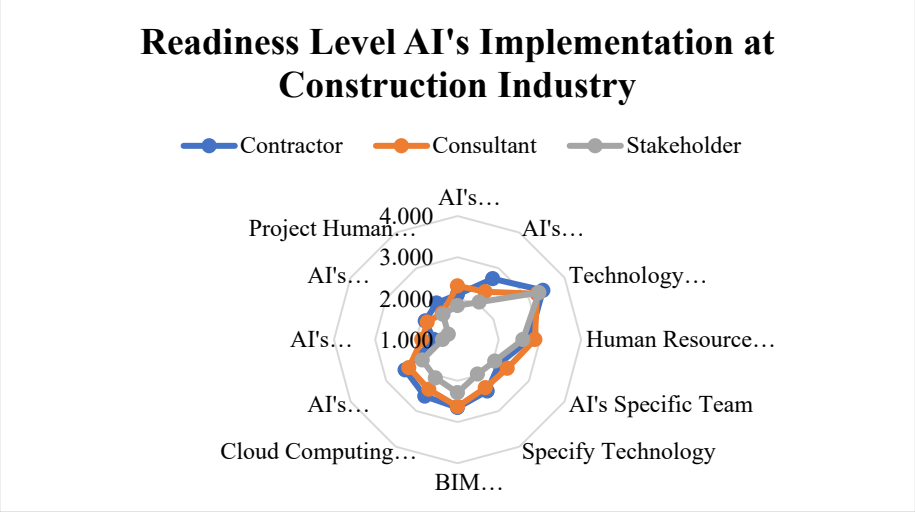


Figure 4: Readiness Level of AI's Implementation at Construction Industry

One of the obstacles faced by construction projects is the ability of the human resources in the project. This can be seen from the results of the questionnaire evaluation, which showed a value of 1.824. The human resource development policy has been implemented to help improve the skills of construction workers through training and certification, although this has not been done comprehensively. The implementation of AI in construction projects is still carried out at the pre-construction stage, where AI is used for survey, investigation, design, and prediction activities. Meanwhile, the party that is more advanced in implementing AI is the contractor with an average value of 2.396, while the consultant is 2.361. Referring to the evaluation of the Spider Web method, both contractors and consultants are still in the medium readiness stage, which is still in the early stage of implementing AI on construction projects. The detailed result is shown in Table 3.

Table 3: Indicator Variable for AI's Implementation in the Construction Project

Code	Dimension	Indicator	Result
A1	**Government Policy Pillars**		2.092
A2.1	AI's Implementation Vision	Availability of strategic plan documents	2.342
A2.2	AI's Implementation Policy	Data security protection policy	2.461
A2.3		Data storage procurement policy	2.461

Code	Dimension	Indicator	Result
A2.4		Data formatting input quality policy	2.421
A2.5		Data outline policy	2.526
A2.6		Data accountability policy	2.026
A3.1		Specific budgeting policy for AI implementation	3.145
A.3.2	Technology Infrastructure	Hardware (Computer, VR, Laser Scan, Drone, etc.)	**3.289**
A3.2		Software (BIM Software, CAD, Project Management Software, Coding Software)	**3.303**
A.3.3		Cloud Computing	**3.539**
A.4.1		Connectivity (WiFi, Router, LAN)	2.789
A.4.2	Human Resources Competency Improvement	Digital training (BIM, AI, Machine Learning)	2.737
A.5.1		Certification (Drone Pilot, BIM, Data Analyst)	2.250
A.5.2	AI Specific Team	Ethics Team (Data privacy, Data security)	2.211
B.1.1		Development Team (UI/UX Designer, Product Manager)	2.605
B.1.2	**Construction Project Pillars**		
B.1.3	Specific Technology	BIM (3D, 4D, 5D, 6D)	2.474
B.1.4		Internet Of Things (IoT)	1.684
B.2.1		Cloud Computing	2.579
B.2.2		Artificial Intelligence (AI) & Machine Learning (ML)	2.618
B.2.3	BIM Implementation Level	Pre-Construction Phase (Planning and Design)	2.421
B.3.1		Construction Implementation Phase	2.461
B.3.2		Post Construction Phase (Evaluation and Monitoring)	2.276
B.3.3	Cloud Computing Collaboration	Data storage	2.368
B.4.1		Data analysis	1.987
B.4.2		Collaboration between teams	2.737
B.4.3	Pre-Construction Phase AI Implementation	Tenders and contracts	2.447
B.4.4		Use of drones for field surveys	2.224
B.4.5		Use of lidar for field surveys	2.342
B.4.6		Project delay prediction	2.171
B.4.7		Project cost estimation	2.171
B.5.1		Material procurement	**1.526**
B.5.2		Risk management	1.658
B.5.3	AI Implementation Construction Phase	Utilization of AI for monitoring PPE discipline	**1.566**
B.5.4		Use of sensors in projects	1.684
B.5.5		Utilizing AI for construction worker productivity monitoring	**1.592**
B.5.6		Leveraging AI for heavy equipment monitoring	1.803

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Code	Dimension	Indicator	Result
B.5.7		Utilizing AI for construction material monitoring	1.711
B.6.1		Utilizing AI for field condition monitoring	1.605
B.6.2		Utilizing AI to Accelerate Work	1.829
B.6.3	Implementation of AI in the Post-Construction Stage	Utilizing AI for cross-checking work handovers	1.711
B.7.1		Utilization of AI for building energy sensors (lights, AC, water flow)	1.895
B.7.2		Leveraging AI for maintenance	1.763
A1	Project HR Capability	Data Analyst Expertise Certification	2.461
A2.1		Coding and Algorithm Skills	2.461

Source: Research Result, 2024

One of the biggest challenges in implementing AI in construction projects is budget. The use of cutting-edge technology is inseparable from the increase in budget in its implementation. Implementing AI requires quite a large initial funding. However, if it can be implemented, AI will be a catalyst for every job in the construction project. This hinders the implementation of AI in construction projects, especially if it is applied in medium-scale projects. Medium-scale projects can be risky, which is why contractors and consultants must think twice if they want to add an AI implementation budget to their projects. Contractors will prefer to use manual methods rather than automating their projects. In addition, human resource capability in applying AI is still limited. Not many of them in construction projects can process coding algorithms or perform data analysis processing because this field is not the main focus of civil engineering. As a consequence, civil engineers will need to relearn programming languages or coding to be able to implement AI in construction projects. The research outcome also can used by government to plan the construction industry vision for 2025-2030 that can improve the lowest indicator to be a mature AI's implementation in Indonesia.

CONCLUSION

The results of this study revealed that the implementation of AI in construction projects in Indonesia is still in the medium readiness stage. This is reflected in the readiness of parties involved in construction projects, such as contractors, consultants, and stakeholders in the field of public works, who are still in the process of preparing for the implementation of AI into construction projects. The technological infrastructures used in construction projects are quite up-to-date, including hardware, software, cloud computing, and connectivity, but the human resources that support them are still insufficient. In addition, government policies to improve the implementation of AI have been reflected in the policies that have been prepared along with the skills improvement programs provided. However,

internal project funding has not been able to improve the ability to process data automatically in construction projects. Automation of construction work is still limited to large-scale infrastructure projects and national strategic projects. The limitations of the civil engineering field in studying algorithmic materials and programming languages are also an obstacle to the unpreparedness of the application of AI in construction projects. This study only focused on evaluation of AI's implementation in Indonesia with government policy and construction site pillars, the future research can be enhanced to discuss related to human resource readiness level for understand AI's implementation in construction. Comparing the development country for evaluation also another opportunity for the future research.

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LIVELIHOOD RESILIENCE OF MICRO, SMALL, AND MEDIUM ENTERPRISE (MSME)-BASED URBAN KAMPONGS DURING THE COVID-19: A CASE STUDY OF SEMARANG, INDONESIA

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Abstract

While social restriction policies effectively curbed the spread of COVID-19, they disruptedthe livelihoods of Micro, Small, and Medium Enterprises (MSMEs) in Semarang's urban kampongs, underscoring the critical role of resilience in sustaining these communities. This study examines the livelihood resilience of MSME-based urban kampongs affected by the pandemic using the Livelihood Resilience Index (LRI). Surveys were conducted with 100 MSME actors across three urban kampong clusters. The results reveal a moderate average LRI score (0.41–0.60), indicating adequate but not robust levels of resilience. Nevertheless, substantial improvements are required to strengthen the clusters' adaptive and transformative capacities to enable recovery, build resilience, and exceed pre-crisis conditions. These findings highlight the need for targeted interventions to reinforce the long-term resilience of MSME-based urban kampongs against future shocks.

Keywords: Covid-19; Urban Kampong's; Livelihood Resilience; MSME, Semarang

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INTRODUCTION

The COVID-19 pandemic has caused unprecedented global disruption. Within a short period, the virus spread rapidly, resulting in over 6 million deaths worldwide (Okezone Health, 2022; WHO, 2022). Urban areas were disproportionately affected, accounting for approximately 95% of COVID-19 cases and impacting more than 1,500 cities globally (Acuto et al., 2020). To control the spread, governments worldwide implemented two primary measures: vaccination programs and lockdown or social restriction policies. However, these measures have had adverse effects on Micro, Small, and Medium Enterprises (MSMEs) across many countries. For example, in Malaysia, informal workers comprise over three-quarters of the service sector workforce, making this sector particularly vulnerable to pandemic-induced economic disruptions (Lm et al., 2024). In Indonesia, MSMEs numbered 67 million units in 2020 and contributed 60.5% to the national GDP by 2021 (Syamsudin, 2020). Many of these enterprises operate within urban kampongs, underscoring their critical role in urban economies and livelihoods.

Geographically, urban kampongs are predominantly located near sources of livelihood, giving rise to the specific forms of employment, most of which are informal (Obermayr, 2017b). This explains why urban kampongs host many MSMEs and function as key drivers of community livelihoods. In Semarang, one of Indonesia's metropolitan areas, MSMEs are highly concentrated in three urban kampong clusters: central, eastern, and southern Semarang (Sundaro et al., 2024). However, the pandemic has raised serious concerns about the sustainability of these settlements, where residents' livelihoods depend heavily on MSME activities. Many enterprises were forced to close, leaving their operators— particularly those in urban kampongs—in a state of social and economic uncertainty. Urban kampongs, defined as unplanned and densely populated settlements typically located in the city centers (Obermayr, 2017b), evolve organically over time through both physical and non-physical processes. They are characterized by high building density, inadequate infrastructure, limited land availability, and strong social and kinship interactions (Anindito et al., 2019; Sundaro et al., 2024).

Despite their vital role in the urban economies, urban kampongs remain socially and economically vulnerable (Lindarni et al., 2014). Their sustainabilty is thus closely tied to the resilience of community livelihoods in the face of diverse shocks, including the COVID-19 pandemic. Livelihood assets—such as social, human, physical, financial, and natural capital—are widely recognized as key components that strengthen community resilience (DFID, 1999). Considering the likelihood of emerging urban threats in various forms, examining livelihood resilience in urban kampongs during the COVID-19 pandemic is essential.

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Previous studies on livelihood resilience—such as those by Galarza-Villamar et al. (2024), Hossain et al. (2020), Insani et al. (2022), Sahoo & Sivaramakrishnan (2024), and Weldegebriel & Amphune (2017)—have primarily focused on the impacts of climate change on farmers, fishers, communities, or other vulnerable groups. By contrast, research on livelihood resilience outside the context of climate change, such as in outbreaks or pandemics (e.g., COVID-19), remain limited. This study seeks to address this gap by assessing the livelihood resilience of urban kampongs during the COVID-19 pandemic. In doing so, it broadens the resilience discourse, which has been dominated by climate change studies, by highlighting COVID-19 as a new urban threat to community livelihoods, particularly MSME actors in urban kampongs.

LITERATURE REVIEW

Over the past decade, the concept of resilience has evolved significantly in both literature and policy (Meerow et al., 2016). In urban studies, diverse frameworks for urban resilience have been developed to address contemporary urban challenges (ARUP et al., 2014). Resilience is used to evaluate a system's capacity to absorb, adapt to, and transform in response to external shocks and pressures (Walker et al., 2004). This principle applies to both local communities and their surrounding ecosystems (Folke, 2006). Urban kampongs—a common type of local community in Indonesian cities—are characterized by narrow road access (micro-mobility) and limited public spaces (Anindito et al., 2019). From a non-physical perspective, urban kampongs are dense settlements marked by heterogeneous populations, high levels of social interaction, and a strong sense of kinship (Anindito et al., 2018).

Kampongs remain a preferred choice for affordable housing, particularly among low-income groups, including those working in the informal sector or MSMEs earning below the Regional Minimum Wage (UMK) (Violita & Yuliastuti, 2020). They are a typical feature of Indonesian cities and are expected to remain a dominant part of the country’s urban landscape (Putra et al., 2019). According to Law Number 20 of 2008 on MSMEs, the Indonesian government classifies businesses based on asset and revenue criteria, focusing on operational performance. The development of MSMEs in Indonesia has been rapid, particularly in urban kampongs. However, the COVID-19 pandemic significantly impacted this sector. Caused by the SARS-CoV-2 virus, COVID-19 spreads through airborne transmission and direct contact. It was first detected in Wuhan, China, in December 2019, and the first confirmed case in Indonesia was reported on March 2, 2020. Following this, the government issued Government Regulation Number 21 of 2020, which introduced large-scale social restrictions and community activity restrictions, which significantly affected businesses and residents in urban kampongs that rely on MSMEs.

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Livelihood resilience is essential not only for physical survival but also for long-term well-being in the face of uncertainty. The concept of livelihood was first introduced by Robert Chambers in 1991, who developed the Sustainable Livelihoods Framework (SLF) to assess the sustainability of community livelihoods (Chambers, 1991). Livelihood resilience refers to the capacity of individuals, households, or communities to cope with, adapt to, and recover from shocks and stresses that affect their livelihoods, while maintaining or even improving their well-being (Chambers, 1991; DFID, 1999). In urban kampongs, livelihood assets—such as human capital, physical capital, social capital, and financial capital—are used as variables to assess livelihood resilience. These assessments are conducted using the Livelihood Resilience Index (LRI) and resilience radar developed by DFID (1999) and Bolte et. al (2017).

RESEARCH METHOD

Study Area

The selection of Semarang as the research location is based on several key factors. First, Semarang has a rich historical background dating back to the colonial era, with urban kampongs playing a vital role in preserving local traditions and culture—elements that are integral to the city's development. Second, as a major center for trade and services, Semarang is one of Indonesia's cities with relatively strong economic growth and is home to numerous MSMEs that contribute significantly to the city's economic dynamics. Third, Semarang is among the citiees most economically affected by the COVID-19 pandemic, raising concerns about the sustainability of urban kampongs, particularly those where most residents are employed in the MSME sector. This research build on previous studies conducted by Sundaro et., al (2024), which examined three clusters encompasing 16 urban kampong areas: Cluster 1 in Central Semarang, Cluster 2 in East Semarang and Gayamsari, and Cluster 3 in South Semarang (Figure 1).

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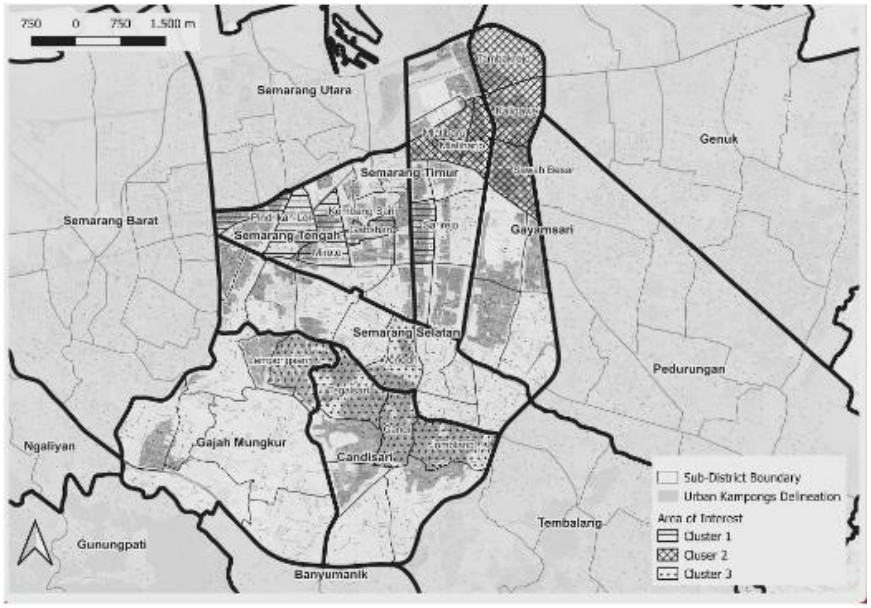


Figure 1. Study area of three clusters of urban kampongs

Data and Method

The data for this study consists of both secondary and primary sources. The secondary data include information from 925 MSMEs obtained from the Semarang City Bappeda in 2024. Primary data were collected through questionnaires on livelihood assets, administered before, during, and after the COVID-19 pandemic. The questionnaires were distributed in September 2024. The respondents for this study included 100 MSME actors from three clusters, with the sample size calculated using the Slovin formula: $n = \frac{N}{1+N\ (e)^2}$

This study employs the LRI framework developed by DFID (1999). The assessment is based on questionnaire data comprising 60 items across four variables and 17 indicators (Table 1). These questionnaire design draws on indicators adapted from DFID (1999) and Weldegebriel & Amphune (2017).

Table 1. Variables and indicators of Livelihood Resilience Index

Variable	Indicator	Category
Human Capital	Business Motivation	Levels of motivation and commitment in operating businesses before, during, and after the COVID-19 pandemic
	Workforce	Ease of access to labor before, during, and after the COVID-19 pandemic
	Knowledge	Level of understanding regarding business-related activities before, during, and after the COVID-19 pandemic
	Skills	Skill level in managing a business before, during, and after the COVID-19 pandemic

Variable	Indicator	Category
	Education	Formal and/or informal educational attainment before, during, and after the COVID-19 pandemic
	Health	Health status before, during, and after the COVID-19 pandemic
Physical Capital	Business Location	Business premises, location, and facilities before, during, and after the COVID-19 pandemic
	Production Tools	Production tools in terms of quantity and quality before, during, and after the COVID-19 pandemic
	Market Access	Ease of market access before, during, and after the COVID-19 pandemic
Social Capital	Business Networks	Business network reach before, during, and after the COVID-19 pandemic
	Trust	Trust among residents before, during, and after the COVID-19 pandemic
	Cooperation	Level of cooperation among residents in community activities, characterized by meeting frequencies ranging from more than once per month to less than once every three months before, during, and after the COVID-19 pandemic
Financial Capital	Financial Access	Ease of financial access before, during, and after the COVID-19 pandemic
	Annual Turnover	Annual turnover ranging from less than 60 million/year to over 181 million/year before, during, and after the COVID-19 pandemic
	Daily Income	Daily income ranging from less than Rp 165,000/day to over Rp 660,000/day before, during, and after the COVID-19 pandemic
	Monthly Expenditures	Household expenditures ranging from less than Rp 2 million/month to over Rp 7 million/month before, during, and after the COVID-19 pandemic.
	Savings	Savings ranging from less than Rp 500,000/month and irregular to over Rp 1 million/month and regular before, during, and after the COVID-19 pandemic

A Likert scale was applied to assign numerical values to the 17 indicators representing all variables under study. Scores ranged from 1 (minimum) to 4 (maximum). The resulting data were used to analyze the LRI and to construct the resilience radar framework introduced by DFID (1999) and Bolte et.,al (2017). The analytical process is outlined as follows:

1. Calculating the Variable Index

$$M_h = \frac{the \sum_{i=1}^{n} \ Indeks}{n} \quad \text{.....(i)}$$

M_h is one of the four variables used to evaluate the Livelihood Resilience Index. The index Shi represents the indicators indexed by i that form each variable, where n is the number of indicators in each variable.

2. Calculating the Livelihood Resilience Index

$$LRI = \frac{the \sum_{i=1}^{n=4} \ Mhi}{n} \quad \text{.....(ii)}$$

LRI is the average resilience index of the four variables. Mhi represents the index value of each variable, and n is the number of variables.

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3. Interpreting the Index Value

After the LRI is determined, the next step is to interpret the index value by grouping it to understand the level of resilience, as shown in Table 2.

Table 2. Interpretation of the Livelihood Resilience Index (LRI)

Index Value	Resilience Level
0.81 – 1.00	Very High
0.61 – 0.80	High
0.41 – 0.60	Moderate
0.21 – 0.40	Low
0.00 – 0.20	Very Low

Source: Bolte et al. (2017)

RESULT

Livelihood Resilience Index for Cluster 1 (Central Semarang)

In Cluster 1, social capital emerges as the strongest livelihood asset both before, during, and after the COVID-19 pandemic, as indicated by the resilience radar (Figure 2). This strength is underpinned by high level of trust and cooperation among the residents of the urban kampong, although the business networks remain relatively moderate. The frequency of community meetings—held more than once a month for social and religious activities—demonstrates strong participation and collaboration. Notably, the trust among residents, which had declined during the pandemic, has shown substantial improvement.

Financial capital is the weakest livelihood asset in Cluster 1, with all related indicators calssified as low. During the COVID-19 pandemic, financial capital declined further and was categorized as very low. In contrast, physical and human capital were both classified as moderate. Post-pandemic, the human capital index has improved slightly, particularly in indicators such as work motivation and knowledge, although the increase is not statistically significant (Table 3).

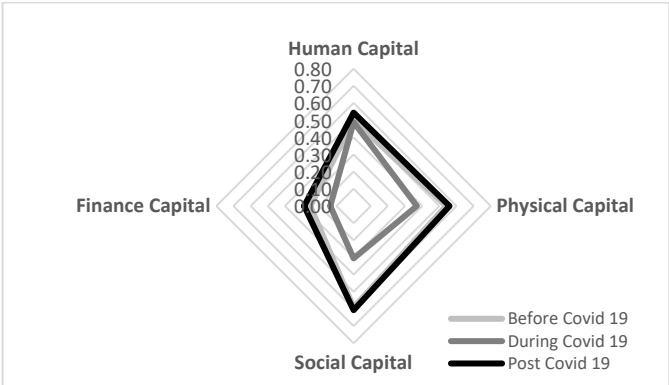


Figure 2. Cluster 1 Resilience Radar

Table 3. Livelihood Resilience Index for Cluster 1

Variable	Indicator	Livelihood Resilience Index		
		Before Covid 19	During Covid 19	Post Covid 19
Human Capital	Motivation to work	0.61	0.54	0.69
	Availability of workforce	0.43	0.25	0.40
	Knowledge	0.37	0.48	0.49
	Skills	0.55	0.46	0.52
	Education	0.39	0.39	0.39
	Health	0.65	0.81	0.76
	Average	0.50	0.49	0.54
	Category	Moderate	Moderate	Moderate
Physical Capital	Place of Business	0.49	0.38	0.52
	Production Tools	0.55	0.42	0.60
	Market access	0.58	0.31	0.56
	Average	0.54	0.37	0.56
	Category	Moderate	Low	Moderate
Social Capital	Business network	0.46	0.33	0.52
	Trust	0.63	0.50	0.64
	Cooperation	0.68	0.08	0.65
	Average	0.59	0.31	0.61
	Category	Moderate	Low	High
Finance Capital	Financial access	0.39	0.27	0.49
	Annual turnover	0.11	0.02	0.14
	Income / day	0.26	0.05	0.29
	Expenses / month	0.12	0.11	0.15
	Savings	0.38	0.23	0.37
	Average	0.25	0.14	0.29
	Category	Low	Very Low	Low

Livelihood Resilience Index for Cluster 2 (East Semarang and Gayamsari)

The average resilience index for Cluster 2 is 0.41, placing it in the moderate resilience category. However, this score lies at the lower threshold category, suggesting that Cluster 2 is at risk of falling into the low resilience range (0.21-0.40). Financial capital is the weakest livelihood asset in Cluster 2 after COVID-19 (Figure 3), with this index remaining in the low category from pre- to post-pandemic (Table 4). In contrast, social capital is the strongest asset, although its index declined slightly from 0.61 (high) before the pandemic to 0.59 (moderate) afterward. Indicators of physical capital—such as business premises, production tools, and market access—also decreased compared to pre-pandemic levels. Meanwhile, the human capital index has recovered to the moderate category, returning to its pre-pandemic condition.

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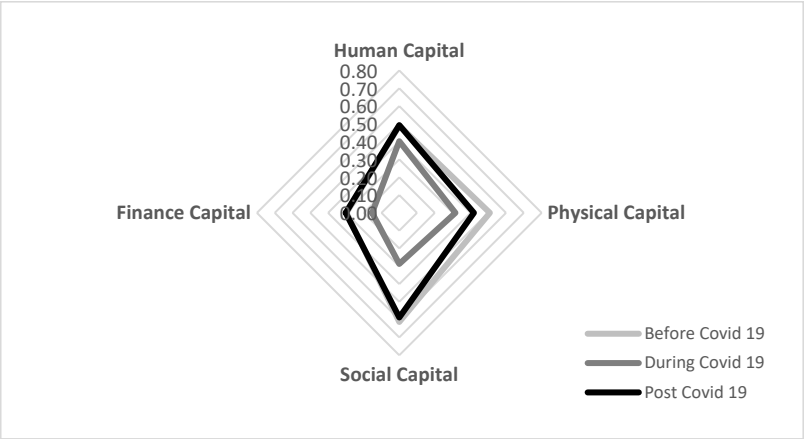


Figure 3. Cluster 2 Resilience Radar

Table 4. Livelihood Resilience Index for Cluster 2

Variabel	Indicator	Livelihood Resilience Index		
		Before Covid 19	During Covid 19	Post Covid 19
Human Capital	Motivation to Work	0.71	0.51	0.70
	Availability of Workforce	0.41	0.18	0.35
	Knowledge	0.27	0.34	0.42
	Skills	0.45	0.20	0.33
	Education	0.37	0.37	0.37
	Health	0.73	0.82	0.78
	Average	0.49	0.40	0.49
	Category	Moderate	Low	Moderate
Physical Capital	Place of Business	0.51	0.37	0.34
	Production Tools	0.53	0.37	0.45
	Market Access	0.49	0.22	0.46
	Average	0.51	0.32	0.42
	Category	Moderate	Low	Moderate
Social Capital	Business Network	0.41	0.22	0.35
	Trust	0.65	0.48	0.59
	Cooperation	0.78	0.16	0.82
	Average	0.61	0.29	0.59
	Category	High	Low	Moderate
Finance Capital	Financial Access	0.44	0.22	0.43
	Annual Turnover	0.20	0.05	0.19
	Income / day	0.22	0.08	0.24
	Expenses / month	0.22	0.15	0.29
	Savings	0.41	0.27	0.35
	Average	0.30	0.15	0.30
	Category	Low	Very Low	Low

Livelihood Resilience Index for Cluster 3 (South Semarang)

The average resilience index for Cluster 3 is 0.43, placing it in the moderate resilience category. Similar to Clusters 1 and 2, social capital is the strongest livelihood asset, whereas financial capital is the weakest. All physical capital indicators declined slightly, with the average index decreasing by 0.02 compared

with pre-pandemic levels, although theey remain within the moderate category. Human capital improved by 0.05 relative to its pre-pandemic score but continues to fall within the moderate resilience category (Table 5).

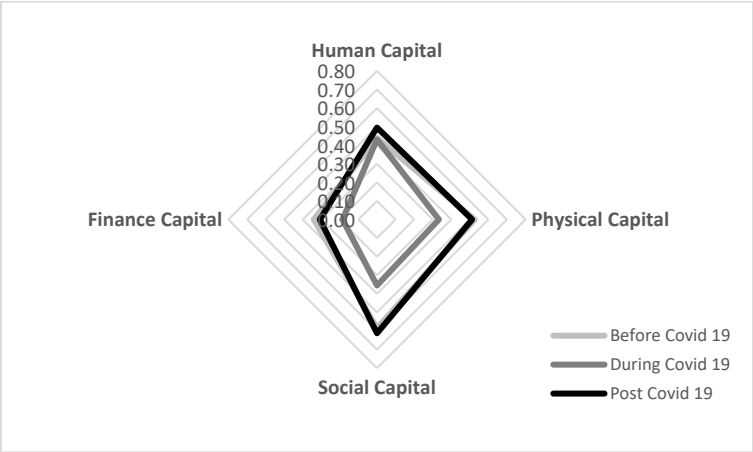


Figure 4. Cluster 3 Resilience Radar

Table 5. Livelihood Resilience Index for Cluster 3

Variabel	Indicator	Livelihood Resilience Index		
		Before Covid 19	During Covid 19	Post Covid 19
Human Capital	Motivation to Work	0.66	0.50	0.68
	Availability of Workforce	0.33	0.24	0.32
	Knowledge	0.24	0.40	0.49
	Skills	0.48	0.29	0.47
	Education	0.33	0.34	0.34
	Health	0.59	0.81	0.67
	Average	0.44	0.43	0.49
	Category	Moderate	Moderate	Moderate
Physical Capital	Place of Business	0.54	0.37	0.51
	Production Tools	0.53	0.35	0.52
	Market Access	0.51	0.28	0.50
	Average	0.53	0.33	0.51
	Category	Moderate	Low	Moderate
Social Capital	Business Network	0.44	0.29	0.44
	Trust	0.66	0.63	0.68
	Cooperation	0.66	0.14	0.72
	Average	0.59	0.36	0.61
	Category	Moderate	Low	High
Finance Capital	Financial Access	0.45	0.28	0.42
	Annual Turnover	0.16	0.04	0.15
	Income / day	0.44	0.15	0.37
	Expenses / month	0.20	0.16	0.20
	Savings	0.45	0.30	0.39
	Average	0.34	0.19	0.31
	Category	Low	Very Low	Low

Source: Author's Calculation, 2024

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Comparison of Livelihood Resilience Index (LRI) Across Clusters

The analysis results indicate that the average resilience index values across clusters are relatively low. As shown in Table 6, the average resilience index for all clusters falls within the moderate category but lies close to its lower threshold. This suggest that, although each cluster demonstrates a moderate level of resilience, their resilience foundations remain weak, leaving them vulnerable to external shocks and pressures.

Table 6. Comparison of Average LRI Across Clusters

Lokasi	Before Covid 19	During Covid 19	Post Covid 19	Average	Category
Cluster 1	0.47	0.32	0.50	0.43	Moderate
Cluster 2	0.48	0.29	0.45	0.41	Moderate
Cluster 3	0.47	0.33	0.48	0.43	Moderate

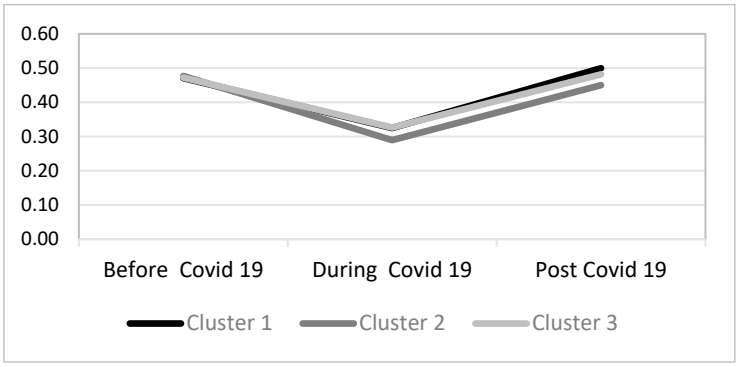


Figure 5. The Resilience of MSMES-Based Urban Kampongs In Response to COVID- 19

Figure 5 illustrates that during the COVID-19 pandemic, all clusters experienced a marked decline in resilience indices, falling into the low resilience category. In the post-pandemic period, Clusters 1 and 3 showed increases in their indices, though not significant when compared with pre-pandemic levels. In contrast, Cluster 2 recorded a further decline. These results suggests that ooverall adaptive and transformative capacities of the clusters remain relatively weak. This is reflected in the post-pandemic resiliience index values, which have either failed to surpass or only marginally exceeded their pre-pandemic levels.

DISCUSSION

This studies provides insights into the resilience of livelihoods in each cluster of urban kampongs based on the LRI assessment. In general, the LRI scores among clusters is relatively small, indicating no major differences in livelihood characteristics. While the average LRI value in all cluster falls within the moderate resilience category, each cluster demonstrates distinct strengths and

weaknesses across livelihood variables and their indicators. Among the four variables analyzed, only social capital in Clusters 1 and 3 reached the high resilience category in the post-COVID-19 period. The strong social capital in these clusters significantly contribute to livelihood resilience, aligning with Istanabi (2020), who emphasized the role of social capital in sustaining livelihood in urban kampongs. Trust and cooperation emerge as the strongest indicatorsm, consistent with the identity of urban kampongs, which are charactherized by high levels of social cohesion (Obermayr, 2017a). Previous studies also highlight the importance of social capital and local values in driving economic recovery, strengthening livelihood, and supporting the resilience of Small and Medium Enterprises (SMEs) (Branicki et al., 2018; Galarza-Villamar et al., 2024; Huggins & Thompson, 2015).

In contrast, physical capital and human capital fall within the moderate resilience category across all clusters. Although physical capital remains moderate, its index has improved compared with the pre-pandemic conditions. This improvements appears to be linked to location. Cluster 1, situated in Central Semarang—a hub for trade and services—offers locational advantages for MSME actors in urban kampongs. Previous studies (Lindarni et al., 2014; Setiyawan et al., 2020) also emphasize the role of location in supporting business growth, which may explain the post-pandemic increase in Cluster 1's physical capital index.

Human capital likewise demonstrates moderate resilience across clusters. MSME actors in all clusters exhibit strong business motivation, and knowledge indicators also show improvement compared with pre-pandemic conditions. Notably, awareness of business diversification and digital technology has increased. Although these improvements not yet statistically significant, they signal important adaptation efforts. In particular, the rise in motivation and knowledge provides a strong foundation for strengthening livelihood resilience through MSME development. As Hadi and Rudiarto (2018) argue, human capital plays a central role in business growth and recovery. Branicki et al. (2018), studying SMEs in the UK, found that entrepreneurs' experiences in navigating difficulties and uncertainty foster resilience, which becomes the basis of MSME sustainability.

Financial capital, however, remains the weakest livelihood asset across all clusters, both before and after the pandemic. Conditions worsened during COVID-19, with all financial capital indicators falling into the low resilience category. Annual turnover was especially weak, reaching the very low category across all clusters. This finding resonates with previous research on livelihood resilience, which has largerly examined the impacts of natural disasters such as floods on community livelihoods (Sulaiman et al., 2019; Galarza-Villamar et al., 2024; Insani et al., 2022; Sahoo & Sivaramakrishnan, 2024). These results

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confirm that threats to livelihoods resilience may arise from diverse sources, including pandemics. However, limited studies have investigated resilience in the context of pandemics such as COVID-19. This study therefore contributes a fresh perspective by examining livelihood resilience beyond natural disasters, expanding the resilience discoursse. Nevertheless, a limitation of this research lies in its focus on urban kampong contexts.

CONCLUSION

An examination of livelihood resilience indices across clusters reveals that Cluster 1 has a higher resilience index, followed by Cluster 3 and Cluster 2. Although all clusters fall into moderate resilience category, indicating adequate capacity to withstand external shocks and pressures, they remain vulnerable. This underscores the need to strengthen the livelihood capital of urban kampong to enhance their ability not only to absorb and recover from external shocks but also to adapt and transform beyond pre-crisis conditions. Considering that urban kampongs have an important role in the dynamics of the economy in the city center, as a recommendation, the Semarang City Government and urban planners need to facilitate the strengthening of community livelihoods through policy support that focuses more on increasing the livelihood resilience in urban kampongs. Support for increasing livelihood capital through capacity-building activities will have a good impact on increasing livelihood resilience in urban kampongs.

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DISCLOSURE STATEMENT

All authors have no conflicts of interest to declare.

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GOVERNANCE OF HOUSING SPATIAL PLANNING OF SEMARANG CITY IN LANDSLIDE MITIGATION AND THE INFLUENCE OF BIOPHYSICAL, CLIMATIC, AND SOCIO-ECONOMIC FACTORS

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Abstract

The highland areas of Semarang City are vulnerable to landslide disasters. This study investigated the governance of Semarang's spatial planning and the factors that influence the mitigation of landslide disasters. We used spatial and descriptive analysis to evaluate the data. This study found that most of the designated housing areas in highland areas of Semarang City are laid on vulnerable landslides. Biophysical factors such as steepness levels of up to 40 percent, volcanic rock formations that are susceptible to landslides, and the changes in rainfall intensity due to climatic change have caused vulnerability to landslides. Poor mitigation governance such as land use conversion, unsuitability of spatial plans, huge extraction of groundwater, and weak evaluation and monitoring of spatial planning also increase landslide disasters and risk in Semarang. Incorporating hazard assessment into spatial planning and tightening the implementation of spatial plans are very important to be noticed by the government to reduce landslides.

Keywords: Governance, housing planning, landslides, mitigation, risk reduction, spatial analysis

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INTRODUCTION

Indonesia is one of the countries that is vulnerable to hydrometeorological disasters. A landslide disaster is a natural disaster occurring when there is a sudden and rapid movement of rock, soil, and debris down a slope that can be caused by several factors, such as heavy rain, earthquakes, volcano activities, and human activities. Landslides are simply a type of "mass wasting" of soil and rocks moving along a slope. Landslides or ground movements result from natural dynamic phenomena due to an imbalance that causes a mechanical process, causing part of the slope to move following the force of gravity. Furthermore, after a landslide occurs, the slope will be balanced or stable again to achieve a new condition due to the disturbance of the slope balance.

Landslide disasters have caused severe impacts to humans and ecology. Their impact will be greater because this is related to aspects of land use that are not following their designation. For example, many houses are built on the lower slopes of hills that are prone to landslides. To reduce the impact of landslides, spatial planning must be adjusted, such as estimating the vulnerability of an area predicted from topography (slope), soil type, land cover, and rainfall patterns.

Semarang City, located in Central Java, Indonesia, is one of the business centers in Java due to its role as the capital of Central Java, a freight transportation route from the north coast land transportation route, and one of the port and industrial centers in Java. With these conditions, population growth and the need for built-up areas are very high so this has the potential to result in the improper placement of settlements. Previous studies state that the upper areas of Semarang City are prone to landslides causing negative economic and social impacts on residents, such as damage and loss of housing, damage to infrastructure, and insecurity (Purba et al., 2014; Yufahri and Widjajanti, 2022). Residential space planning plays a vital role in protecting vulnerable communities, promoting sustainable development in the face of these natural hazards, and reducing risk (Wijaya et al., 2017). Therefore, evaluating residential planning is important to be conducted in rapidly developing cities like Semarang.

Previous studies have evaluated the distribution of landslide-vulnerable areas in Semarang (Purba et al., 2014; Susanto and Putranto, 2016). However, limited studies have assessed the comprehensive study to evaluate the suitability of the existing spatial plan of settlement areas for landslide risk management in Semarang City and the relation of climate hydro-meteorological and human factors that can cause landslides. Therefore, the study aimed to investigate the current housing spatial planning towards landslide risk management in Semarang and the influencing factors that can trigger landslide incidents in Semarang, which include biophysical, climatic, and anthropogenic or human factors.

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LITERATURE REVIEW

Definition and Basic Principles of Spatial Suitability

Spatial suitability is a key concept in geography, urban planning, and environmental management, referring to the evaluation and identification of areas that are most appropriate for specific activities or purposes based on a range of physical, environmental, and socioeconomic factors. It is a process that seeks to align land characteristics with human needs, ensuring that land use is optimized in ways that balance development goals with sustainability and environmental protection. In practice, spatial suitability analysis involves a complex integration of multiple criteria such as land use, topography, accessibility, and environmental constraints to identify the optimal locations for various types of land uses (Jeong et al., 2013; Omar and Raheem, 2016; Wahyuddin et al., 2021).

To carry out spatial suitability analysis, Geographic Information Systems (GIS) are frequently employed to capture, store, analyze, and visualize the spatial data involved. GIS-based spatial analysis is an essential tool for modern planning and resource management which is making it easier for decision-makers to evaluate different land-use scenarios and optimize resource allocation (Wahyuddin et al., 2021).

Spatial Planning's Contribution to Reduce Landslide Risk

One crucial aspect of spatial planning is its potential to mitigate the risk of landslides. Incorporating landslide susceptibility mapping and hazard assessment into spatial planning can inform land use decisions, guide development away from high-risk areas, and promote the adoption of structural and non-structural mitigation measures. By strategically organizing land use, infrastructure, and disaster response, spatial planning can play a vital role in protecting vulnerable communities and promoting sustainable development in the face of these natural hazards. However, the successful implementation of such strategies often faces challenges. Overcoming barriers related to data availability, institutional coordination, and community engagement requires a holistic, multi-stakeholder approach (Muhamad et al., 2015; Diana et al., 2021).

Factors affecting Landslide Vulnerability and Assessment Methods

Paimin et al., 2006 stated that 2 (two) factors cause landslides, namely natural factors and management factors. Natural factors are (1) consecutive days of cumulative daily rainfall, (2) land slope, (3) geology/rock, (4) presence of faults/fractures/wires, (5) soil depth to impermeable layer; while management factors are: (1) land use, (2) infrastructure, and (3) settlement density. Arsyad (2010) further added that there are at least 3 (three) conditions that cause landslides, namely (1) the slope is steep enough, (2) there is a layer below the ground surface that is impermeable and soft as a gliding field, and (3) there is

enough water in the soil so that the soil layer just above the impermeable layer becomes saturated. Excessive rainfall, earthquakes, volcanoes, forest fires and other similar things, vibration, as well as dangerous human activities such as deforestation in the upstream areas and sloping areas are some of the main causes that can trigger landslides (Highland, 2008; Karnawati, 2005; Isnaini, 2019).

Evaluation of landslides can be conducted through direct observation and the utilization of technology. One way of evaluating landslides is by map analysis. Required maps include bedrock and surface geology, topography, soils, and geomorphology maps (Highland, 2008). The most commonly used method is the overlay method. The overlay method is good for analyzing landslide hazard (Aminatun, 2017), landslide vulnerability (Susanti et al., 2017), landslide capacity, and landslide disaster risk (Naryanto, 2011; Faizana et al., 2015).

Landslides in a Changing Cimate

Landslides are one of the hydrometeorological disasters. Hydrometeorological disasters are closely related to climate change (weather and climate) that occurs in the world including in Indonesia (Azizah, 2022). Hydrometeorological disasters are caused by climate and weather anomalies in the atmosphere, especially in increasing frequency and intensity, which are thought to be caused by climate change. In Indonesia, hydrometeorological disasters are closely related to rainfall or precipitation. According to Febrianti (2009), rainfall anomalies will increase the threat of landslides and floods. Rainfall is considered as the main factor causing landslides. Rainfall has the potential to cause landslides provided it has a high intensity (4 inches/hour) and lasts more than six hours. Climate change on a regional or global scale causes changes in the frequency and intensity of tropical cyclones that can cause strong winds and high rainfall (Hadi et al., 2022).

Considering the above conceptual framework and the aim of the study, the framework of this study is provided in Figure 1:

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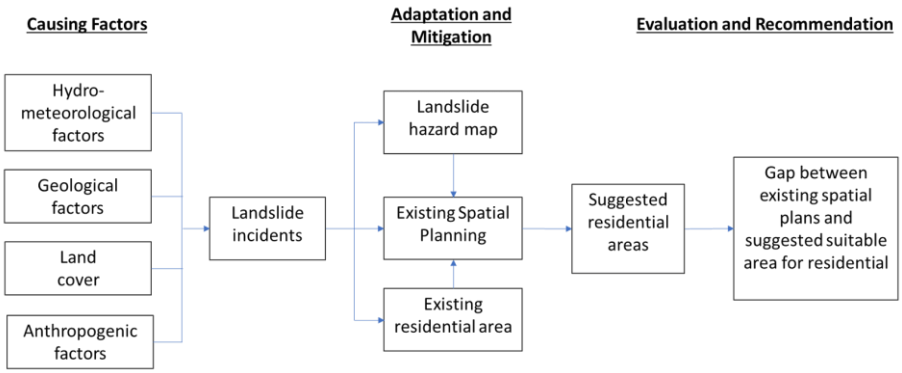


Figure 1. Research Framework

RESEARCH METHODOLOGY

The study area is in Semarang. Semarang is the capital city of Central Java, Indonesia. The city is divided into lowland and highland areas, characterized by different landscapes and challenges. The map of Semarang is provided in Figure 1. The focus study area is the highland areas of Semarang City, located to the south and southeast area which include Gunung Pati and Banyumanik District. These areas are situated at higher elevations.

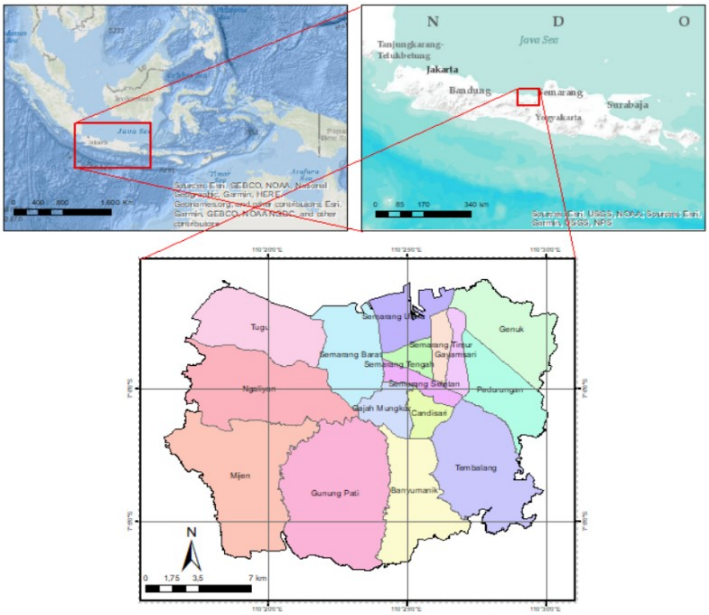


Figure 2. Map of Semarang City

The data consist of digital thematic maps and primary data collected through interviews and field observation. Interviews were conducted with 31 government officers and 26 citizens. The institutions consisted of the spatial planning agency, the regional disaster management agency, of Semarang, the river basin institute, the housing department, the environmental department, and the sub-district government of Semarang City. Community respondents are citizens from the villages of Mangunharjo, Sukorejo, Trangkil, and Tinjomoyo, administratively located in Banyumanik and Gunung Pati.

The spatial analysis used an overlay method of several categories of physical and climatic aspects that potentially cause landslide risk. The categories of landslide risk include soil type, slope, rainfall, land cover, and water potential. The result of this overlaying procedure is a landslide vulnerability distribution/map of Semarang. The levels of vulnerability are categorized into four categories (very low, low, medium, and high) following the category provided by the Indonesia National Disaster Agency or BNPB (2012). The very low and low categories are scored at 0.33, medium at 0.67, and high at 1.00). Analysis of the current spatial planning (*Rencana Tata Ruang Wilayah*, RTRW) and landslide-prone area distribution was carried out to evaluate the suitability of the existing spatial planning of Semarang toward mitigation of landslide disaster in residential areas. The analysis also uses spatial analysis.

To figure out the causing factors of landslide incidents and the unsuitability of spatial plan implementation, we evaluate the biophysics, climate change, and human factors. The evaluation was based on descriptive analysis using tabulation and percentage. Land use change is one of the main factors of landslides. Evaluating the built-up land areas of Semarang using the Sentinel-2 data involves leveraging the satellite's high-resolution multispectral imagery, which includes 13 spectral bands. Launched as part of the European Space Agency's Copernicus program, Sentinel-2 offers valuable data for urban analysis, with image filtering from 2018 to 2024. The analysis uses the Google Earth Engine (GEE), an efficient cloud-based tool that processes images automatically. The Normalized Difference Built-up Index (NDBI), which highlights built-up areas, is calculated using Band 8 (NIR) and Band 11 (SWIR) based on the formula (SWIR-NIR) / (SWIR+NIR), as suggested by Celik (2018).

ANALYSIS AND DISCUSSION

Distribution of Landslide Vulnerable Zone of Semarang City

Landslide distribution prediction in Semarang was obtained by overlaying slope, geological, soil, rainfall, and land use map, and the distribution, and the result is presented in Figure 3. The south, southeast, and southwest areas of Semarang which include Banyumanik, Gunung Pati, Tembalang, and Mijen Districts are

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more vulnerable to landslide risk. Gunung Pati and Banyumanik District seem the most vulnerable areas among the other districts.

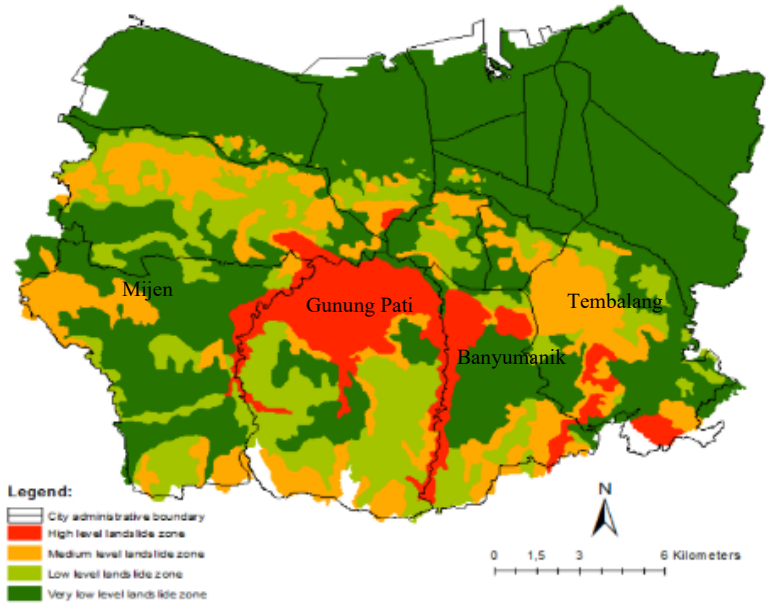


Figure 3. Landslide zone in Semarang City

Analysis on Residential Areas of Semarang Spatial Planning toward Landslide Risk Mitigation

Effective spatial planning that incorporates landslide risk reduction can make a significant contribution to building more resilient communities and mitigating the devastating impacts of these hazards. The distribution of the existing residential areas in Banyumanik and Gunung Pati is in Table 1 and the spatial planning is in Table 2.

Table 1. Spatial analysis of existing housing areas toward landslide risk in Banyumanik and Gunung Pati

	Area (ha)				Percentage (%)		
Districts	**Low**	**Medium**	**High**	**Total**	**Low**	**Medium**	**High**
Banyumanik	33.71	181.29	15.59	230.58	14.62	78.62	6.76
Gunung Pati	22.79	156.35	68.93	248.08	9.19	63.03	27.79
Total	**56.50**	**337.64**	**84.52**	**478.66**	**11.80**	**70.54**	**17.66**

Table 2. Spatial analysis of housing spatial plan toward landslide risk in Banyumanik and Gunung Pati

	Area (ha)				Percentage (%)		
Districts	**Low**	**Medium**	**High**	**Total**	**Low**	**Medium**	**High**
Banyumanik	33.70	174.89	15.61	224.21	15.03	78.00	6.96
Gunung Pati	22.89	146.98	68.86	238.72	9.59	61.57	28.85
Total	**56.59**	**321.87**	**84.47**	**462.93**	**12.22**	**69.53**	**18.25**

Most existing residential areas in Banyumanik and Gunung Pati Districts are laid on medium risk of landslide (70.54%), and only less of them (11.80%) are safe from landslide risk potential. Even 17.66% of residential areas are at high risk from landslides, and Gunung Pati seems to have more highly risky settlement zones (27.79%). Not much different from the planned areas, the residential planned areas in Gunung Pati and Banyumanik are mostly semi and high risk of landslide as presented in Table 3. Most of the settlement zones (69.5 %) are allocated in prone areas with medium risk to landslide, and 18.25% of the designated area is at high risk of landslide. Comparing between the existing and the planning, both look similar. It indicates that the residential space plan in the city of Semarang is more adjusted to existing settlements which is less suitable to the land function and capacity indicating less awareness of landslide disaster mitigation. As a result, there are many residents living in prone areas such as Sukorejo and Trangkil Village in Banyumanik. They have been struggling with the landslides and land subsidence that have cracked and destroyed their houses. Most of them keep staying in those prone areas due to no option of a place to live.



Figure 4. Figure of the damaged house caused by slow and sudden landslides in Sukorejo Village, Gunung Pati District.

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Causing Factors Influencing Landslide in Semarang

Improper land use is one of the factors that cause landslides. This is because each land use has a different level of risk in affecting landslides. Land uses in this area are settlement, plantation, moor, permanent production forest, and paddy field. The dominant land uses are settlements and plantations, especially in areas with a high risk of landslides. The Semarang is experiencing rapid development which results in an increase in built-up land that changed the land use from green space to settlements, administrative centers, economy, and infrastructure. Spatial analysis of built-up areas In Banyumanik and Gunung Pati is presented in Table 3. The built areas increased about by 79.61 percent in Banyumanik and 107.61 percent in Gunung Pati.

Table 3. Spatial analysis on built-up area in Banyumanik and Gunung Pati 2018-2024

Year	Banyumanik (ha)	Gunung Pati (ha)
2018	18.49	8.93
2019	29.97	15.78
2020	29.34	13.71
2021	30.57	15.73
2022	32.01	16.87
2023	35.45	19.54
2024	33.21	18.54

As the capital of the province and a business center, efforts to reduce the rate of population growth from births and migration in Semarang are difficult to handle. Therefore, equitable development in the Java region needs to be improved to prevent migration to the capital city. The risk of landslides in Banyumanik and Gunung Pati also increases because of land use changes in the upstream area of the Semarang, namely the Garang watershed catchment area that influenced the hydrology cycle in Semarang. The study of Saifudin et al. (2017) found that land use change and deforestation in the Garang watershed catchment area from 2000 to 2013 significantly increased the surface water flow to 301,88 mm (an increase of 14.64%). This increase potentially affects erosion and landslides in hilly areas including Banyumanik and Gunung Pati.

Biophysical factor like topography improves the vulnerability of an area from landslides. The South Semarang has a relatively high topography. The slope classes of Gunung Pati and Banyumanik Districts are relatively varied but many tend to have moderately steep (15-25%), steep (25-40%), very steep (>40%), and even very steep (>40%) slope classes. The higher the slope, the greater the potential for erosion or landslides (Pasaribu and Situmorang, 2022). However, especially in areas with high landslide risk in Gunung Pati and

Banyumanik, the dominant slopes are relatively steep (25-40%) and very steep (>40%).

Climate factors such as rainfall are also one of the key factors for landslides. This is because water is an object that plays a major factor in washing away soil. In the 10 years (2014-2023), the average rainfall of Semarang City was recorded at 162.23 mm and was categorized as medium. In normal situations, Semarang City has variations in the amount of rainfall. In January and February, the rainfall of Semarang City is in the high category; June to October is in a low category; while in March, April, May, November, and December is in the medium category. The rainfall pattern in Java Island, which includes Semarang City, is affected by the Monsoonal rainfall pattern (Sofan, 2013). This monsoonal rainfall pattern occurs due to the movement of monsoon winds, particularly western monsoon winds that blow from the Indian Ocean and carry a lot of water vapor. Hence, in this period, Semarang City experiences the rainy season. In this situation, the high-intensity rainfall increases the water saturation of land and rocks and forces the rock layers to landslide (Naryanto, 2011). However, the characteristics of rainfall in Java including Semarang changed in the last 30 years. The annual rainfall and maximum daily rainfall tend to increase by an average of 22.64 mm/year, while the daily rainfall increases by an average of 2.56 mm/year (Suripin and Kurniani, 2016). This potentially causes the increase in water volume and duration of rainfall in the months of high rainfall intensity (usually in January and February).

Geological formation is one of the physical factors causing landslides. Geological formation or rock type contributes greatly to the occurrence of landslides. Sturdy rock types will be stronger to resist water flow than Fraggle rock types. Geological formations in this landslide-prone area are andesite, alluvium, Gajah Mungkur volcanic rocks, Kaligesik volcanic rocks, Damar formation, and Kaligetas formation. The dominant geological formations are Kaligetas Formation and Damar Formation. The Kaligetas Formation is composed of breccia and lava with fine to coarse lava and tuff inserts. The Kerek Formation is composed of clay, Marl, tuffaceous sandstone, conglomerate, volcanic breccia, and limestone. The Damar Formation consists of volcanic breccia, conglomerate as a lens, and tuffaceous sandstone. The Kalibeng Formation consists of Marl, tuffaceous sandstone, and limestone (Thanden et al., 1996).

Soil type is an important factor in influencing landslide occurrence. Soil types have their sensitivity to erosion or landslides. Therefore, each soil type has a different level of erosion or landslide sensitivity. The soil types in this area are dark brown Mediteran, reddish brown latosol, and brown latosol. The most dominant soil types are dark brown Mediteran and reddish-brown latosol. Likewise, the soil types in areas with high landslide risk levels are dark brown

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Mediterranean and Reddish-brown Latosol. Concerning landslides, Mediterranean soil types have moderate erosion sensitivity. Meanwhile, latosol soil types are quite sensitive to erosion (Asdak, 2004). The rock and soil type incorporated with watering are the important factors that influence landslide risk (Yufahri and Widjajanti, 2022).

Human Factors Influencing Landslide Management and Implementation in Semarang

Planning control is one of the effective and economical ways to reduce landslides and their impact on humans and the environment. Hence, alignment between planning and implementation is essential to reduce landslide disasters and their impacts. We evaluated some factors that influence the landslide's spatial planning by asking about the perception of government officers and local communities (urban citizens of upper areas of Semarang City). The evaluated aspects included spatial planning governance, the role of stakeholders, and awareness of local people, and the result is presented in Figure 5.

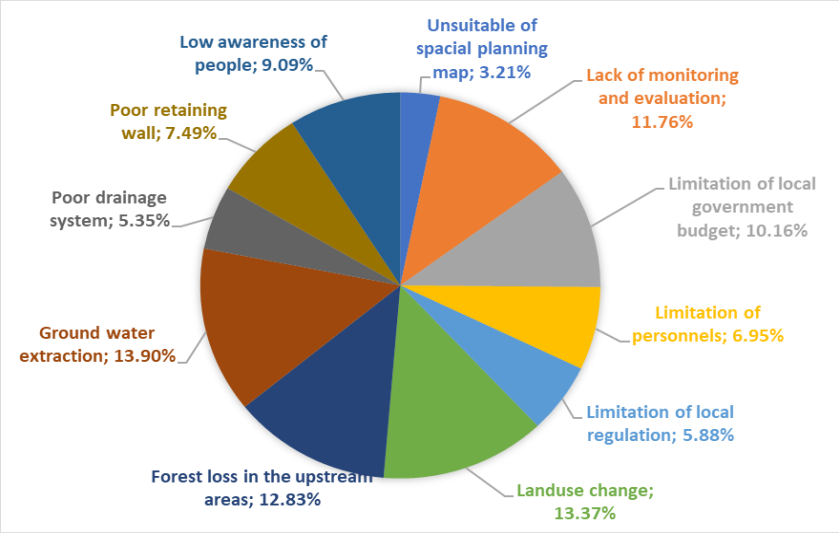


Figure 5: Human factors causing unsuitable landslides spatial plan implementation in Semarang highland based on stakeholders' and community's views

The result in Figure 5 describes that the main causes of landslide incidents in Semarang were groundwater extraction (13.90%), land use change (13.37%), and forest loss in the upstream areas of Semarang (12.83%). Groundwater extraction causes the depletion of groundwater which disrupts the

structure of the soil layer and causes land subsidence. Groundwater is often as primary source of clean water in Semarang, both for fulfilling household, industrial, and hotel needs. Based on our survey, nearly all residents in Semarang use artesian wells with an average depth ranging from 50 to 100 meters. Recent studies have revealed that Semarang City is experiencing significant groundwater vulnerability, with approximately 41.3% of the area classified as highly vulnerable and 50.3% as moderately vulnerable (Marjuanto et al., 2019). Extraction of groundwater in the lowland and highland areas of Semarang has led to groundwater depletion, which causes land subsidence and landslides, also similarly stated by Kodoatie and Sjarief (2005) in their study. In the lowland areas of Semarang, groundwater extraction has caused land subsidence of up to 10 cm per year which causes tidal flooding (rob) and seawater intrusion. In the upper areas, depletion of groundwater causes land movement and landslides. As the city's population has increased, the water demand has risen, leading to a higher rate of groundwater extraction. This is particularly problematic in Semarang, where residents still rely on non-piped water sources, further exacerbating the issue of groundwater availability. The permit for groundwater drilling in Central Java has been released by the Central Java Governor in Regulation No. 3 of 2018. However, this regulation is not properly implemented and lacks monitoring and sanctions.

Forest loss and land use change cause the reduction of water infiltration by the expansion of urbanization and rapid construction of buildings and roads. Deforestation also increases the risk of landslides due to the loss of plant roots that play a role in retaining soil, especially in steep areas. Deforestation has increased particularly in the upstream areas of Semarang. The changing of forests generally occurs due to development and population growth which convert forests into agriculture, tourism, residential areas, and other built-up areas.

Unsynchronized implementation of spatial planning is also caused by weak governance practices. Figure 7 indicates that local governments have weak monitoring and evaluation (11.76%) toward the planning and real implementation, limitation of budget (10.16%), and shortage of personnel (officers) to monitor the areas (6.95%). The city of Semarang has enacted Regional Regulation Number 5 of 2021 to govern spatial planning in Semarang City called RTRW regulation. The RTRW regulation has urgency as a blueprint for the utilization of space for regional development activities. However, keeping in mind the empirical practices of drafting regional regulations, political and economic considerations have greatly influenced the formulation of RTRW regulations on spatial planning. Many industries and settlement areas have been arranged on the beach border which opposes the principles of environmental sustainability. In Banyumanik and Gunung Pati, many housing estates, hotels,

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and restaurants have been placed on hillsides and steep areas with inadequate drainage systems and retaining walls that increase the potential risk of landslides.

Weak monitoring and inconsistency in the implementation of Semarang spatial planning (RTRW) are suspected to be the causes of landslide incidents in Semarang. The areas that are designated for protection functions become densely populated residential areas, such as settlements in Trangkil Village, Sukorejo, in Gunung Pati District that are experiencing landslide incidents and severe house cracks. Surprisingly, government institutions at various levels seem to be out of sync in implementing this spatial planning policy. Housing in Trangkil has been built for decades with permits from the local government and other technical institutions during its development. However, when the local people came to apply for land ownership rights for settlements, there were rejections from the Land Agency due to the inconsistency of the land use function and designation. This condition often occurs in Indonesia, and people continue to live in these areas due to economic limitations and low public awareness. Weak monitoring was acknowledged by most of the officers from the agencies that we interviewed. They argued that supervision was less than optimal due to limited field personnel and lack of financial support. Moreover, we realized that the weakness of law enforcement towards citizens and business actors who violated the spatial planning regulations worsened spatial governance.

The role of local people in environmental protection is very important to reduce landslides and their risks. However, public awareness seems low (9.09%). Even though they have faced landslide incidents and their houses have cracked, they are still living in the villages due to the no options and weak awareness. Infrastructure such as retaining walls and drainage systems are built to reduce landslides. The responders perceived that the development of infrastructure to reduce landslides and the risk in the highlands of Semarang City are still low.

CONCLUSION

The highland areas of Semarang City are vulnerable to landslide disaster, and the designated housing areas in Banyumanik and Gunung Pati are laid on vulnerable landslides, which is 69.53 % at medium risk and 18.25% at high risk. Various factors have resulted in the vulnerability to landslides in Banyumanik and Gunung Pati including biophysical factors such as steepness levels of up to 40 percent, volcanic rock formations that are susceptible to landslides, and the changing rainfall intensity which is noted to increase an average of 22.64 mm/year due to climatic change. However, poor landslide disaster mitigation management is the main factor causing the increasing number of landslide disasters in Semarang. The improper management included deforestation and land cover change in the upstream water catchment areas of Semarang. The built-

up areas increased by 79.61 % in Banyumanik and 107.61 % in Gunung Pati from 2018 to 2024. Huge extraction of groundwater for housing and industrial demand have caused depletion of groundwater which causes land subsidence in lowland areas and landslides in upper areas of Semarang. Weak evaluation and monitoring of the spatial planning and implementation at the site level also indicate an inconsistency of government in reducing landslide disaster risk in Semarang. Limitations of personnel and budget and lack of people awareness have caused the spatial plan implementation to face various problems.

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ETHICAL CLEARANCE

This research had received and implemented ethical clearance lined in the ethical clearance approval on social studies and humanities research Number 428/KE.01/SK/05/2024 issued by Ethical Committee on Social Studies and Humanities, National Research and Innovation Agency, Indonesia.

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IMPLEMENTATION OF RISK MANAGEMENT IN SUSTAINABLE BRIDGE CONSTRUCTION

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Abstract

The Indonesian government is currently intensifying infrastructure development, with bridge construction being one of its key initiatives. The Pandansimo Bridge is built over the Progo River in Ngentak, Poncosari, Srandakan, Bantul Regency, connecting to the Kulon Progo Regency in the Yogyakarta Special Region, Indonesia. The bridge plays a crucial role in transportation mobility, economic sector development, and logistics in the Bantul and Kulon Progo regions. However, the construction of the Pandansimo Bridge involves various risks, one of which is earthquakes, as the bridge is located only 10 km from the Opak Fault, which caused a major earthquake in 2006. Therefore, a risk management study is essential in constructing the Pandansimo Bridge. This study aims to identify potential risk factors that may arise during construction, determine the level of risk, and control potential risks that could impact the bridge's sustainability and functionality. The initial step involves identifying risk sources through literature studies and interviews. Subsequently, risk assessment is conducted through questionnaires, followed by risk analysis. The risk rating matrix is used to classify risk levels. The analysis identified seven main risk sources with thirty-seven specific risks, of which seven are classified as high-risk: flooding, river overflow, unpredictable weather conditions, frequent equipment failures, earthquakes, material damage or theft, and unstable soil conditions. Mitigation strategies are integrated into urban planning to ensure the sustainability and resilience of Pandansimo Bridges. The mitigation measures implemented are improved drainage systems, riverbank reinforcement and embankments, bridge elevation and structural adaptation, early warning and monitoring systems, and sustainable land use planning.

Keywords: Infrastructure, Bridge, Risk Management, Risk Factor, Risk Rating

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INTRODUCTION

One of the infrastructure developments currently being promoted by the Indonesian government is the construction of bridges. A bridge is a structure that connects two parts of a road that are cut off due to obstacles such as deep valleys, rivers, railroads, and so on.

On the south coast of Yogyakarta, the Pandansimo Bridge was built. The Pandansimo Bridge stands 1,900 meters above the Progo River, connecting the Srandakan District in Bantul Regency with the Galur District in Kulon Progo Regency. The construction of the Pandansimo Bridge is a priority program as it is part of the Trans-South Java route, which is expected to improve the community's economy, promote economic equality, and support the development of tourist destinations in Southern Java.

The Pandansimo bridge was designed with attention to environmental sustainability with local cultural aesthetics. Namely, in the middle of the bridge, it is designed using mountains with typical Yogyakarta batik motifs. Along the bridge, typical south coast plants such as shrimp pine are planted. On the right and left, pedestrian paths are made for those who want to enjoy the beauty.

In bridge construction, there are many risks. The risks that occur can cause losses. According to Rivida et al. (2019), risks can affect productivity, performance, and costs. According to several studies, the risks associated with bridge construction vary. There are also risks in the construction of the Pandansimo bridge. One of the risks that occurs is an earthquake. It occurs because D.I. Yogyakarta is an area with a complex geological structure and is located near the plate collision zone. The presence of fault activity on the surface, namely the Opak-Oyo fault, causes the Yogyakarta area to experience a fairly high earthquake frequency (Wibowo and Sembri, 2017).

Meanwhile, the Pandansimo bridge is located near the epicenter of the Opak fault earthquake with a radius of less than ten km. Therefore, the Pandansimo bridge is designed to be earthquake-resistant. Although it has been designed to be earthquake-resistant, it still has a liquefaction vulnerability, which causes the construction of this bridge to be included in the category of high-risk projects, in addition to the risk of earthquakes. Other risks arise, including social problems that have numerous impacts, both negative and positive, on the surrounding environment.

Not all risks that will occur can be prevented. These risks can be minimized. It is done to reduce the losses that will be incurred. To minimize the occurrence of risk, risk management is needed. Risk management is a science used to identify, analyze, and respond to risks. The purpose of this research is to identify risk factors that affect construction. In addition, it is also necessary to calculate the level of risk that occurs and how to handle the risk.

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The purpose of this research is to identify risk factors that affect construction. In addition, it is necessary to calculate the level of risk and determine how to handle it.

LITERATURE REVIEW

Risk Management

Risk contains the possibility that it could cause a loss. Risk can be defined as an uncertain condition that, if it occurs, can hinder the objectives of a project (Mbachu and Taylor, 2014). Risks can occur in construction, such as bridges or some types of construction projects (Safayet et al., 2018). The owner, consultant, or contractor can experience the risks that occur. According to Sebayang et al. (2018), the risk is the potential for an incident to occur that can be avoided and minimized so that the impact that occurs is as small as possible according to the plan or can be accepted above the permitted tolerance. To minimize losses caused by risk, risk management is needed. The risks that will occur can be minimized by using risk management. Risk management, as defined in PMBOK (2013), is a systematic process that involves identifying, analyzing, responding to, and controlling risks on a project. In risk management, there are several stages, namely risk management planning, risk identification, risk analysis, risk response planning, risk monitoring, and control.

Risk Identification

Risk identification is carried out to identify potential problems. Therefore, in identifying risks, it starts with identifying the source of the problem. Mohamed Azmi and Ramli (2023) explain risk management in construction property projects based on strata-titled, including employee competencies, litigation, financial liquidity, non-compliance laws, security management, and customer service. Abdullah Habib et al. (2020) identified risks based on risk sources, namely social, legal, political, contractual, financial, process, and technical risks. Meanwhile, Septiani et al. (2015) identified risks at the construction stage, namely licensing (pre-construction), design and study, land acquisition, financing, construction (construction), risk equipment, force majeure, and social politics. Another risk that occurs in construction is work accidents. According to Nik Him et al. (2023), the construction sector is known for its high risk of work accidents. Work accidents can occur due to several factors, including workers' negligence in performing tasks or being in unhealthy conditions without using personal protective equipment. According to Damayanti and Wahyuningsih (2023), the number of work accidents in construction increased by 5.7% in 2021 and by 12.36% in 2022.

Risk Assessment

After risk identification based on the risk source, a risk assessment is carried out. Risk assessment will prioritize the risks that need to be managed based on the predefined risk categories, such as project, design, material, labor, financial, and human risks (Mohd Nawi et al., 2020). Risk assessment is carried out to determine the level of possibility and level of impact, where the possibility and impact are given a score of 1 to 5. After the risk assessment is carried out, the risk level can be determined using a risk level matrix.

Risk Response Planning

Risk response planning is grouped into several categories. The first approach is to avoid risk by not carrying out activities that can cause it. Another strategy is reducing risk through mitigation, where the risk that occurs can be reduced by implementing measures that minimize the potential impact. In some cases, accepting risk may be appropriate, which means accepting the losses that arise; this approach can be adopted when the risk is relatively small and manageable. Finally, risk can be transferred to another party, allowing organizations to shift the potential consequences to entities better equipped to handle them or through mechanisms such as insurance or outsourcing arrangements.

RESEARCH METHODOLOGY

This study began by conducting risk identification to find the source of risk. It was obtained from literature studies and field observations. Field observations were conducted through interviews with related parties. The related parties are the service providers for the construction of the Pandansimo bridge. From the results of the interviews, seven sources of risk were obtained. The seven sources of risk are project risk, technical risk, natural risk, human resource risk, financial risk, and environmental risk. From the seven sources of risk, thirty-seven risks were obtained.

Based on the interview results, a questionnaire was created. Six individuals from competent service providers completed the questionnaire. The questionnaire aims to assess the likelihood and magnitude of potential risks. In the questionnaire, a scale of likelihood and impact is created so that a risk assessment can be carried out. The scale of likelihood and impact can be seen in Tables 1 and 2.

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Table 1: Likelihood

Likelihood	Scale
Usual	5
Likely	4
Possible	3
Unlikely	2
Rare	1

Source: Standards Australia/Standards New Zealand (AS/NZS: 4360) in Rifani et al. (2018)

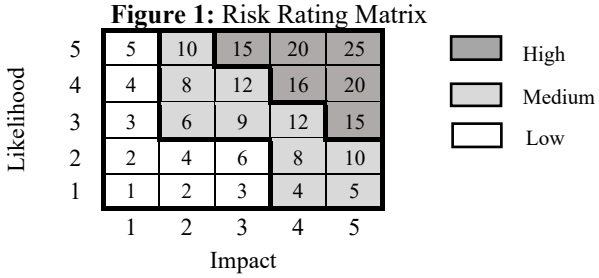
Table 2: Impact

Impact	Scale
Severe	5
Major	4
Moderate	3
Minor	2
Incidental	1

Source: Revantoro, et al. (2017)

From the results of the questionnaire distribution, the probability level and impact level were obtained. Next, a risk analysis was carried out. In analyzing the likelihood of occurrence and its impact, the average value was found. Then, we multiply the likelihood of occurrence by the impact to determine the risk rating. The risk rating is grouped into low risk, medium risk, and high risk. Then the risk level is entered into the risk rating matrix. The risk rating matrix can be seen in Figure 1.

Figure 1: Risk Rating Matrix



Source: Sebayang, et al. (2018)

RESULTS

From the literature study and the results of interviews with service providers in the construction of the Pandansimo bridge, risk identification was obtained. Risk identification was carried out to determine the source of risk. From the results of risk identification, seven risk variables were obtained, namely project risk, engineering risk, natural risk, human resource risk, occupational health and safety risk, financial risk, and environmental risk. From the seven risk variables, thirty-

seven risk indicators were obtained. The seven risk variables and thirty-seven risk indicators obtained from the results of risk identification can be seen in Table 3.

Table 3: Risk Identification

Source of Risk	Code	Indicator
Project Risk	RK1	Lack of availability of large-scale material unloading sites
	RK2	Damage or loss (theft) of materials
	RK3	Delay in the delivery of materials from suppliers
	RK4	Materials that do not meet requirements
	RK5	Slow delivery of construction equipment
	RK6	Lack of available labor in the field
	RK7	Difficult site conditions
	RK8	Differences in basic soil conditions
	RK9	Difficulty in installing foundations
	RK10	Concrete quality does not meet specifications.
	RK11	Wrong implementation methods
	RK12	Structural collapse
Technical Risk	RK13	The equipment used is often damaged
	RK14	Damage or interference with lifting equipment
	RK15	Design changes
	RK16	Incomplete design data
Natural Risk	RK17	River overflows
	RK18	Earthquakes
	RK19	Floods
	RK20	Unpredictable weather
Human Resource Risk	RK21	Lack of personnel who can operate certain equipment
	RK22	Security disturbances at the project site
	RK23	Less disciplined equipment operators (arrive late) so that productivity is less than optimal
	RK24	Unskilled labor
	RK25	Low labor productivity
	RK26	Ineffective working hours
	RK27	Lack of control and coordination within the team
	RK28	Inexperienced staff
Occupational Health and Safety Risks	RK29	Lack of worker discipline in using PPE
	RK30	Lack of implementation of K3 in the field
Financial Risk	RK31	Cost estimation error
	RK32	Time estimation error
Environmental Risk	RK33	Unstable soil conditions
	RK34	Water pollution
	RK35	Soil pollution
	RK36	Air pollution
	RK37	Endemic flora and fauna population

Source: Data processing (2024)

After risk identification is done, the next step is to conduct a risk assessment. This risk assessment is obtained from the results of filling out the

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questionnaire from the service provider. The likelihood level is obtained with the impact level. Then conduct a risk analysis. In analyzing the risk, the impact that occurs with likelihood is multiplied. The results of the risk analysis for the risk assessment can be seen in Table 4.

Table 4: Risk Assessment Results

Source of Risk	Code	Impact	Probability	Risk	Risk Level
Project Risk	RK1	4.0	2,0	8.00	Moderate
	RK2	4.3	3.8	16.61	High
	RK3	3.8	3.0	11.50	Moderate
	RK4	4.5	2.0	9.00	Moderate
	RK5	3.5	3.0	10.50	Moderate
	RK6	4.0	2.2	8.66	Moderate
	RK7	3.2	3.0	9.50	Moderate
	RK8	3.7	3.0	11.00	Moderate
	RK9	3.5	3.0	10.50	Moderate
	RK10	5.0	2.0	10.00	Moderate
	RK11	5.0	2.0	10.00	Moderate
	RK12	5.0	2.0	10.00	Moderate
Technical Risk	RK13	4.2	4.0	16.66	High
	RK14	3.3	3.5	11.66	Moderate
	RK15	3.8	3.0	11.50	Moderate
	RK16	4.3	2.5	10.83	Moderate
Natural Risk	RK17	4.0	4.3	17.33	High
	RK18	4.3	3.8	16.61	High
	RK19	4.0	4.3	17.33	High
	RK20	4.2	4.0	16.66	High
Human Resource Risk	RK21	3.7	2.3	8.55	Moderate
	RK22	3.0	2.8	8.50	Moderate
	RK23	4.7	2.0	9.33	Moderate
	RK24	3.5	2.6	9.33	Moderate
	RK25	3.8	2.0	7.66	Moderate
	RK26	3.8	3.0	11.5	Moderate
	RK27	4.7	2.0	9.33	Moderate
	RK28	3.5	2.0	7.00	Moderate
Occupational Health and Safety Risks	RK29	3.7	3.0	11.00	Moderate
	RK30	4.3	2.0	8.66	Moderate
Financial Risk	RK31	4.5	2.0	9.00	Moderate
	RK32	4.0	2.5	10.00	Moderate
Environmental Risk	RK33	5.0	3.0	15.00	High
	RK34	3.0	2.0	6.00	Low
	RK35	3.0	2.0	6.00	Low
	RK36	4.0	2.8	11.33	Moderate
	RK37	3.0	2.0	6.00	Low

Source: Data processing (2024)

The results of the risk assessment are entered into the risk rating matrix. The risk levels that occur can be seen in Figure 2.

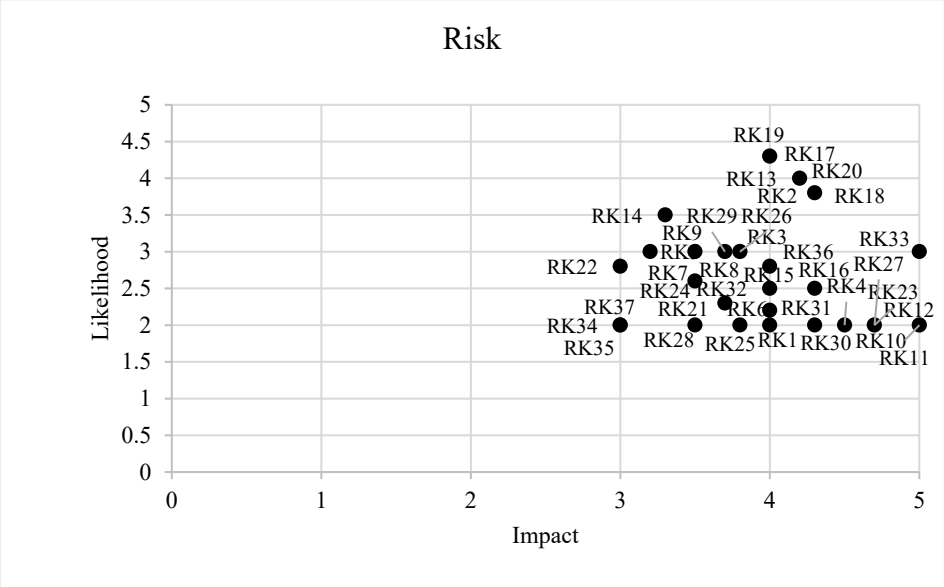


Figure 2: Risk Level Matrix
Source: Data processing (2024)

DISCUSSION

Risk According to Contractor Perception

Based on the contractors' perception, seven sources of risk have been identified. These seven sources encompass a total of thirty-seven risks. The analysis results indicate that three risks fall into the low-risk category, twenty-seven risks are classified as moderate, and seven risks are categorized as high. The high-risk category includes project risk variables (RK2), engineering risk variables (RK13), natural risk variables (RK17, RK18, RK19, RK20), and environmental risk variables (RK33). The high-risk levels can be observed in Table 5.

Table 5: High Risk Level

Source of Risk	Code	Probability	Impact	Risk	Risk Level
Project Risk	RK2	3.83	4.33	16.61	High
Technical Risk	RK13	4	4.16	16.66	High
Natural Risk	RK17	4.33	4	17.33	High
	RK18	3.83	4.33	16.61	High
	RK19	4.33	4	17.33	High
	RK20	4	4.16	16.66	High
Environmental Risk	RK33	3	5	15.00	High

Source: Data processing (2024)

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The Pandansimo Bridge is located approximately 10 kilometers from the Opak Fault, which was responsible for the earthquake in 2006. Due to this seismic risk, the construction of the Pandansimo Bridge incorporated *Lead Rubber Bearing* (LRB) technology to enhance its structural resilience.

LRB is a type of seismic isolator composed of laminated rubber, a lead core, and steel plates, designed to increase deformation capacity and dissipate energy during earthquakes.

The implementation of LRB serves several important purposes in bridge engineering. First, it provides damping of seismic vibrations, thereby reducing the transmission of earthquake forces to the main structure. Additionally, LRB enhances bridge flexibility, allowing it to adapt to ground movements caused by tectonic activity. Finally, this technology contributes to extending the service life of the bridge by minimizing damage from dynamic loads, ultimately improving the structure's long-term performance and safety under seismic conditions. In addition to LRB technology, the Pandansimo Bridge is also equipped with earthquake detection instruments. It enables the mitigation of potential losses during seismic events. Thus, the application of LRB in the Pandansimo Bridge is an integral part of an urban planning strategy focused on disaster resilience and sustainable development. With this technology, the bridge can function optimally in supporting regional mobility and economic activities while providing maximum protection against earthquake risks.

Pandansimo Bridge, situated in a dynamic coastal and riverine environment, is susceptible to river overflow, especially during heavy rainfall and extreme weather events. Flooding can disrupt transportation, damage infrastructure, and threaten surrounding communities. Therefore, mitigation strategies must be integrated into urban planning to ensure the bridge’s sustainability and resilience.

Mitigation strategies for river overflow encompass a comprehensive approach involving multiple engineering and planning solutions. Improved drainage systems play a crucial role, where efficient drainage channels and retention ponds are constructed around the bridge to control water flow and reduce surface runoff, with proper stormwater management preventing excessive water accumulation on the bridge and nearby roads. Riverbank reinforcement and embankments provide additional protection by strengthening riverbanks with retaining walls, gabions, and vegetation to prevent erosion and reduce flooding risk, while elevated embankments along the river serve as protective barriers during high water levels. From a structural perspective, bridge elevation and adaptation are essential, with the bridge deck designed at sufficient height to minimize the impact of rising water levels and the use of flood-resistant materials ensuring durability even in extreme conditions. Early warning and monitoring systems enhance preparedness through sensors that detect changes in water levels and flow rates, enabling authorities to issue flood warnings and take preventive

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actions such as temporary road closures or traffic diversions. Finally, sustainable land use planning integrates the bridge's flood mitigation plan with broader urban planning policies, ensuring that surrounding land use does not exacerbate flooding through proper zoning regulations, watershed management, and green infrastructure that help control water absorption and flow.

Thus, the Pandansimo Bridge can continue to function optimally even in the event of an increase in river discharge. Moreover, the implementation of these mitigation strategies contributes to the sustainability of infrastructure and the resilience of the surrounding environment, ensuring that the bridge can continuously support community mobility and regional economic development safely and sustainably.

It was known that seven high risks occurred in the construction of the Pandansimo bridge, namely flood, river overflow, unpredictable weather, equipment used is often damaged, earthquake, damage or loss (theft) of materials, and unstable soil conditions. Then it is necessary to carry out seven risk controls. This risk control was obtained from the results of interviews with the service provider. This risk control is carried out to minimize the occurrence of risk. Risk control can be seen in Table 6.

Table 6: Risk Control

No	Code	Risk Variables	Description
1	RK19	Flood	Work is temporarily stopped, and equipment is moved to higher ground.
2	RK17	River overflow	Monitoring local rainfall and river water discharge to predict flooding.
3	RK20	Unpredictable weather	Maximizing work productivity is best when the weather is sunny.
4	RK13	Equipment used is often damaged	Conduct equipment maintenance before and after routine use, and consider bringing in more productive equipment.
5	RK18	Earthquake	The bridge is designed to be earthquake-resistant with LRB (Lead Rubber Bearing) technology, which increases resistance to earthquakes by reducing lateral forces, thereby preventing deformation or damage to the building. Conducting an emergency evacuation to a safer location away from the buildings.
6	RK2	Damage or loss (theft) of materials	Enhanced supervision is being implemented for individuals entering and leaving the project.
7	RK33	Unstable soil conditions	Conducting land repairs, such as rehabilitation.

Source: Data processing (2024)

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CONCLUSION

The conclusion of the research on risk management in the Pandansimo Bridge case study is that, based on interviews with contractors, seven sources of risk were identified, namely project risk, technical risk, natural risk, human resource risk, financial risk, and environmental risk. From the seven sources of risk, thirty-seven risk variables were obtained. Risk analysis was obtained from the contractor's assessment to determine the level of impact and frequency, thereby assessing the level of risk. From the results of the risk analysis, high-level risks were obtained, namely flooding, river overflows, equipment used is often damaged, earthquakes, damage, loss (theft) of materials, and unstable soil conditions. These seven high risks require risk control. This risk control is to minimize the occurrence of risk. The seven controls are work is temporarily stopped, equipment is moved to highlands, monitoring local rainfall and river water discharge to anticipate flooding, carrying out maximum and optimal work productivity during good or sunny weather, carrying out equipment maintenance before and after routine use or bringing in more productive equipment, bridges are designed to be earthquake resistant with LRB (Lead Rubber Bearing) technology to increase earthquake resistance by reducing lateral forces so that there is no deformation or damage to the building, carrying out emergency evacuation to a safer place and away from the building. Increasing supervision of people entering and leaving the project, and carrying out land improvements such as rehabilitation.

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CONFLICT OF INTEREST

The authors have no conflict of interest with any parties in writing this article.

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ADAPTING ISO 45001:2018 FOR OPTIMIZING SAFETY PERFORMANCE IN DEVELOPING COUNTRIES: A CASE STUDY ON LIBYA'S CONSTRUCTION SECTOR

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Abstract

The construction industry plays a vital economic role. Still, it remains one of the most hazardous sectors, particularly in developing countries like Libya, where systemic challenges hinder the implementation of effective occupational safety and health (OSH) practices. This study aims to develop and validate two innovative OSH assessment tools— the COSPL 1.0 Calculator and FLARE 1.0 Matrix—designed to enhance safety performance in Libya's construction sector by adapting ISO 45001:2018 standards to local challenges. These tools integrate Libya-specific metrics with international standards to address critical gaps in leadership, planning, performance evaluation, and worker engagement. Data from 121 professionals across four Libyan construction companies were analysed using statistical techniques, including partial least squares structural equation modelling (PLS-SEM). Validation confirmed the tools' reliability and practicality, facilitating quantitative safety assessments and classifying Organisations into five adaptation levels. Findings underscore leadership and worker participation as critical to fostering a proactive safety culture and enhancing safety outcomes. Adaptable to resource-constrained settings, these tools provide scalable solutions for improving OSH practices in developing regions. Future research should explore digital integration and cross-industry applications to enhance their global impact on sustainable safety performance.

Keywords: Occupational Safety and Health, ISO 45001:2018, Construction Industry, Safety Performance Indicators, Developing Countries, Libya.

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INTRODUCTION

The construction industry is a significant contributor to global economic development, employing 180 million workers and contributing 3-5% of GDP. Nevertheless, it remains one of the most hazardous sectors. Construction workers encounter a fatality risk three to four times higher than that of other industries, with around 2.93 million work-related deaths globally each year, particularly affecting developing countries due to insufficient safety management (ILO, 2022). ISO 45001:2018 has enhanced occupational safety and health standards in developed countries via policy integration and the utilisation of new technologies like BIM and IoT; nevertheless, its implementation in Libya is obstructed by resource constraints, inadequate enforcement, and political instability (Boadu et al., 2021). From 2015 to 2020, Libya reported 5,816 construction-related accidents, representing 27% of all workplace accidents, with a 63.98 fatality rate per 100,000 employees (Elkaseh et al., 2024; LPHS, 2020). Addressing these systemic challenges requires context-specific safety interventions to enhance OSH compliance and mitigate workplace risks.

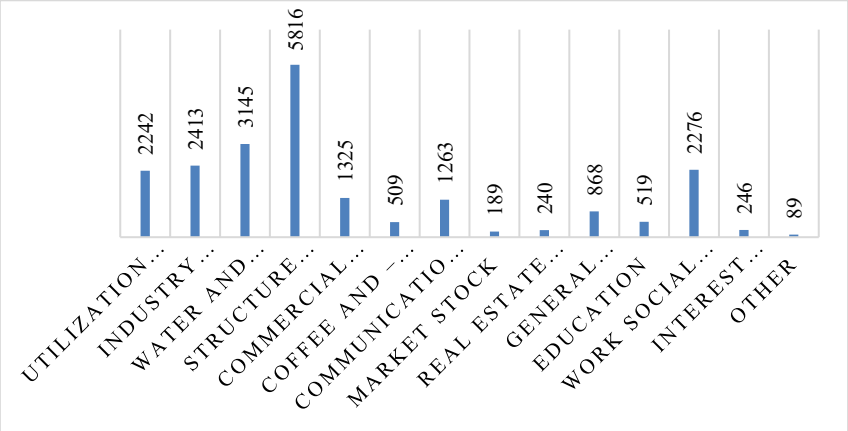


Figure 1: Libyan Work Accidents by Economic Activity (2015–2020)
Source: LPHS (2020), *Commissioner of Buildings (2020), & Author's Calculation* (2021)

Effective ISO 45001:2018 implementation in resource-constrained environments requires strategies tailored to socio-economic and cultural dynamics. Lack of adaptability of existing OSH tools, such as SHASSIC and ConSASS, necessitates localised models (Abas et al., 2017; Teo Ai et al., 2017). In order to improve safety performance in Libya's construction industry, this study integrates workforce behaviors, cultural attitudes, and resource constraints to design and validate two customised OSH evaluation tools: the FLARE 1.0 Matrix and the COSPL 1.0 Calculator. The FLARE 1.0 Matrix categorises organisations into adaptation levels and directs safety improvements, while the

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COSPL 1.0 Calculator statistically evaluates OSH adaptation. By addressing leadership, planning, and worker participation, these tools provide structured evaluations aligned with ISO 45001:2018, offering both theoretical and practical contributions to safety performance optimisation in developing economies.

LITERATURE REVIEW

Occupational safety and health (OSH) practices are crucial for reducing workplace risks in high-hazard industries like construction. Despite progress, the construction sector consistently reports high injury and fatality rates worldwide. ISO 45001:2018 offers a standardised framework for managing OSH risks and enhancing safety performance. However, its adoption varies between developed and developing countries due to differences in enforcement, resources, and organisational culture (Him et al., 2023; Ting & Yahaya, 2024). The COSPL 1.0 matrix improves safety performance assessment by combining organisational and worker-related indicators, ensuring a comprehensive approach to safety management. Organisational indicators include management commitment, policy enforcement, resource allocation, and safety culture, which collectively define the overall safety environment. Worker-related indicators cover aspects like training programs, compliance with safety protocols, use of personal protective equipment (PPE), and hazard reporting mechanisms. By addressing these areas holistically, the matrix provides a structured framework for identifying and reducing gaps in safety performance, ultimately encouraging a safer and more productive work environment (M Misnan et al., 2024).

Global OSH Practices in the Construction Industry

Effective OSH systems reduce accidents, enhance project outcomes, and boost productivity (Teo Ai Lin et al., 2017). Developed countries, such as the United Kingdom and Australia, have made headway by integrating safety into company policy and utilising well-regulated frameworks (Othman et al., 2020). The COSPL 1.0 matrix emphasises the importance of safety policies (15%) and safety culture (33%) as the key elements driving compliance and accident prevention. In contrast, developing nations face challenges such as weak enforcement, outdated regulations, and limited infrastructure (Eljamay et al., 2022; Manu et al., 2019). The COSPL 1.0 matrix found critical gaps in organisational commitment (30%) and training (40%) that require focused actions to enhance safety results.

ISO 45001:2018 Standards

ISO 45001:2018 offers a globally accepted framework for continuous improvement in OSH through leadership involvement and risk-based thinking. Organisations that implemented the standard claim a decrease in accidents, an improvement in their safety culture, and a rise in employee involvement

(Abudabbus et al., 2023). However, barriers such as financial constraints and fragmented regulatory systems hinder implementation in developing countries (Pfaffel et al., 2019). The COSPL 1.0 matrix emphasises the need for infrastructure investments and capacity building by highlighting issues with communication (32%), as well as regulatory compliance (37%). Key benefits include improved safety culture (33%) and worker participation (30%), which requires systemic changes to attain desired outcomes.

Safety Performance Indicators (SPIs)

Proactive and reactive indicators are included in the COSPL 1.0 matrix to provide a thorough assessment of safety performance. Training (40%) and hazard identification are leading indicators that enable proactive risk management, whereas lagging indicators, such as incident rates (24%), evaluate the success of safety measures (Abudabbus et al., 2023; Markowski et al., 2021). Continuous improvement is supported by compliance with ISO 45001:2018's Clauses 6 (risk assessment) and 9 (incident evaluation) (Šolc et al., 2022). Incidents are nevertheless underreported (Othman et al., 2020), underscoring the significance of open communication and responsibility (Pourmazaherian et al., 2021). The matrix categorises indicators into Organisational (e.g., Safety Policy, Culture) and Worker-related (e.g., Leadership, Competency), ensuring comprehensive safety improvements (Chen & Wang, 2018; Macdonald et al., 2023).

The Libyan Context: Challenges and Opportunities

Libya's construction sector faces significant OSH challenges, including limited regulatory oversight, insufficient training, and financial constraints, leading to high workplace accident rates (Eljamay et al., 2022). The COSPL 1.0 matrix identifies critical areas for improvement, such as training (40%), Organisational commitment (30%), and compliance (37%). Aligning with ISO 45001:2018 provides a pathway to enhance safety performance through proactive risk management and systematic evaluations (Šolc et al., 2022). Analysis of Libyan firms shows that worker participation (30%) and leadership competency (27%) are pivotal for achieving compliance (Abudabbus et al., 2023). Localised training initiatives that are adapted to Libya's requirements are crucial to addressing these issues (Asamani, 2020).

Adopting tools like the COSPL 1.0 matrix facilitates comprehensive evaluation and continuous improvement of safety practices. It is essential to strengthen regulatory frameworks and promote a safety culture by including leaders and encouraging active worker participation. Encouraging communication and accountability will further enhance transparency and promote proactive safety practices, reducing accidents and improving outcomes (Pourmazaherian, 2020).

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RESEARCH METHODOLOGY

This study uses a phase-wise methodology to create OSH evaluation tools adapted to Libya's building industry by applying ISO 45001:2018 requirements. Key OSH indicators were found by a thorough literature study and categorised into organisational (such as safety culture and management commitment) and worker-specific (such as competency and leadership) aspects (Zekri et al., 2022; Capasso et al., 2019). These were confirmed by previous studies and professional opinions (Mbanaso et al., 2023).

The study employed structured 5-point Likert scale questionnaires to collect data from 384 participants in accordance with Libyan Government Law No. 544 of 2011. The dataset's adequacy was confirmed by KMO (0.884) and Bartlett's Test ($p < 0.000$) (Napitupulu, 2017). Cronbach's alpha (>0.8) was used to ensure reliability, while factor analysis (Varimax rotation) and Average Mean Value metrics (Maamor, 2009) refined the assessment dimensions.

The FLARE 1.0 Matrix and the COSPL 1.0 Calculator were created to evaluate OSH adaptation levels and categorise organisations into five performance tiers: Elite, Learn, Ascend, Reinforce, and Found. The development process incorporated expert consultations, industry feedback, and multiple refinement stages. Four construction companies in Libya participated in User Acceptance Testing (UAT), which confirmed their usefulness, adaptability, and practicality. As a result, indicator weighting, categorisation thresholds, and reporting procedures were improved.

This methodological framework integrates theoretical insights, empirical validation, and industry applications, providing practical solutions to enhance safety performance in Libya's construction sector and ensuring alignment with ISO 45001:2018.

Table 1: Research Method Procedures

Procedures	Description
Research Design	Quantitative approach using structured questionnaires to assess OSH indicators aligned with ISO 45001:2018 (Flick, 2015).
Data Collection	Structured questionnaires employing a 5-point Likert scale (Mbanaso et al., 2023).
Sampling	384 participants selected using Al-Emad et al.'s (2017) formula.
Data Analysis	SPSS and SMART PLS-SEM were used for statistical assessments, including KMO and Bartlett's Test (Hair et al., 2009).
Tool Development	COSPL 1.0 Calculator and FLARE 1.0 Matrix assess adaptation levels.
Validation	UAT was conducted with four companies to evaluate the tool's practicality and alignment with ISO 45001:2018.
Findings	Summarise results, offering actionable frameworks for assessing and improving OSH performance in the Libyan construction sector, aligned with ISO 45001:2018 standards (Zekri et al., 2022).

Source: Author

ANALYSIS AND DISCUSSION

Organisational Safety Performance Practices in Libya's Construction Sector

This study examines key factors influencing safety performance and ISO 45001:2018 compliance in Libya's construction sector, collecting data from 121 professionals through stratified random sampling and a PDCA-based structured questionnaire. Demographic analysis showed 35.2% in leadership roles, 56% with bachelor's degrees, and 45.1% aged 31–40, ensuring diverse perspectives. Statistical validation confirmed data reliability, with KMO values > 0.6 and high Cronbach's alpha scores.

Four latent constructs were found using PCA (Varimax rotation), which accounted for 63.41% of the variance. The two most important components were hazard identification competence (P3: 0.702) and leadership and commitment (L1: 0.824). According to M. Bulazar (2016), transactional leadership improves compliance, whereas transformational leadership encourages participation through trust and a safe environment. These findings demonstrate the strong correlation between leadership engagement and safety performance. Similarly, MICHA (2017) found that structured leadership training reduced workplace accidents by more than 50%.

However, worker engagement remains a challenge due to low participation rates, limited awareness, and fear of reporting hazards. In Libya's informal labor market, weak enforcement mechanisms exacerbate these issues, alongside a lack of structured training. To enhance worker involvement, targeted interventions such as risk assessment workshops, leadership accountability sessions, and participatory training models are necessary. Studies highlight peer-led safety programs and incentive-based engagement as effective strategies. Additionally, digital reporting tools can streamline communication between workers and management, ensuring timely hazard resolution.

Strengthening leadership engagement and worker participation fosters a proactive safety culture, while structured OSH training, multilingual safety materials, and mentorship programs empower workers in risk management, enhancing safety performance and compliance with international standards.

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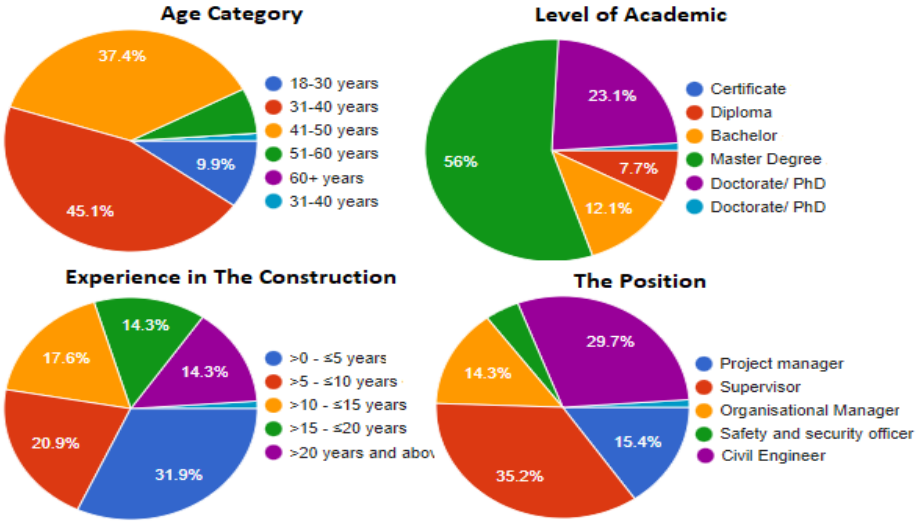


Figure 2: Respondent Demographic Statistics
Source: Author

The underutilisation of worker participation—just 5.8% of safety officers and 14.9% of supervisors—indicates the necessity for inclusive frameworks. There were educational disparities, with 33.9% having less than five years of experience and 12.4% holding advanced degrees, highlighting the significance of capacity-building specifically for Libya. High factor loadings (0.800–0.755) in performance evaluation and improvement phases indicated their critical impact on safety outcomes. Communication (0.845) and Organisational context (0.803) were identified as key drivers of a proactive safety culture. Addressing leadership gaps, fostering worker participation, and improving technical and educational competencies are essential for advancing safety standards in Libya's construction sector.

Safety Performance Indicators in the Libyan Construction Sector

The ISO 45001:2018 standards served as a framework for the evaluation of safety performance indicators, which were divided into organisational and worker-specific aspects. Comprehensive quantitative insights are given in Tables 2 and 3. The mean scores for organisational indicators, including safety policy, increased from 3.653 during the planning phase to 4.246 during the improvement phase, demonstrating a steady development. Leadership commitment (4.331) and safety training (4.136) emerged as key strengths, emphasising their role in sustaining effective safety practices. With a mean score of 4.331, safety inspections demonstrated strong performance across operating phases, demonstrating proactive compliance monitoring. However, moderate scores for

safety culture during performance evaluation (3.373) and improvement phases (3.169) underscore challenges in fostering a proactive safety mindset, highlighting the need for Organisational efforts to embed a safety-oriented culture at all levels.

Table 2: Average Mean Value Safety Performance Indicators: Organisational Indicators

In-Depth Mean Value Assessment for Safety Performance Indicators within ISO 45001:2018					ISO 45001 Elements						
					PLAN			DO		CHECK	ACT
ID	Core Criteria	ID	Main Criteria	Sub Criteria	Context of the Organisation	Leadership and Worker Participation	Planning	Support	Operation	Performance Evaluation	Improvement
SPC	Safety Performance Criteria	SPC-OI	Organisation Indicators	Safety Policy	4.034	2.805	2.653	3.96	2.915	2.720	4.246
				Safety Culture	2.644	3.169	3.195	3.04	3.237	3.373	2.890
				Inspection	4.254	4.263	4.212	4.27	4.331	4.246	4.237
				Commitment	4.229	4.186	4.237	4.17	4.169	4.110	4.331
				Safety Training	4.102	4.025	4.025	4.12	4.136	4.136	4.085
				Compliance	3.975	3.924	4.008	4.01	4.136	4.042	4.042
				Communication	4.127	4.051	4.008	4.11	4.093	4.042	4.161
				Workplace	4.068	3.847	3.983	3.92	3.983	3.898	3.958
				Average Mean	3.929	3.784	3.790	3.95	3.875	3.821	3.994

Source: Author

Worker-specific indicators showed moderate engagement levels. Workers' leadership improved from 3.958 in early phases to 4.212 during the improvement phase, reflecting the impact of skill-building efforts. Conversely, workers' conscientiousness declined from 4.297 during operations to 4.042 in the improvement phase, indicating a need to strengthen safety protocols and sustain engagement. Table 3 illustrates variability in worker participation scores across Organisations, with an average mean score of 4.179 during the improvement phase, highlighting the critical role of inclusivity and proactive involvement in cultivating a strong safety culture.

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Table 3: Average Mean Value Safety Performance Indicators: Worker safety indicators

In-Depth Mean Value Assessment for Safety Performance Indicators within ISO 45001:2018					ISO 45001 Elements						
					PLAN			DO		CHECK	ACT
ID	Core Criteria	ID	Main Criteria	Sub Criteria	Context of the Organisation	Leadership and Worker Participation	Planning	Support	Operation	Performance Evaluation	Improvement
SPC	Safety Performance Criteria	SPC-WI	Workers Indicators	Competency	4.076	4.102	4.068	3.992	4.186	4.136	4.076
				Leadership	4.076	3.958	4.000	4.025	4.017	4.051	4.212
				Participation	4.153	4.144	4.085	4.076	4.102	4.212	4.229
				Extraversion	4.169	4.008	4.127	4.110	4.119	4.119	4.161
				Agreeableness/ Openness	4.492	4.288	4.305	4.254	4.237	4.229	4.356
				Conscientiousness	4.339	4.161	4.169	4.271	4.297	4.212	4.042
				Average Mean	4.218	4.110	4.126	4.121	4.160	4.160	4.179

Source: Author

Statistical analysis confirms the dataset's reliability and the significance of safety performance indicators, with PCA (Varimax rotation) identifying leadership and commitment (L1: 0.824) as pivotal for aligning Organisational practices with ISO 45001:2018 standards. High mean scores for communication (4.161) and Organisational context (0.845) emphasise their role in fostering collaboration and shared responsibility for safety outcomes, while worker-related factors, including participation (4.229) and agreeableness/openness (4.356) during the improvement phase, highlight the necessity of worker involvement in safety planning and evaluation. However, gaps in Planning (3.653) and Performance Evaluation (3.821) within the PDCA cycle underscore the need for targeted interventions, particularly leadership programs that promote accountability and safety-oriented practices. Strengthening inclusive worker participation frameworks is crucial for improving hazard identification and evaluation processes. Capacity-building initiatives, including advanced training and skill development, are essential for enhancing safety performance in Libya's construction sector. Continuous monitoring and structured evaluations will further sustain improvements, ensuring alignment with global safety standards despite the resource constraints and Organisational challenges in developing contexts.

Development of the Measurement Model for OSH Performance

This study proposes a measurement model for evaluating OSH performance in Libya's construction sector by integrating ISO 45001:2018 standards with localised indicators through the COSPL 1.0 Calculator and FLARE 1.0 Matrix, which are designed to address industry-specific challenges and provide a structured approach to enhancing safety performance. Validation confirmed the

model's reliability, with high KMO values (0.780–0.934) and significant Bartlett's Test results ($p < 0.05$), ensuring suitability for factor analysis. Partial least squares structural equation modeling (PLS-SEM) further validated relationships among OSH indicators, achieving SRMR of 0.082 and NFI of 0.704. PLS-SEM identified leadership commitment, compliance monitoring, and worker participation as key determinants of safety performance, with leadership commitment ($\beta = 0.78$, $p < 0.01$) enhancing compliance monitoring, thereby improving safety adherence. Additionally, worker participation ($\beta = 0.64$, $p < 0.05$) mediates the relationship between Organisational safety culture and performance evaluation, emphasising the need for an inclusive safety environment to drive OSH improvements.

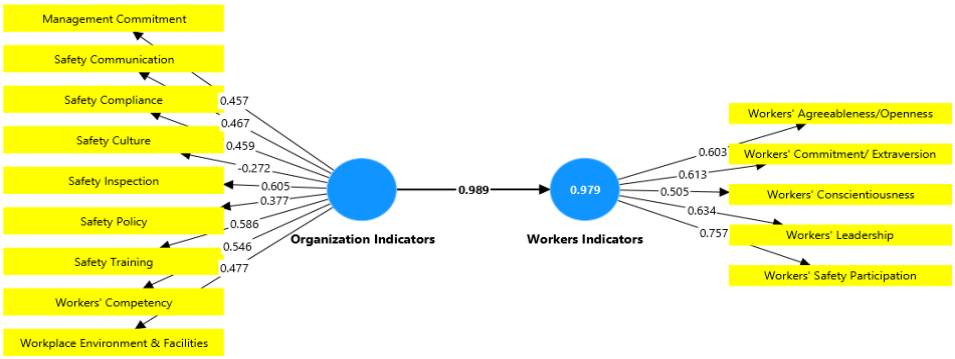


Figure 3: PLS-SEM Model for the Context of the Organisation Element
Source: Author

Principal Component Analysis (PCA) identified safety culture, leadership engagement, and training as key OSH performance drivers, explaining 63.41% of variance, with leadership engagement (0.824) as the most influential factor. This underscores the need to prioritise leadership interventions for OSH improvements. PCA also streamlined data interpretation by grouping related safety indicators, enabling targeted interventions. Organisational indicators showed strong adherence in management commitment and safety inspections, yet gaps in safety culture and performance evaluation highlight the need for proactive safety initiatives. Worker-specific metrics revealed strengths in participation and agreeableness, but conscientiousness requires improvement for sustained engagement. By integrating PLS-SEM and PCA, this study offers data-driven insights to enhance leadership, compliance monitoring, and policy recommendations, strengthening the practical applicability of COSPL 1.0 and FLARE 1.0 in guiding targeted OSH interventions.

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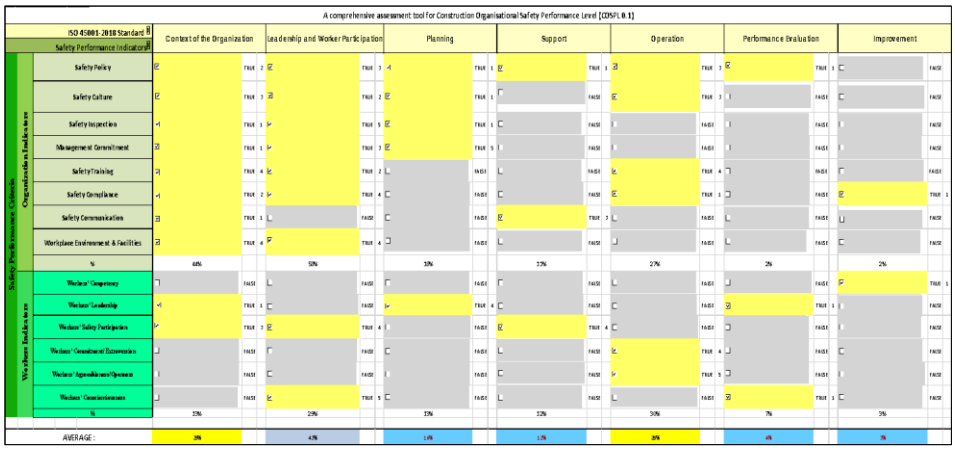


Figure 4: Overall Layout of COSPL 1.0 Calculator
Source: Author

The COSPL 1.0 Calculator (Figure 4) integrates ISO 45001:2018 elements with Organisational and worker-specific indicators, enabling systematic performance assessments. The FLARE 1.0 Matrix (Figure 5) categorises firms into five adaptation levels—ranging from Found to Elite—providing a clear structure for assessing and improving safety practices. Application of these tools to four construction firms revealed variations in adaptation levels. Company A exhibited strong performance in management commitment (71% in the Context of the Organisation) and Support (67%), while gaps in Safety Officers' contributions pointed to areas for improvement.

The tools' diagnostic capabilities were reinforced by User Acceptance Test feedback, which emphasised their practical utility under Libyan Government Law No. 544 of 2011. This application highlighted the tools' value in providing actionable insights to align safety practices with ISO 45001:2018 standards and address universal challenges in resource-constrained environments. The COSPL 1.0 Calculator identified disparities between firm classifications, highlighting the need for tailored strategies to bridge performance gaps, particularly in lower-tier firms.

FLARE 1.0: A Tool for Visualizing the current level of adaptation of ISO 45001-2018 Standards by the construction organizations.

LEVEL	CONTEXT OF THE ORGANIZATION	LEADERSHIP AND WORKER PARTICIPATION	PLANNING	SUPPORT	OPERATION	PERFORMANCE EVALUATION	IMPROVEMENT
80%-100% (Elite)	Top management fully comprehends and drives the OH&S certification process, ensuring the system's effectiveness aligns with strategic goals.	Top management is fully versed in the OH&S certification process and ensures system effectiveness aligns with our strategic vision.	The organization and employees systematically identify risks and opportunities, integrating them into a dynamic OH&S Management System for continuous improvement.	The organization secures and continually advances resources critical for maintaining and enhancing the OH&S Management System's effectiveness.	Processes are defined and enacted to meet OH&S Standards, ensuring system efficacy and organizational compliance.	We've established methods to monitor and measure OH&S, ensuring the acquisition of useful, actionable data for system improvements.	Identified improvements are actioned to meet OH&S goals, enhancing health and safety organization-wide effectively.
60%-79% (Reinforce)	The OH&S Management System mirrors the strategic vision, with a clear policy to prevent workplace injuries communicated throughout the organization.	The OH&S policy, designed to prevent workplace incidents, is well-defined and communicated across the organization in line with our objectives.	Comprehensive plans are in place to meet our OH&S objectives, ingrained into daily activities and organizational ethos.	Regular resource reviews ensure ongoing provision of well-trained staff and proper equipment, meeting OH&S standards and customer expectations.	Systematic reviews of the OH&S Management System ensure adaptations are made for continued relevance and effectiveness.	Timelines for analyzing OH&S results are set, promoting regular evaluation and data-driven decision-making.	Processes manage non-conformities, with clear steps to correct issues and align with OH&S Standards.
40%-59% (Ascend)	Objectives are communicated across all levels, integrating OH&S policies into everyday operations and emphasizing risk-based thinking for success.	OH&S policies and procedures are integrated into daily operations, with managers emphasizing the importance of risk-based thinking for success.	Daily practices now incorporate OH&S steps, transitioning from isolated tasks to consistent, integrated actions.	Resources are identified for accurate OH&S measurement and monitoring, aiming for reliable conformity to safety criteria.	Operations, including contractor coordination, are managed to assess and mitigate risks, aligning with OH&S objectives.	An internal audit program formalizes the evaluation of our OH&S Management System for consistent performance assessment	Prioritization for continual improvement of OH&S system suitability, adequacy, and effectiveness is established.
20%-39% (Learn)	The organization proactively addresses risks and opportunities within processes, with defined responsibilities for OH&S System success.	Risks and opportunities within organizational processes are assessed, with actions taken to enhance OH&S outcomes and decision-making clarity.	We're evaluating potential changes to the OH&S Management System to preserve its future efficacy.	Infrastructure is established, upholding conformance to OH&S standards and legal requirements now and in the future.	Collaboration with external providers is formalized to achieve OH&S goals through clear, defined processes.	Potential improvements are identified, aiming for integration into management reviews to enhance the OH&S Management System.	Worker consultation and participation in the development and continuous improvement of OH&S is ensured.
1%-19% (Found)	Decision-making roles within the OH&S Management System are clearly delineated, ensuring accountability and systematic implementation.	Clear roles and responsibilities are assigned to ensure each part of the OH&S Management System is effectively implemented and maintained.	The need to periodically update our OH&S Management System to maintain effectiveness is acknowledged.	Training and understanding within the workforce are developing to operationalize OH&S process and product criteria effectively.	Emergency protocols are documented and communicated, preparing staff for effective response to preserve safety.	Management review structures are defined, committed to overseeing and improving OH&S implementation regularly.	Commitment to leveraging evaluation outcomes for systematic OH&S advancements is recognized.

Figure 5: The FLARE 1.0 matrix
Source: Author

The FLARE 1.0 Matrix, by categorising firms into distinct adaptation levels, offers a roadmap for organisations to prioritise and implement targeted safety improvements. By integrating localised indicators with ISO 45001:2018 standards, this framework fosters a proactive safety culture and aligns safety practices with international benchmarks. Its adaptability to diverse organisational contexts enhances its potential for application in other developing regions, making it a valuable contribution to improving OSH performance globally.

Evaluation of ISO 45001:2018 Adaptation Using COSPL 1.0 and FLARE 1.0

The COSPL 1.0 Calculator and FLARE 1.0 Matrix were applied across four Libyan construction companies to evaluate ISO 45001:2018 adaptation, categorising them into five levels: Found, Learn, Ascend, Reinforce, and Elite. The assessment identified organisational strengths and gaps, with Company A excelling in planning (57%) and leadership, but struggling with operational execution (50%) and support (54%), while Companies C and D faced resource and leadership challenges. Worker participation varied, with Company A scoring 4.229 compared to 3.742 for Company D, highlighting the importance of inclusivity in fostering a proactive safety culture. Figure 6 illustrates strong user satisfaction with COSPL 1.0 and FLARE 1.0, particularly for accessibility (4.75), readability (5.00), and graphical presentation (4.75).

Beyond Libya, these tools hold potential for broader OSH applications. In Southeast Asian manufacturing, they could address machine safety and compliance challenges, while in the Middle Eastern oil and gas industry, they could strengthen risk management and emergency readiness. Their structured

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classification can also support SMEs in Latin America struggling with regulatory oversight.

Compared to SHASSIC and ConSASS, COSPL 1.0 and FLARE 1.0 offer greater adaptability to informal labor markets and weak enforcement environments, making them more effective for developing regions. Unlike SHASSIC and ConSASS emphasise structured audits, COSPL 1.0 and FLARE 1.0 focus on incremental improvement, flexibility, and cost-effectiveness, ensuring accessibility for SMEs with financial constraints.

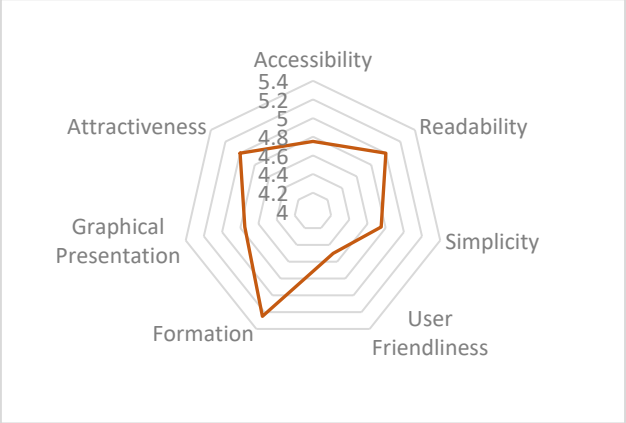


Figure 6: Average Index of the User Acceptance Test
Source: Author

Validation confirmed their reliability and usability, with user acceptance feedback emphasising practicality and standardisation potential, while recommending simplified interfaces and enhanced support materials. Lower-adaptation firms require targeted OSH strategies to strengthen leadership and foundational safety practices. By aligning local OSH challenges with ISO 45001:2018 standards, these tools enhance safety culture, bridge compliance gaps, and improve Organisational performance in resource-limited environments globally. Future research should explore digital integration and cross-industry applications to maximize their impact.

CONCLUSION

This study develops and validates the COSPL 1.0 Calculator and FLARE 1.0 Matrix, providing a structured framework for enhancing occupational safety and health (OSH) performance in Libya's construction sector, aligned with ISO 45001:2018. These tools integrate Libya-specific indicators—cultural attitudes, workforce behaviors, and organisational contexts—to address critical gaps in leadership, planning, performance evaluation, and worker engagement. The

COSPL 1.0 Calculator quantitatively assesses safety compliance, with field testing revealing a 15% improvement in safety performance. Stakeholders found it effective for identifying deficiencies and resource allocation. The FLARE 1.0 Matrix classifies organisations into adaptation levels, guiding strategic OSH improvements. Application across firms demonstrated its effectiveness in distinguishing high-performing companies from those requiring targeted assistance. For example, a mid-sized contractor improved safety training and leadership commitment, advancing to a higher adaptation level within six months. Compared to existing tools, COSPL 1.0 and FLARE 1.0 offer greater adaptability to resource-constrained environments, making them particularly effective for small and medium-sized enterprises (SMEs). These tools foster a proactive safety culture, enhance ISO 45001:2018 compliance, and improve organisational performance, with potential applications in other developing regions and high-risk industries. Future research should explore digital integration, such as artificial intelligence for predictive safety analytics, and cross-industry adaptations to extend their global impact. This study contributes to both academic and practical OSH advancements, offering a scalable model for sustainable safety performance improvements worldwide.

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CRITICAL DETERMINANTS OF UNCERTAINTY IN INDONESIAN'S CONTAINER SHIPPING INDUSTRY

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Abstract

The current research explores the aspects contributing to uncertainty in Indonesian container shipping from the viewpoints of shipping lines and freight forwarders. The data exhibited a non-normal distribution with a total of 338 respondents, 172 from shipping lines and 166 from forwarders, hence a non-parametric methodology was implemented (the Friedman and Mann-Whitney U tests). Notably, schedule precision emerges as the prime performance determinant for both shipping lines and freight forwarders, closely shadowed by safety and security, with no significant divergence in their perceptions of these factors (p-value > 0.05). However, forwarders attribute remarkably greater importance to administrative technical hurdles owing to their extensive involvement in documentation and licensing, diverging explicitly from the view of shipping lines (p-value < 0.05). Other aspects such as container conditions, external influences, and loading/unloading processes revealed no substantial variance. The study recommends harmonized administrative practices to boost collaboration and streamline processes, potentially enhancing global supply chain dependability. Through a shared-focused approach and improved administrative practices, the container shipping industry can reduce risks, bolster efficiency and strengthen the reliability of global supply chains.

Keywords: container shipping, uncertainty factors, shipping liners, forwarder, non-parametric analysis

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INTRODUCTION

In Indonesia, the container shipping industry is marked by its complexity, driven by factors such as technological adaptation, safety standards, infrastructure, and corporate image. PT Pelindo Terminal Petikemas, as a major player in the marine logistics sector, experience how these factors interplay to influence operational efficiency and strategic orientation. The transition from paper based to electronic system and the emphasis on Rubber Tyred Gantry (RTGC) Cranes' efficiency exemplify efforts to reduce uncertainties in container delivery. Such operational changes, alongside strategic enhancements like digital asset management and employer branding, are vital for maintaining competitiveness Whitin Indonesia's bustling maritime logistics landscape. Research on RTGC performance indicated that one of the main topics was on container reception and delivery process; the result of the research indicated that if reception and delivery was executed on time it was also one of the main contributor to TOS crane performance, therefore this means any abnormalities on this procedure could easily trigger uncertainty on its expected delivery time(Cantias et al., 2019). Moreover, as detailed in the study concerning online delivery orders, the transition from paper-based to electronic systems for the management of receipt of delivery orders and container interchange receipts aims to reduce uncertainty by quite literally optimizing processes to facilitate the flow of imported goods. However, in certain sectors, persisting with human methodologies may create uncertainty to some degree regarding delivery periods(Prastyorini & Syaputra, 2020). Moreover, environmental concern, particularly those impacting the construction industry, pose significant uncertainties, affecting project schedules and logistics (Ignatius et al., 2024). This study seeks to examine the views of organizations uncertainty, including logistical complications, regulatory changes, unpredictable operating costs, and external factors like weather conditions and geopolitical risks.

Given the differing focusses of Shipping lines and freight forwarders, their perceptions of what primarily driven uncertainty may vary. Shipping lines typically prioritize aspects such as fuel expenses, route optimization, and port timetables, whereas freight forwarders may emphasize port congestion, customs requirements, and availability of inland passage. This study aims to provide deep insight into how different logistics chain parties perceive uncertainty in container shipping, fostering the development of tailored risk management solutions that effectively address the specific needs and challenges of each type of organization. The transition from exploring the operational factors influencing container shipping in Indonesia to broader examination of the literature, it become clear that the uncertainties discussed are not isolated to local contexts but are echoed globally across the logistics sector. While discussing strategies for uncertainty management in shipping and logistics, it is beneficial to draw parallels with other industries. For instance, a systematic literature review on delay mitigation strategies Whitin the construction industry reveals various approaches that could

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potentially be adapted to maritime logistics to enhance efficiency and reduce disruptions (Abd Aziz et al., 2022).

Following this introduction, the paper is organized as follows to further elaborate on container shipping uncertainties. In the Literature Review the existing research are elaborated and illustrated how global and local factors are interacting by affecting operation efficiencies and creating uncertainties in the maritime logistics sector. We now move to the Research Methodology section, where the mixed methods used to collect and analyze data are described, which are an integrated part of the framework to understand the dynamics at play. The implications of the data are then critically analyzed in the Analysis and Discussion section, translating passive information into a meaningful overview of the management and mitigation of operational, environmental, and/or technical challenges. Lastly, the Conclusion section summarizes these insights and provides recommendations for industry stakeholders, as well as potential avenues for further research. The structured nature of umbrella reviews allows for the identification of key issues and may contribute to a more thorough exploration of each issue, thereby facilitating a better understanding of the challenges in container shipping and potentially more targeted solutions.

LITERATURE REVIEW

The issue of uncertainty and its effects on the dispatching of containerized cargo is a complex problem that needs to be addressed through multiple lenses, including operational, environmental, and technical perspectives. These uncertainties can impact service providers as well as consumers in terms of the efficiency and reliability of container delivery. As studied under exchange economies, the uncertain delivery in markets suggests that the voting power of agents could affect delivery in a more general sense, emphasizing the ability of agents to distinguish between products. This notion is pertinent as uncertainties in the maritime container supply process, exacerbated by global issues, lead to disruptions and delays, causing substantial financial losses for logistics companies (Shin et al., 2024). Especially for Shipping liner and Freight forwarder which affected those uncertainty. The shipping industry can be substantially impacted by the uncertainty surrounding liner shipping container operations, which can affect both operational efficiency and supply chain reliability. The unpredictability of shipping schedules, with over 40% of vessel arriving late, exacerbates this issue, leading to the rising costs for shippers and consignees and the increased level of safety stock (ITF, 2022). Container accidents, frequently attributable to controllable human factors such as improper loading, lead to operational disruptions and financial losses, underscoring the necessity of following to safety protocols to mitigate these risks(Babu & Aithal, 2023). Human factors are among the most common causes of operational disruptions that contribute to financial losses and can be prevented by following to safety

protocols. Container shipping's uncertainty significantly impacts goods forwarders, as it paves a way for many aspects of their operations and decisions. This uncertainty could lead to increased time costs and pressure on the global supply chain, since delayed container shipping would precipitate asymmetrical responses, as longer delays increase supply chain pressure but shorter delays do not alleviate it as rapidly (AÇIK, 2023; Jia et al., 2020). Moreover, the structural transformations in the container shipping sector, including the exit of shipping lines and the establishment of strategic alliances, have engendered additional uncertainty. These alterations require ocean freight forwarders to focus more intently on cargo claims, operational dynamics, and risk management to maintain competitiveness and responsiveness to shippers' logistical requirements (Lu & Wu, 2022).

On this matter, the fluctuating global fuel prices have one of the biggest impacts on operational costs, whereas these changes in circumstances demand a model to ensure the viability of the routes deployed (Huang et al., 2024). Forecasting periods for shipments is a critical aspect as unforeseen disruptions such as inclement weather, port congestion, and geopolitical tensions can delay shipments and necessitate near-real time ship schedule retrieval technologies to mitigate the impacts (Elmi et al., 2022; Mike, 2022). The need to continuously adjust shipping networks and reposition fleets along the regional coastlines in response to continuous changes in container demand volumes and uncertain voyage durations leads to administrative and procedural uncertainties (Kuhlemann et al., 2021). External factors like political instability and the lingering impact of the COVID-19 pandemic also complicate shipping operations as they affect demand patterns and create supply chain disruptions. Technologically advanced ships' increasing vulnerability to cyberattacks poses further safety and security challenges that can affect shipping schedules and operations (Mike, 2022).

Uncertainty affects the loading and unloading operations due to port capacity and variation in handling times at ports, which can cause significant delays (Ksciuk et al., 2023). The imperative to develop infrastructure is a costly and lengthy process that is compounded by the limitations of port capacity (Mike, 2022). A recent study on Malaysian logistics and infrastructure management indicates similarities with Indonesian condition both address logistics uncertainty, while Tarudin et al. (2023) discuss the strategic planning needed for the green logistics adoption and emphasize that some sustainable practices could reduce uncertainty in container shipping. This reference is essential as it corresponds with the operational and environmental solutions that may be implemented in Indonesia to improve the predictability and dependability of shipping operations. The unpredictability of container slot reservations resulting from fluctuating demand can cause revenue losses and suboptimal ship capacity utilisation, necessitating the implementation of strategic booking and reservation

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fee models to enhance profitability (Guo et al., 2021). Emerging shipping routes, such as the Northern Sea Route, allow uncertainties about meteorological and oceanographic conditions in these regions, which can affect the stability of such ways and the tendency of shippers to use these ways (Li et al., 2022). The strategic sourcing of liner services further complicates the process of considering service schedules and their impact on supply chain resilience in the face of demand uncertainties (Lee et al., 2021). Since liner services may also have a considerable impact on how the supply chain withstands uncertainties. The container shipping industry must navigate an intricate web of uncertainties and challenges that require them to implement innovative strategies and agile approaches to maintain functional efficiency and competitiveness within a rapidly changing world. Therefore, this study aims to identify and analyse in depth the most significant uncertainty factors, as well as their impact on the operational performance of both parties. This analysis is expected to provide clearer insights into the variables that affect container shipping, so that it can help industry players in developing risk mitigation strategies and planning that are more adaptive to global dynamics.

RESEARCH METHODOLOGY

In this study, was employed a mixed-methods approach (qualitative & quantitative) to analyze uncertainty in Indonesia's container shipping sector, as depicted in the figure 1. According to statistical principles (Memon et al., 2020), ten standardized factors were pre-identified for shipping liners and forwarders (10 factors) subsequently setting the minimum required number of 100 respondents per sector. Case studies and surveys were used to collect data through INAPORTNET, with purposive sampling for active users. Uncertainty is shaped by factors such as safety/security, schedule reliability, container condition, enable-costs, regulatory and non-regulatory import barriers, process, port capacity, exogenous, and loading/unloading. So, these independent variables influence perceived uncertainty in shipping operations. The selection of factors was driven through expert input, literature review, and preliminary data analysis. To test for robustness and compare uncertainty perceptions between shipping liners and forwarders, statistical methods including normality tests, validity tests, the Friedman test, and the Mann-Whitney U test were used

Upon conducting the Friedman test to compare the perceptions of uncertainty factors, the study proceeded to analyze the similarities and differences in perception between the groups. This further analysis was critical in identifying specific areas of consensus and divergence in views on operational uncertainties. The findings from these analyses were then meticulously summarized, highlighting the implication for the shipping industry. This comprehensive assessment not only detailed the individual and collective impacts of these factors but also provided actionable insights into addressing the

underlying causes of uncertainty in container shipping operations. The test's results are expected to provide broader insights into the major drivers of uncertainty in container shipping and explain possible differences in the perception and striving for those challenges between both types of organizations.

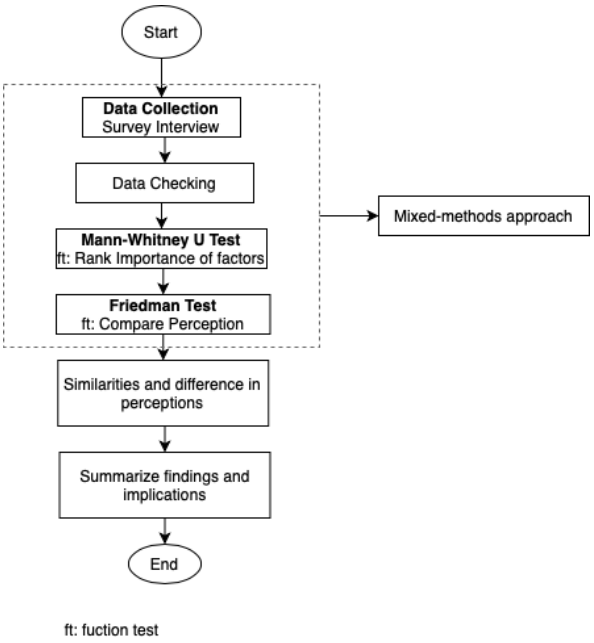


Figure 1: Nonparametric Statistical Tests

Mann-Whitney U

Building upon the principles of the Mann-Whitney U test as explained by Hascheck et al. (2013), a non-parametric method ideal for non-normally distributed data and small sample size, was employed in our study to compare the perceptions of shipping liner and freight forwarder companies on factors contributing to uncertainty in container shipping. Hashim Lim et al. (2023) was exploring utilize the Mann-Whitney U Test that focuses on factor influencing transport mode shift due to COVID-19, notably highlighting hygiene and comfort. This methodological similarity enriches our understanding of how non-parametric tests can effectively analyse shifts in transportation preferences under varying circumstances. The null hypothesis from this method assumed no significant difference between the group, while the alternative suggested significant perceptual difference. We aggregated response, calculated total ranks for each group using formula (1) and (2) as below:

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$$U_x = R_x - \frac{nX(nX+1)}{2} \quad (1)$$

$$U_y = R_y - \frac{nY(nY+1)}{2} \quad (2)$$

In where R_X and R_Y are the rank sums for shipping liners and forwarders, and N_X and N_Y are their respective group sizes. Due to the large category of tied responses at least with respect to the less influential factors, the procedure for handling ties was applied in the Mann–Whitney U test and we averaged the ranks to provide a more analytical approach.

Friedman Test

In particular, the Friedman test investigates uncertainty in container transportation by breaking down uncertainties to their respective determinants that can be tracked through dataset from shipping liners and forwarders. It is a non-parametric test that doesn't assume normality of data, which is perfect as our distributions are non-normal. The formula X_F^2 for computing the test statistic is:

$$X_F^2 = \frac{12N}{K(K+1)}\left[\sum_{j=1}^{K} R_j^2 - \frac{K(K+1)^2}{4}\right] \quad (3)$$

Where N is the total subjects per group, K is the number of groups, and R_j is the sum of ranks for the jth group. If the computed statistic exceeds the chi-square critical value at 0.05 **significance**, the null hypothesis is rejected, indicating significant factor differences. This study applies the **T-Friedman test by** Liu & Xu (2022) refining statistical analysis by incorporating a conservativeness parameter to address data imperfections and variance homogeneity. This enhances analytical precision, aligning statistical methods with data characteristics for better decision-making in container shipping.

ANALYSIS AND DISCUSSION

This study involved a survey questionnaire was distributed to some of shipping liner and Forwarder companies and there were 338 responds with 172 from shipping liner and 166 from forwarder. As outlined in the methodology, a minimum of 10 respondents per factor was required. With ten factors identified (Memon et al., 2020), this established a threshold of 100 respondents per sector. This approach, detailed in the methodology, helps maintain the reliability and validity of the analysis by adequately powering the statistical tests for each variable, thus preventing overfitting and ensuring stable results across predictive models. The number of respondents in this study meets these criteria, confirming the methodological soundness and strengthening the findings derived from the

data. Based on findings from previous studies, this survey analyses the factors affecting container shipping. A normality test was performed after data collection to evaluate the distribution of the data, ensuring the applicability of subsequent statistical analyses. Each attribute significantly influences the operational uncertainty in shipping, affecting everything from logistical delays to cost management and overall operational efficiency. Table 1 shows that the Kolmogorov-Smirnov normality test results of all variables show that significance values are less than 0.05. Performance distributed across multiple factors including safety, punctuality, cost and technical effectiveness display non-normal data distributions. So, to analyze further using a more flexible model to better fit the data behavior and trends a non-parametric method.

Considering the complex challenges earlier recognized this study examines ten individual factors that significantly add to the uncertainty in container shipping. As discussed previously, each of these variables plays a unique role, affecting the operational efficiency and reliability. Their safety implications are risks in manipulating and transport, possibly resulting in postponement of proceedings and added liability in common. Secondly, delays can disrupt the supply chain, and therefore timeliness is of utmost importance, along with the potential issues of cost variability, which makes financial planning challenging due to varying fuel prices and other geopolitical issues. Process inefficiencies and resource waste are a direct result of operational effectiveness, technical constraints, and efficiency levels. The unloading speed, management quality, and outside factors such as weather conditions and container conditions are also significant, pointing to the complex and interlinked nature of practical, operative and external factors governing the uncertainty in the industry. All these plays in tandem to amplify the intricacy of the container shipping sector and together elucidate the interdependence nature in logistics, operations and the external impact which results in the overall uncertainty for shipping companies.

Table 1: Normality Test

Factors	Statistic	Sig
Safety and Security	0.185	<0.001
Schedule Accuracy	0.235	<0.001
Container Condition	0.161	<0.001
Costs	0.189	<0.001
Administrative Technical Effectiveness	0.106	<0.001
Administrative Technical Barriers	0.103	<0.001
Process Efficiency	0.147	<0.001
Port Capacity Management	0.148	<0.001
Influence of External Factors	0.139	<0.001
Loading and unloading	0.154	<0.001

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Given the multifaceted challenges identified within the container shipping industry, it becomes evident that traditional parametric testing methods are inadequate due to the non-normal distribution of data. As evidenced by the normality test results, the data containing these factors do not fit a normal distribution, necessitating the use of the Friedman Test. This non-parametric method is crucial for evaluating differences among the factors influencing uncertainty in container shipping. According to the results of the Friedman Test presented in Table 2, there is a significant variation in how the 338 respondents perceive these uncertainty factors. The test yields a Chi-Square value of 864.191 ($p < 0.001$), highlighting distinct priorities among the factors. Notably, schedule accuracy emerges as the most critical factor, with a mean rank of 2.85, underscoring its pivotal role in shaping operational efficiency and customer satisfaction amidst the prevailing uncertainties.

Besides the punctuality, it is believed that the safety and security factors (mean rank 3.91) and cost (mean rank 4.07) are also significant. The risk of damage to or loss of goods in transit could increase uncertainty, and variability in operating costs, such as gasoline prices and port fees, could affect a company's bottom line. In contrast, port capacity management variables (mean rank 7.37), and loading and unloading operations (mean rank 7.34) are considered less critical in generating shipping uncertainty. Process efficiency (mean rank 6.78) and influence of external factors (mean rank 6.91) are in between, but are even lower ranked than punctuality or cost. For instance, as illustrated in earlier research, the accuracy of the timetable becomes the most relevant aspect of uncertainty (mean rank 2.85), which emphasizes the more frequent concerns about being timely in shipping operations. Similarly, safety (mean rank 3.91) and expenses (mean rank 4.07) are often cited as major drivers of uncertainty, which also aligns with global research. Notably, this study finds that administrative technical issues create a much greater level of uncertainty for Forwarders (p-value < 0.05), a finding that is rarely highlighted in other research. Unlike global-studies medium-grade path forming that dominantly elaborates the operational efficiency and cost aspect, this research explicates Forwarders in Indonesia are having more ambiguity likely in documentation and license pathways. It could be more about the complex landscape of a regulatory structure within the port in Indonesian ports, whereby, the Forwarders more practically take charge of the administrative task than Shipping Liner. Moreover, port capacity management and loading/unloading processes were ranked relatively lower in importance by respondents, in contrast to previous studies that had a higher emphasis on system-failure or infrastructure/operational bottlenecks, as though van Battum et al. (2023) the bottleneck mitigation cycle for container terminals, which not only addresses single bottlenecks but also considers their interdependencies and the need for real-time application.

Table 2: Friedman Test Results for the Ranking of Container Shipping Uncertainty Factors Based on Respondents' Perceptions

Factors	**Mean Rank**
Safety and Security	3.91
Schedule Accuracy	2.85
Container Condition	4.38
Costs	4.07
Administrative Technical Effectiveness	5.72
Administrative Technical Barriers	5.68
Process Efficiency	6.78
Port Capacity Management	7.37
Influence of External Factors	6.91
Loading and unloading	7.34
N	**338**
Chi-Square	**864.191**
Asyp.Sig	**<0.001**

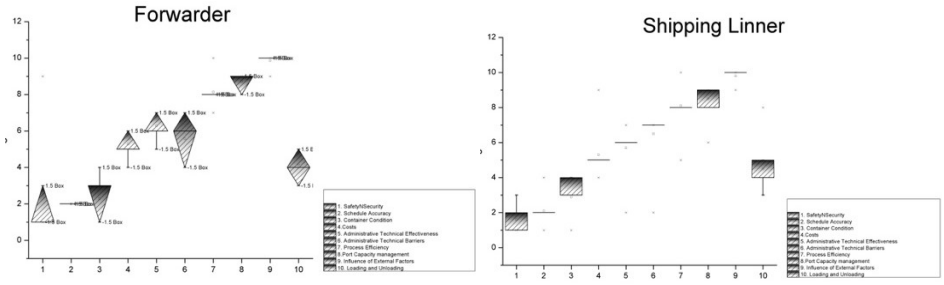
This discrepancy might hint at Indonesia's particular challenges, in which administrative bottlenecks and regulatory hindrances tend to trump more classical operational ones. Thus, this research not only supports a number of existing uncertainty factors, but also extends it by emphasizing administrative technical barriers which is an important but less-explored floor in the scheme of Indonesian container shipment. In Table 3, Mann-Whitney U Test compares Shipping Liners and Forwarders perception about uncertainty factors of container shipping. Most of the factors are considered common for both organizations as safety, punctuality, cost, process efficiency, and port capacity management are significant factors with p-value>0.05. Significant differences, however, arise regarding administrative technical redundancy restrictions, considered more relevant to forwarders (p-value < 0.05), probably due to their involvement in document management and licensing. There are other variables such as container conditions, external factors, loading and unloading processes that do not show a significant difference so that in general both Shipping Liners and Forwarders have a similar perspective in dealing with shipping uncertainty, except for the administrative level.

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Table 3: Mann-Whitney U Test Results on Uncertainty Factors in Container Shipping between Shipping Liners and Forwarders

Factor(s)	Mann-Whitney U	Z	p-value
Safety and Security	13,098.5	-1.320	0,128
Schedule Accuracy	19,3398	-1.005	0,219
Container Condition	12,924	-1.518	0,089
Costs	14,176	-0.113	0,632
Administrative Technical Effectiveness	13,501	-0.868	0,267
Administrative Technical Barriers	11,699.5	-2.886	0.004
Process Efficiency	13,288	-1.110	0,185
Port Capacity Management	14,022	-0.287	0,537
Influence of External Factors	13,670	-0.682	0,344
Loading and unloading	13,890.5	-0.434	0,461

The findings of this study are essentially a reflection of the operational shortcomings tackled by Mohd Fateh et al. (2023) who researched improvement in consultants and contractors communication during construction in Malaysia. Similar to that of the Indonesian scenario, Mohd Fateh et al. emphasise the need for streamlined processes and enhanced collaboration between actors to reduce uncertainty. It demonstrates that the proposed solutions to control for and/or alleviate the discovered sources of uncertainty in Malaysian construction logistics are arguably applicable in the Indonesian container shipping domain as well.



(a) (b)

Figure 2. Distribution of Uncertainty by (a) Forwarder; (b) Shipping Liner

Figures 1 (a) and (b) show the distribution of uncertainty factors in container shipping in the views of forwarders and shipping liners, respectively. As shown with the boxplot, forwarders have a larger spread of data, especially in administrative technical barriers and port capacity governance, which points towards a more diverse experience in terms of being exposed to operational uncertainties. For shipping liners, they display a more organized and even spread, backed by safer & security and more controlled schedule accuracy. External factors and port capacity management are perceived by both groups as major sources of uncertainty. This divergence in distribution indicates that

shipping liners are relatively more stable, while forwarders are mainly driven by admin/regulatory aspects. That is the key to decreasing uncertainty and increasing certainty in maritime supply chain reliability by improving administrative efficiency, optimizing port capacity, and implementing risk mitigation.

In addition, as Table 2 the grouped boxplot which visually compares the distributions of different uncertain factors in container shipping with regard Shipping Liners and Forwarders, revealing quite similar distributions around medians. Both groups have a very similar IQR (Interquartile range), which means most of the data is found in a similar spread. Despite this, outliers and small variations in whiskers indicate that the more extreme cases are more extreme on one side than the other which can be explained by differences in operational structure, in that Shipping Liners maintain a more stable, internally influenced process whereas Forwarders are much more influenced by external and administrative factors. The diamond boxplot gives us additional indication of a relatively symmetric distribution, suggesting that the levels of uncertainty in both groups are evenly distributed without significant skew, one way or another. What this signifies is that the uncertainty is equal for Forwarders and Shipping Liners, but the reasons may be different. As a result, risk mitigation must be directed towards improving operational efficiency and regulatory management for Forwarders and Shipping Liners, whereas the priority must be in optimizing capacity management and reducing external shocks.

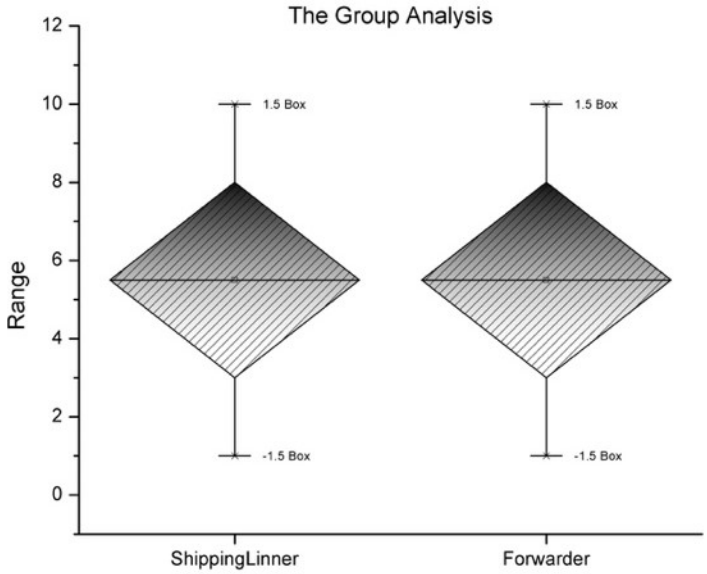


Figure 3. Distribution of Uncertainty by Group

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CONCLUSION

Through this study, uncovered how great the difference is between the shipping liner and the freight payment regarding those uncertainty variables that affect Indonesian container shipping. Most respondents emphasized the fundamental nature of punctuality, saying it was more important than safety and cost combined. They are widely recognized to affect both operational efficiency and customer satisfaction of shipping industries. It would be prudent to suggest that the observed variations in effectiveness among stakeholders were perceived not as failings, but as opportunities to enhance administrative technical controls. This perspective was broadly shared across the industry, as evidenced by shipping liners and forwarders collectively emphasizing the assurance of safety, timely dispatch and receipt of shipments, improved efficiency within the booking sequence, and more strategic distribution of port capacities. Such concerted efforts were underpinned by a thorough commitment to bolstering operational integrity. Supplementary Issues Administrative and documentation issues such as forwarders' licenses are significant issues in this direction and urgently require the sector to revise its administration system to increase its overall efficiency and significantly reduce uncertainty. A consensus of views on operational issues indicates a good basis for coordination to address common issues. Nevertheless, while such differences need to be addressed each group has its challenges that need specialized approaches that cater specifically to the diversity of these groups and their work environments. Policymakers and business leaders involved in creating rules and technologies intended to reduce bureaucratic friction and improve transparency need to bear these findings in mind.

There is a lot of additional research needed into how digital solutions (e.g., blockchain, artificial intelligence) should be applied to combat some of the administrative frictions and enable data to be available and transparent in real time. Going forward, comparative studies with other states with an international maritime outlook could showcase best practices and concepts that might be transferable to the Indonesian context. This study presents some of the fundamentals that create uncertainty for container shipping and advocates for strategic reforms and technologies. Working with common and niche vulnerabilities, the industry can enable and enable practices that support resilience, reliable and ultimately stewardship of the global marketplace.

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PASSENGER PREFERENCES AT GENERAL AHMAD YANI AIRPORT, SEMARANG, INDONESIA

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Abstract

Aligned with Indonesia's commitment to providing reliable and comfortable air transportation, this study investigated passenger preferences at Ahmad Yani Airport, Semarang, aiming to inform strategic improvements to terminal facilities. Employing the Slovin formula, a sample of 375 respondents was derived from 2019 passenger data, adjusted to reflect post-COVID-19 travel patterns. The research explored variables encompassing alternative travel options, travel attributes, passenger perceptions, attitudes towards the airport, as well as alternative and individual limitations. Methodologically, the study utilized descriptive qualitative analysis, Pearson correlation for validity testing, and binary logistic regression for reliability. The findings revealed a demographic profile dominated by male passengers (58.93%), with a significant majority possessing higher education (85.86% holding diplomas or above) and high incomes (78.81% earning over 6 million). Critically, the analysis demonstrated a significant influence of individual passenger capabilities on their preferences, as evidenced by a t-statistic of 22.82228, which significantly exceeds the critical t-value of 1.966. This study concludes that airport managers should prioritize the customization of airport facilities and services to effectively meet the nuanced needs and preferences of this specific demographic, acknowledging the substantial impact of individual capabilities on passenger preferences.

Keywords: Passenger Preferences, Airport, Education, Capabilities

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INTRODUCTION

The increase in demand for air transportation passengers, both on an Asian and national scale, is significant (Tri et al, 2017) and the growth in passenger demand, especially at Ahmad Yani Airport in Semarang, is 8-9% (BPS, 2017). The increase in demand for air transport passengers will affect airport planning and management, which is important in determining infrastructure needs (Tito, 2014), this will affect capacity and infrastructure on both the air and land sides. The land side facilities needed by passengers are efficient, comfortable and safe, for this reason it is necessary to know passenger preference so that passengers can be satisfied. Indonesia is currently actively building representative airports that are comfortable and safe.

Demographics can be used to measure the characteristics of airplane passengers, age groups, gender, education and income of passengers can be analyzed as subcultures because they have different values and behavior, income subcultures will make people have different incomes and also have different behavior and lifestyle. So for airport development it is necessary to observe this behavior.

PROBLEM BACKGROUND

What parameters influence passenger preferences at Ahmad Yani Airport in Semarang, so that in preparing facilities for airplane passengers on the land side they can feel comfortable and safe when they are at the terminal.

LITERATURE

Airports are an important node in the transportation system and can have an important role in supporting the socio-economic development of urban areas (Paolina, 2016), as the current development of airport platforms changes its activities, namely the relationship between commercial activities and aeronautical activities (Estelle, 2016) and to optimize Airport functions need to increase air traffic capacity, including terminal modernization, airport infrastructure and purchase of operational equipment (Dariusz, 2016).

Characteristics of passengers at the airport on behavioral intentions through technology acceptance and customer satisfaction. The results are that customer satisfaction has a significant influence on behavioral intentions (Jong and Jin, 2019), the level of education influences understanding and perception (Yi Shi, et all, 2023). Airport services significantly influence passenger preferences, as in other markets, by impacting passengers' choice of airline and the utilization of available terminal facilities (Sofia & Filipe,2021). The attitude of forgetting and destroying the environment reflects irresponsible humans which is contrary to ethical and religious values (Normah, et all, 2023)

There is an increasing trend in the number of disruptive airline passengers taking flights, so the safety of passenger preference is critical to the

comfort, well-being and safety of other passengers, crew and the smooth operation of airlines. Safety culture has been proven to have an impact on the implementation and efficiency of safety management (Katherine, 2022), increasingly rapid development will change people's behavior (Normah, 2020), while service quality and availability of facilities have a partial or simultaneous influence on passenger satisfaction in waiting room at Ahmad Yani Airport Semarang (Mohammad & Nur, 2022), Airport facilities and service quality have a significant and positive effect on passenger satisfaction, where passengers feel more satisfied when the facilities available at the airport are complete and in good condition (Jumawana & Primadi, 2022 ; Immanuel, et al, 2024 ; Alex, et all, 2024). Characteristic factors of passengers that can influence the choice of mode to get to the airport include distance from residence, type of work, income level, private vehicle ownership, passenger age and gender (Wahadi & Iwan, 2017)

Travel motivation substantially increases the intention to travel (Nor Hayati, et all, 2024) while the factors that are statistically significant influence passengers in choosing the Taipei-Kuala Lumpur-Jakarta flight route are the airport's reputation for transit, flight ticket prices, flight duration , comfort in connection, and number of luggage (Dwi D, et al, 2021), customer satisfaction is influenced by their behavior, which has an impact on satisfaction (Aznor, et all, 2023), the ability to pay makes it possible to choose environmentally friendly facilities (Aisyah, 2024)

RESEARCH METHODOLOGY

The annual population of airplane passengers at Ahmad Yani Airport in Semarang as secondary data was taken before Covid hit the world, data taken for 2019 from Angkasa Pura 1, Semarang Branch was 1,618,109 passengers, including the number of departing and arriving airplane passengers, so the number of daily passengers was 4,433 passengers. which is the daily population. The number in the last year of 2019 before Covid was 8250 passengers/day. The number of sample respondents was determined from the daily passenger population using the Slovin formula (Sugiyono, 2017), with an error accuracy of 5% (e value = 0.05), so that a sample size of 375 respondents was obtained. The sampling method is using an instrument in the form of a questionnaire which is distributed directly to respondents and online to airplane passengers. Behavioral analysis was conducted using a descriptive and qualitative approach while for testing the instruments used are tested including their validity and reliability (Riduwan, 2008), calculating the validation and reliability of all variables in this study using SPSS version 29 software.

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RESULT AND DISCUSSION

The results of calculating 375 data (rounded) can be presented as follows, for passengers according to gender, they are 58.93% male and 41.07% female, which can be seen in table 1,

Table 1: Gender of Airplane Passengers

Amount	Gender	Percentage
221	Man	58.93
154	Woman	41.07
375		

Meanwhile, according to age groups, airplane passengers at Ahmad Yani airport are dominated by the productive age group > 21 years, amounting to 85.27%, see table 2 below.

Table 2: Airplane passengers according to age

Age	Respondents	Percentage
< 10 year	1	0.27
11 - 20 year	13	3.47
21 - 30 year	153	40.80
31 - 40 year	144	38.40
> 40 year	64	17.07
Total	375	100

The educational level of airplane passengers is high school graduates or above, amounting to 98.86% and the largest number of education levels above strata-1 amounting to 74.13%, can be seen in table 3.

Table 3: Airplane Passengers by Education Level

Education	Respondents	Percentage
Elementary school	1	0.27
Junior High School	3	0.80
Senior High School	49	13.07
Diploma	44	11.73
Strata-1/2/3	276	74.13
Total	375	100.00

Table 4: Airplane Passengers According to Income

Income (million)	Respondents	Percentage
< 3	30	8.00
3 s/d 6	48	12.80
6 s/d 9	130	34.67
9 s/d 12	109	29.07
> 12	58	15.47
Total	375	100.00

Table 4 shows that the income of airplane passengers with income > 6 million is 78.81%. In table 5, according to the purpose of travel, the largest number is for work matters, namely 59.47% and family matters at 16.80% and for tourist purposes at 12.53, this is in accordance with the location of the airport in the city of Semarang which has the title of service city, so that airplane passengers are for work purposes, with the formula:

Table 5: Passengers by Travel Purpose

Travel Purpose	Respondents	Percentage
Family	63	16.80
Education	22	5.87
Social/religious	20	5.33
Tour	47	12.53
Job/business	223	59.47
Total	375	100.00

This study analyzed the behavior of airplane passengers at Ahmad Yani Airport in Semarang, utilizing a sample of 375 respondents. The variables examined included alternative travel options, travel attributes, perceptions of the airport, attitudes towards the airport, alternative limitations, and individual limitations. Regarding alternative travel, 45% of respondents agreed that air transportation is their primary mode, while 77% indicated they could use other modes, and 81% found it easy to access these alternatives. In terms of travel attributes, 41% perceived airport capacity as tight, 53% reported that flight departures and arrivals were often delayed, and 33% stated they rarely experienced travel disruptions. However, 73% found air travel cost-effective for their trip purposes, and 89% appreciated the availability of train transportation to the airport. Perceptions about the airport revealed that 85% found air transportation comfortable, 62% considered it safer, and 65% preferred it for long-distance travel compared to other modes. Concerning attitudes towards airport facilities, 92.53% agreed that the waiting area was comfortable, and 93.33% rated the overall facilities and infrastructure as good.

Alternative limits refer to external factors regarding capacity and public facilities at Ahmad Yani Airport in Semarang area; 90.40% agreed that access to the airport was good and easy to reach and 31% agreed that the facilities were still not comfortable, but 49% said they were comfortable.

The individual restrictions related to airplane passengers who have vehicles, income and health to use private means of transportation are; 70% stated that to support the journey to their destination because they have a private vehicle, 64% stated that because of their salary or income it is possible to reach their travel destination by private transportation and 72% stated that your capabilities or physical health is still good enough to use private transportation.

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Validity testing, the results of the validity test of the items for statements show that all statement items regarding alternative travel variables, travel attribute statements, perception statements regarding airports, attitude statements towards airports, alternative limitation statements, and individual limitation statements, all variables are declared valid, this can be seen in table 6. determining the value of r table, in the initial stage 375 samples were used with a = 5%, for df = N – 2, or in this case df = 375-2 = 373, with a significance level of 95% and a 5 %, then r-table.

$$r = \frac{n\sum XY - \left(\sum X\right)\left(\sum Y\right)}{\sqrt{n\sum X^2 - \left(\sum X\right).^2}\sqrt{n\left(\sum Y^2 - \sum Y\right).^2}}$$

Table 6: Distribution of r

df (N-2)	Significance level					
	One tail	0.05	0.025	0.01	0.005	0.0005
	Two tail	0.1	0.05	0.02	0.01	0.00100
373		0.08507	0.10129	0.12010	0.13287	0.16926
374		0.08496	0.10115	0.11994	0.13269	0.16904
375		0.08484	0.10102	0.11978	0.13252	0.16881
376		0.08473	0.10089	0.11962	0.13234	0.16859
377		0.08461	0.10075	0.11946	0.13217	0.16837

The figure obtained is 0.10129, testing the validity of the statement items using the following assumptions. If the r-count is positive and the r-count > r-table then the item or variable is declared valid. Validity test analysis of each variable is presented in table 7.

Table 7: Calculated r and r table Values for Variables

Variable	Statement (item)	Calculated r value	Table r values	Information
Alternative travel	1	0.085	0.1012898	Invalid
	2	0.316	0.1012898	Valid
	3	0.332	0.1012898	Valid
Travel Attributes	1	0.437	0.1012898	Valid
	2	0.521	0.1012898	Valid
	3	0.481	0.1012898	Valid
	4	0.267	0.1012898	Valid
	5	0.234	0.1012898	Valid
Perceptions about airports	1	0.504	0.1012898	Valid
	2	0.586	0.1012898	Valid
	3	0.388	0.1012898	Valid
Attitude towards the airport	1	0.387	0.1012898	Valid
	2	0.342	0.1012898	Valid
	3	0.402	0.1012898	Valid

Variable	Statement (item)	Calculated r value	Table r values	Information
Alternative boundaries	1	0.261	0.1012898	Valid
	2	0.163	0.1012898	Valid
	3	0.228	0.1012898	Valid
Individual limitations	1	0.519	0.1012898	Valid
	2	0.534	0.1012898	Valid
	3	0.557	0.1012898	Valid

Reliability testing is used to show the extent to which a measurement can be trusted and has high reliability, which is called a reliable measurement. A questionnaire is said to be reliable if r count > r table, the results of each variable's reality value are displayed in table 8. with the formula below:

$$r = \left(\frac{k}{k-1}\right) + \sum_{n=1}^{\infty} \left(\frac{\sum \sigma^2 b}{\sigma^2 t}\right)$$

Table 8: Reliability Test

Variables	No item	Cronbach alpha	α
Alternative travel	1	0.704	0.5
	2	0.680	0.5
	3	0.679	0.5
Travel Attributes	1	0.671	0.5
	2	0.659	0.5
	3	0.664	0.5
	4	0.684	0.5
	5	0.686	0.5
Perceptions about airports	1	0.663	0.5
	2	0.653	0.5
	3	0.674	0.5
Attitude towards the airport	1	0.674	0.5
	2	0.677	0.5
	3	0.673	0.5
Alternative boundaries	1	0.696	0.5
	2	0.691	0.5
	3	0.699	0.5
Individual limitations	1	0.660	0.5
	2	0.658	0.5
	3	0.654	0.5

From table 8. The reliability values for all variables are satisfactory because the Cronbach alpha value is greater than the value α = 0.5.

Rating scale analysis is a list containing the traits or characteristics of passenger preferences that you want to assess that are in accordance with the

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criteria you want to assess and recorded in stages starting from the lowest value to the highest value.

The average value of passenger preferences for all points regarding passenger preferences is 3.763 on a scale of 1-5, so the statement about *passenger preferences* is high.

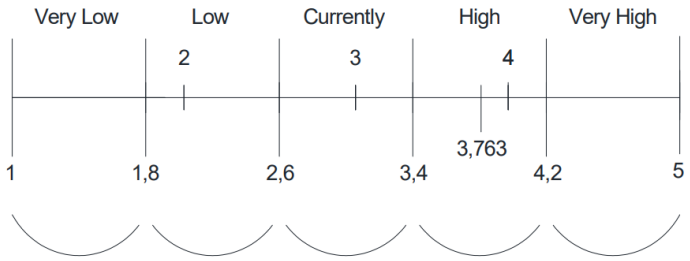


Figure 1. Criteria for Average Level of Behavior

The average value of passenger satisfaction with all points regarding passenger preferences is 3.751 on a scale of 1-5, so the statement regarding satisfaction is high.

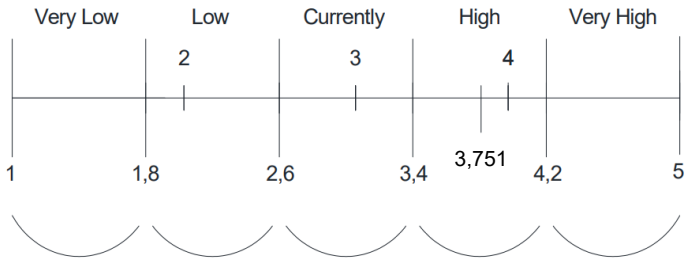


Figure 2. Criteria for Average Capabilities Level

After 375 respondents' data was processed into ordinal data in ranking form so that it was known to be bi^2 as in the table above. Then these results are entered into the Sperm Rank Rank correlation formula for the calculation as follows:

$$\rho = 1 - \frac{6\sum bi^2}{n(n^2-1)}$$

$$\rho = 1 - \frac{6x2862172{,}50}{375(375^2-1)}$$

$$\rho = 0{,}674346$$

From the results of these calculations, it can be seen that there is a positive relationship, namely 0.674346, between the level of passenger preferences towards airport facilities and the abilities possessed by each passenger at Ahmad Yani airport. To be able to provide an interpretation of the strength of this relationship, the following table guidelines can be used:

Table 9: Guidelines for Providing Interpretations of Correlation Coefficients

Coefficient interval	Relationship level
0,000 – 0,199	Very low
0,200 – 0,399	Low
0,400 – 0,599	Neutral
0,600 – 0,799	Strong
0,800 – 1,000	Very strong

Source: Sugiono, 1999.

Based on this table 9, the correlation coefficient found was 0.674346, including the strong category. So there is a relationship between the level of passenger preferences and the level of capabilities of passengers at Ahmad Yani airport.

So that it can be applied to the entire passenger population at Ahmad Yani airport, it is necessary to carry out a significance test. The hypotheses for testing this significance are as follows:

H0 = tcount = ttable (correlation coefficient is not significant)
Ha = tcount > ttable (significant correlation coefficient)

The calculation of the significance test results from the correlation coefficient is as follows:

$$t_0 = \rho \sqrt{\frac{n-2}{1-p^2}}$$

$$t_0 = 0{,}674346 \sqrt{\frac{375-2}{1-0{,}674346^{\,2}}}$$

$$t_0 = 22{,}82228$$

To find out whether it is significant or not, it is necessary to compare it with the t-table value dk = n – 2 with an error level of 5%, using a two-party test, the t-value is seen by a two-party test with an error of 5% and the result obtained is t table = 1.966, then compared with t-count with t-table as above, it can be seen that t-count (22.82228) > t-table (1.966). This means that the null hypothesis (Ho) is rejected and the alternative hypothesis (Ha) is accepted, where the correlation coefficient is significant. With the results of the significance test from the correlation coefficient of a sample of 375 respondents at Ahmad Yani airport, it

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was stated that there was a strong relationship between the level of passenger preferences towards airport facilities and the capabilities possessed by each passenger, the more passengers were able to use the means of transportation, namely airplanes, at Ahmad Yani Airport.

CONCLUSION

According to gender, airplane passengers at Ahmad Yani Airport in Semarang were 58.93% male and 41.07% female, with a strata-1 educational background of 74.13% and 78.81% with an income of > 6 million. There is a strong relationship between passenger preferences and capabilities in airplane passengers, with reliability values above the standard Cronbach alpha value greater than the value $\alpha = 0.5$ and compared with the t-count with the t-table as above, it can be seen that the t-count (22.82228) > t-table (1.966). This study concludes that airport managers should prioritize the customization of airport facilities and services to effectively meet the nuanced needs and preferences of this specific demographic, acknowledging the substantial impact of individual capabilities on passenger preferences.

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URBAN VISUAL INDEX (UVI) BASED ON PUBLIC PREFERENCES FOR EVALUATING THE VISUAL-SPATIAL COMFORT OF KAYUTANGAN, INDONESIA

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Abstract

Kayutangan is a strategic area that will undergo long-term development to increase its attractiveness as a cultural tourism area. Therefore, the government revitalizes the area by redesigning the pedestrian area to improve the quality of public space. However, after the renovation was finished, problems emerged that affected the Kayutangan road corridor's (KRC) visual and spatial comfort, affecting the visitor's impression of the historic area. Therefore, we investigate the Urban Visual Index (UVI) based on public preferences to evaluate the visual-spatial comfort of Kayutangan as a historic urban area. This study used a quantitative descriptive method with multiple linear regression analysis techniques using SPSS. The data are gathered using an online questionnaire. The results show that each zone has different index scores. Each zone has different building and pedestrian street elements that influence the historical impression of the area, depending on the zone's characteristics. However, some spots in each zone lack historical impression due to the failure of the area's authentic image preservation and poor street furniture layout design. As a result, the design and layout of street furniture and preserving the authenticity of the Dutch colonial building design are crucial considerations when designing pedestrian spaces in a historic area to maintain its visual-spatial comfort.

Keywords: Historical impression; Public preference; Streetscape; Visual-spatial comfort; Regression analysis

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INTRODUCTION

Malang City is one of the cities established in 1914 and designed by Dutch urban architect Thomas Karsten (Widodo, 2006). Some colonial heritage urban areas still exist today, including the Kayutangan area. This area has been the main commercial street of Malang City since the beginning of the city's development during the colonial era. Based on the Regional Spatial Plan (RTRW) of Malang City, Kayutangan has been designated as a socio-cultural strategic area and will undergo long-term development to increase its attractiveness as a cultural tourism area. Historic areas have a heritage identity associated with them. The historical value and character are significant if an area is legally designated as historic (Purwantiasning, 2021). Historic areas can develop adaptively if the socio-cultural elements as the main drivers are alive (Pintossi et al., 2023). Historic areas, now popular for heritage tourism, allow tourists to immerse themselves in diverse cultural settings, performances, local food, handicrafts, and activities that reflect present and past cultures (Chhabra et al., 2003).

As one of the strategic areas in the city, this area is at risk of causing unforeseen problems, both visible (visual) and structural (functional) problems, such as problems with the pedestrian space. The Malang City Government revitalized Kayutangan in 2019 to make this area the heritage capital of Malang City. One of the goals is to improve the quality of pedestrian space as a public space on the road corridor and preserve the remaining historical value. According to Antariksa et al. (2024), the development of this historic road corridor has contributed to three Sustainable Development Goals (SDGs), namely Goal 3 (Good Health and Well-Being), Goal 8 (Decent Work and Economic Growth) and Goal 11 (Sustainable Cities and Communities).

Kayutangan, as a developing historic area, is susceptible to changes. The pedestrian space must be designed to consider user comfort, both visually and spatially. These issues can significantly influence the area's perceived image based on the public's preference (Ernawati et al., 2018). The government's late revitalization efforts have resulted in the loss of historical value at several points in this street corridor. The urban design of the Kayutangan road corridor (KRC) is inconsistent, with differences in street furniture design in several segments of this road corridor. In addition, the placement of street furniture that is too close together takes up pedestrian space, making the space for walking narrow, especially when the corridor is crowded.

Several studies have been conducted about urban comfort. The most common research conducted is outdoor thermal comfort in urban spaces, be it parks or street corridors. In addition to thermal comfort, visual and spatial comfort have been studied in previous studies. Research on visual and spatial comfort can help manage and improve urban streetscape through 3D spatial multimedia systems and urban planning (Santosa et al., 2021; Santosa & Fauziah,

2019). Visual comfort is one of the important visual phenomena in the design of transit-oriented development (Achsani & Wonorahardjo, 2020). Exploring the relationship between urban green space and human perception can be related to visual comfort (Meng et al., 2024; Sun et al., 2023). Meanwhile, spatial comfort can be measured using street-view images (Yang et al., 2021).

However, few studies on visual-spatial comfort focus on pedestrian space-creating elements in historic street corridors. Therefore, this paper seeks to fill this research gap by investigating and developing the visual-spatial comfort of pedestrian placemaking elements through an Urban Visual Index (UVI) based on public perception. This research introduces the UVI, an innovative tool to measure urban visual aesthetics systematically. By combining street view images and quantitative spatial analysis, the UVI offers a new perspective on the relationship between urban design and people's impressions. This contribution enriches the science of urbanism and supports urban policies more responsive to visual aspects.

LITERATURE REVIEW

Preference can be described as an individual's perception of the environment. Preferences are formed through a series of processes in the sensory perception of visual information (Widyawati, 2021). The physical characteristics of the environment, the quality of urban design, and people's reactions can determine the public's preferences when walking along a street corridor (Ernawati et al., 2018). From an architectural perspective, visual preferences involve judgments about the visual appearance of building elements. The factors that can influence visual memory capture are shape, form, color, and texture.

Visual and spatial comfort can affect people’s impression and experience of a road corridor by the street furniture and the surrounding buildings. Spatial comfort is affected by road obstruction, spaciousness, vegetation, sky view, and openness (Yang et al., 2021). It can also be affected by building mass, pedestrian shading, space utilization, space functionality, street network complexity, and the liveliness of the street (Li et al., 2023; Marisa & Fuad, 2023). Natural elements, landscape diversity, openness, neighborhood density, and cleanliness can affect the urban landscape’s visual comfort (Achsani & Wonorahardjo, 2020; Meng et al., 2024). In summary, visual and spatial comfort can be determined by the physical elements of the street, such as the building, vegetation, and openness, to support clear visibility and user activity in the corridor throughout the day.

Urban Visual Index (UVI) is a concept for evaluating and analyzing visual elements in urban environments. The UVI concept refers to several theories that cite books related to urban and psychology, such as The Image of the City by Kevin Lynch (1960), Environmental Psychology by Robert Gifford

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(2013), The Theory of Aesthetics and Spatial Quality from Cities for People by Jan Gehl (2010), Theory of Experience and Emotion in Urban Design from A Pattern Language by Christopher Alexander (1977), Social Theory and Urban Identity from Social Justice and the City by David Harvey (1973). The basic concept of the UVI combines various theories from urban planning, environmental psychology, aesthetics, and technology.

In discussing the development of a framework for assessing the historical significance of the Kayutangan historical corridor, the UVI plays an important role in improving the visual and aesthetic character of the urban environment, including the historic corridor. In the context of the Kayutangan historical corridor, the UVI can be used to authenticate and ensure consistency in the architectural and street design elements, determine the extent to which the corridor maintains its historical character, and assess the overall visual-spatial quality of the surrounding environment from the public's preferences as the primary user of the urban space.

RESEARCH METHODOLOGY

The research method used a descriptive quantitative approach. There are several historic road corridors in Malang City; one of them is the KRC, Jl. Basuki Rachmat, Malang City, East Java (see Fig. 2). This road corridor was chosen because this area has undergone massive changes since the renovation and is crowded with visitors compared to other historic road corridors in the city. However, the urban design of the pedestrian area differs between each corridor segment (see Fig. 1). This difference is the main reason for the area's division into three zones. The condition of Zone 1 is not as crowded as the other zones, and the design processing is not as good as that of Zones 2 and 3, making this zone quieter than the other zones. Zone 2 is the busiest of the three research zones. In addition, the design processing in this zone was done more optimally than in Zone 1. Similar to Zone 2, the design processing in Zone 3 is also maximized compared to Zone 1, even though the activities in this zone are not as much as in Zone 2.

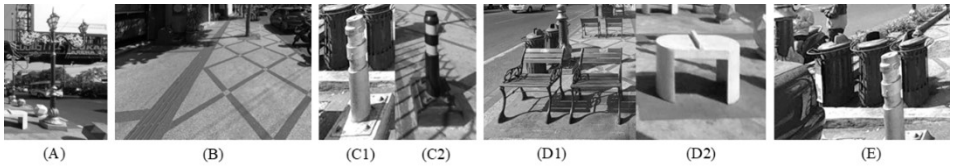


Figure 1: Streetscape elements; (A) Lamp; (B) Pathwalk pattern design; (C1) Bollard design in Zones 1 and 2; (C2) Bollard design in Zone 3; (D1) Chair design in Zone 1 and 2; (D2) Chair design in Zone 3; (E) Trash bin.

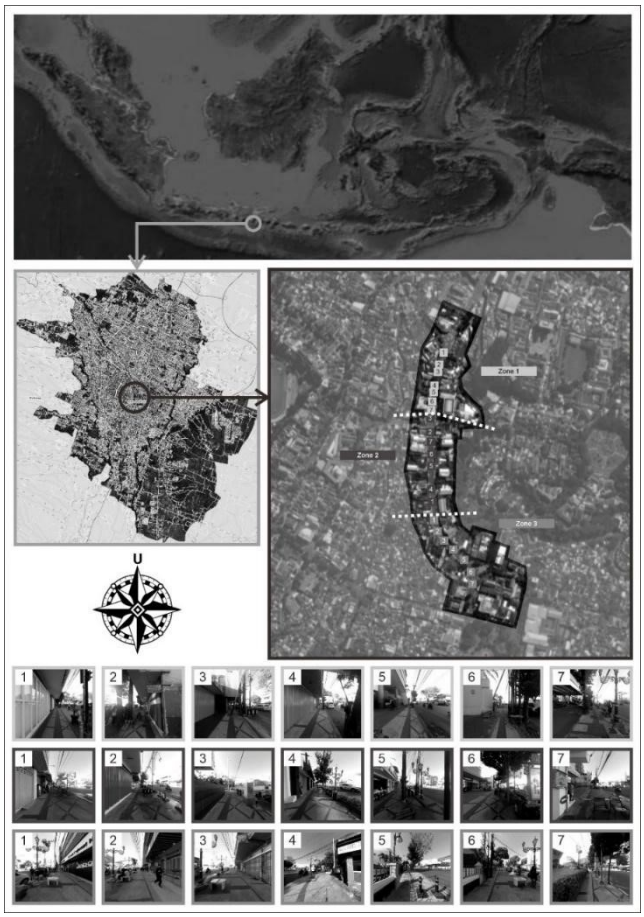


Figure 2: Research location

The sampling method employed was non-probability sampling. The number of samples taken was withdrawn based on the population. However, if the population is uncertain, then a technique or formula from Malhotra (2019) states that the number of samples must be at least four or five times the number of question items. In this study, 16 questions about the variables are to be analyzed. If multiplied by four, the minimum number of samples in this study is 64, to which a 5% margin of error is added so that it is rounded up to 70 samples.

This study's total number of samples was 254 individuals across the three research zones: 80 respondents in Zone 1, 98 in Zone 2, and 76 in Zone 3. The research variables comprised five streetscape elements and three elements of building visual composition within the area (see Table 1). Data were collected

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using a questionnaire distributed online via Google Forms. The acquired data were analyzed using the multiple linear regression method.

Table 1: Research variables

No.	Variables	Sub Variables
1.	Streetscape elements	Lamp Design
		Pathwalk Pattern Design
		Bollard Design
		Chair Design and Layout
		Trashbin Design and Layout
2.	Building composition of the area	Building Colour
		Building Material
		Building Signage

Before entering the linear regression stage to analyze the data that has been collected, a prerequisite test of the questionnaire must be carried out. The questionnaire prerequisite test has two tests, namely the reliability test and the validity test. The reliability test is carried out to determine the level of consistency of the answers submitted. Reliability means that the characteristics of the measurement process or instrument itself do not cause the numerical results produced by an indicator to vary (Neuman, 2014). Validity is how well an empirical indicator "fits" the conceptual definition of the construct it is intended to measure (Neuman, 2014). Testing the validity of question items is done by correlating the score of each item with the total score of all question items.

RESULTS

The multiple linear regression tests are done using the Enter method. The results of the reliability statistical analysis stated that the data collected through the questionnaire for Zone 1 and Zone 2 of the KRC had a high level of reliability ($\alpha > 0.80$), and Zone 3 had a very high level of reliability ($\alpha > 0.90$). The independent and dependent variables in each zone were confirmed valid using Pearson Correlation based on the validity results. Each zone has a normal data distribution based on the Kolmogorov-Smirnov Test ($p > 0.050$). Therefore, the data can be continued for further analysis. The regression analysis reveals that each zone along the KRC demonstrated unique characteristics. Specific to each zone, these characteristics play a pivotal role in shaping the pedestrian environment. The prevalence of these zone-specific elements within the corridor, whether visual elements of buildings or street furniture, significantly influences the strength of the historical impression associated with these zones.

Table 2: Summary of Regression Analysis of Pedestrian Street Elements in Each Zone

Coefficients[a]									
Variable	**Zone 1**			**Zone 2**			**Zone 3**		
	B	**t**	**Sig.**	**B**	**t**	**Sig.**	**B**	**t**	**Sig.**
(Constant)	0.218	0.568	0.572	0.558	1.623	0.108	0.447	0.882	0.381
Lamp Design	0.149	1.906	0.061	0.107	1.913	0.059	**0.354***	**3.234***	**0.002***
Pathwalk Pattern Design	0.108	1.226	0.224	0.076	1.355	0.179	-0.143	-1.135	0.260
Bollard Design	-0.004	-0.063	0.950	0.113	1.889	0.062	**0.352***	**3.693***	**0.000***
Chair Design and Layout	0.054	0.659	0.512	**0.251***	**3.916***	**0.000***	-0.062	-0.694	0.490
Trashbin Design and Layout	0.152	1.910	0.060	0.007	0.114	0.909	0.130	1.779	0.080
Building Colour	**0.203***	**2.471***	**0.016***	0.097	1.354	0.179	-0.018	-0.158	0.875
Building Material	0.052	0.638	0.525	0.069	0.941	0.349	**0.299***	**2.596***	**0.012***
Building Signage	**0.221***	**3.273***	**0.002***	**0.180***	**3.228***	**0.002***	-0.010	-0.107	0.915

a. Dependent Variable: Overall elements score
*) Variable with significant positive relationship, B and t value is positive, $p < 0.05$

Zone 1

The pedestrian space elements in Zone 1 can explain 59.3% of the historical impression along Zone 1 (F (8,71) = 12.929, p = < .001, R^2 = .593). The pedestrian space forming elements that have a partial effect on the suitability of the historical impression along Zone 1 are Building Color (b = .203, t = 2.471, p = .016) and Building Signage (b = .221, t = 3.273, p = .002) (see Table 2). Based on the results of the t-test, a regression model can be formulated based on the eligible independent variables, resulting the UVI of Zone 1:

$$Y_1 = 0.218 + 0.203.\,Building\ Colour + 0.221.\,Building\ Signage$$

Regression was also applied to 7 photo spots within Zone 1, where each pedestrian space element was analyzed against 7 spots in this zone. The results reveal that the pedestrian space elements influence the historical impression of the spots in Zone 1 ($p < 0.050$). However, the elements in spot 7 do not affect the historical impression of this spot ($p > 0.050$).

The historical impression of the spots in this zone is mostly influenced by Building Signage (5 spots) and Pathwalk Pattern Design (4 spots). However, in spots 6 and 7, no elements affect the historical impression of the area because the area has modern buildings, causing the impression to be lost (see Table 4).

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Table 3: Summary of Regression Analysis of Pedestrian Street Elements in Zone 1

Coefficients[a]										
Spot		(Constant)	Lamp Design	Pathwalk Pattern Design	Bollard Design	Chair Design and Layout	Trashbin Design and Layout	Building Colour	Building Material	Building Signage
1	B	2.070	**-0.249****	**0.300***	-0.067	-0.130	**0.378***	0.082	-0.047	**0.216***
	t	4.142	**-2.439****	**2.623***	-0.765	-1.206	**3.656***	0.768	-0.438	**2.455***
	Sig.	0.000	**0.017****	**0.011***	0.447	0.232	**0.000***	0.445	0.663	**0.017***
2	B	0.427	-0.134	**0.348***	-0.134	0.158	-0.132	0.083	**0.314***	**0.257***
	t	0.881	-1.354	**3.148***	-1.575	1.521	-1.313	0.804	**3.021***	**3.015***
	Sig.	0.381	0.180	**0.002***	0.120	0.133	0.194	0.424	**0.004***	**0.004***
3	B	0.427	-0.134	**0.348***	-0.134	0.158	-0.132	0.083	**0.314***	**0.257***
	t	0.881	-1.354	**3.148***	-1.575	1.521	-1.313	0.804	**3.021***	**3.015***
	Sig.	0.381	0.180	**0.002***	0.120	0.133	0.194	0.424	**0.004***	**0.004***
4	B	1.286	-0.158	**0.282***	-0.029	-0.139	**0.243***	0.207	-0.061	**0.243***
	t	2.389	-1.436	**2.295***	-0.308	-1.198	**2.183***	1.791	-0.528	**2.566***
	Sig.	0.020	0.155	**0.025***	0.759	0.235	**0.032***	0.078	0.599	**0.012***
5	B	1.156	-0.122	0.254	-0.014	0.092	0.162	0.151	-0.146	**0.218***
	t	1.917	-0.992	1.842	-0.133	0.711	1.295	1.170	-1.133	**2.050***
	Sig.	0.059	0.325	0.070	0.895	0.479	0.199	0.246	0.261	**0.044***
6	B	1.435	-0.125	0.260	0.110	-0.161	0.167	-0.036	0.165	0.127
	t	2.452	-1.046	1.945	1.065	-1.280	1.376	-0.288	1.315	1.232
	Sig.	0.017	0.299	0.056	0.291	0.205	0.173	0.774	0.193	0.222
7	B	2.285	0.027	0.210	0.084	0.258	-0.151	0.004	-0.092	0.032
	t	3.629	0.207	1.459	0.755	1.909	-1.162	0.028	-0.68	0.288
	Sig.	0.001	0.837	0.149	0.453	0.060	0.249	0.978	0.499	0.774

a. Dependent Variable: Overall elements score
*) Variable with significant positive relationship, B and t value is positive, $p < 0.05$
**) Variable with significant negative relationship, B and t value is negative, $p < 0.05$

Zone 2

The pedestrian space elements in Zone 2 can explain 57.3% of the historical impression along Zone 2 ($F(8,89) = 14.912$, $p = < .001$, $R^2 = .573$). The pedestrian space forming elements that have a partial influence on the suitability of the historical impression along Zone 2 are Chair Design and Layout ($b = .251$, $t = 3.916$, $p = < .001$) and Building Signage ($b = .180$, $t = 3.228$, $p = .002$) (see Table 2). Based on the results of the t-test, a regression model can be formulated based on the eligible independent variables, resulting in the UVI of Zone 2:

$$Y_2 = 0.558 + 0.251.\,Chair\ Design\ and\ Layout + 0.180.\,Building\ Signage$$

Regression was also applied to 7 photo spots within Zone 2, where each pedestrian space element was analyzed against 7 spots in this zone. The results reveal that the historical impression of all spots in Zone 2 is influenced by pedestrian space elements ($p < 0.050$).

Table 4: Summary of Regression Analysis of Pedestrian Street Elements in Zone 2

Coefficients[a]										
Spot		(Constant)	Lamp Design	Pathwalk Pattern Design	Bollard Design	Chair Design and Layout	Trashbin Design and Layout	Building Colour	Building Material	Building Signage
1	B	0.401	**0.254***	0.134	0.134	0.112	-0.126	0.030	0.149	**0.279***
	t	0.859	**3.352***	1.752	1.637	1.289	-1.536	0.312	1.504	**3.677***
	Sig.	0.393	**0.001***	0.083	0.105	0.201	0.128	0.756	0.136	**0.000***
2	B	0.919	0.196	0.175	0.136	0.197	-0.007	0.180	-0.061	-0.044
	t	1.371	1.799	1.604	1.158	1.582	-0.056	1.289	-0.431	-0.402
	Sig.	0.174	0.075	0.112	0.250	0.117	0.955	0.201	0.667	0.689
3	B	0.875	0.088	**0.316***	0.128	0.022	-0.131	0.113	-0.135	**0.304***
	t	1.236	0.764	**2.740***	1.034	0.167	-1.047	0.770	-0.899	**2.645***
	Sig.	0.220	0.447	**0.007***	0.304	0.868	0.298	0.444	0.371	**0.010***
4	B	1.462	**0.317***	0.143	-0.080	**0.305***	-0.089	0.045	-0.040	0.025
	t	2.823	**3.767***	1.692	-0.887	**3.167***	-0.980	0.419	-0.366	0.303
	Sig.	0.006	**0.000***	0.094	0.377	**0.002***	0.330	0.677	0.715	0.762
5	B	1.366	**0.375***	**0.192***	-0.157	**0.253***	**-0.237****	-0.126	0.153	**0.236***
	t	2.694	**4.555***	**2.321***	-1.772	**2.684***	**-2.647****	-1.195	1.420	**2.873***
	Sig.	0.008	**0.000***	**0.023***	0.080	**0.009***	**0.010****	0.235	0.159	**0.005***
6	B	1.844	0.062	0.091	-0.072	0.229	-0.133	0.064	0.294	-0.011
	t	2.623	0.546	0.795	-0.583	1.754	-1.073	0.436	1.971	-0.098
	Sig.	0.010	0.586	0.429	0.561	0.083	0.286	0.664	0.052	0.922
7	B	0.180	0.056	0.030	0.166	**0.306***	-0.102	0.021	0.241	**0.267***
	t	0.298	0.572	0.306	1.568	**2.720***	-0.954	0.169	1.886	**2.726***
	Sig.	0.766	0.569	0.760	0.120	**0.008***	0.343	0.866	0.063	**0.008***

a. Dependent Variable: Overall elements score
*) Variable with significant positive relationship, B and t value is positive, $p < 0.05$
**) Variable with significant negative relationship, B and t value is negative, $p < 0.05$

Significant pedestrian space elements inside the spots in Zone 2 are dominated by Building Signage (4 spots), Chair Design and Layout (3 spots), and Lamp Design (3 spots). Spots 2 and 6 do not have any elements that affect the historical impression of the area because they are an area with modern buildings, which causes the loss of historical impression of the spots (see Table 4).

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Zone 3

Pedestrian space elements in Zone 3 can explain 57.9% of the historical impression along Zone 3 (F (8,67) = 11.518, p = < .001, R^2 = .579). The pedestrian space forming elements that have a partial effect on the suitability of the historical impression along Zone 3 are Lamp Design (b = .354, t = 3.234, p = .002), Bollard Design (b = .352, t = 3.693, p = < .001), and Building Material (b = .299, t = 2.596, p = .012) (see Table 2). A regression model can be formulated based on the eligible independent variables, resulting in the UVI of Zone 3:

$$Y_3 = 0.447 + 0.354.\,Lamp\ Design + 0.352.\,Bollard\ Design + 0.299.\,Building\ Material$$

Regression was also applied to 7 photo spots within Zone 3, where each pedestrian space element was analyzed against 7 spots in this zone. The results reveal that the historical impression of all spots in Zone 3 is influenced by pedestrian space elements (p < 0.050).

Table 5: Summary of Regression Analysis of Pedestrian Street Elements in Zone 3

Coefficients[a]										
Spot		(Constant)	Lamp Design	Pathwalk Pattern Design	Bollard Design	Chair Design and Layout	Trashbin Design and Layout	Building Colour	Building Material	Building Signage
1	B	0.961	**0.280***	0.215	0.053	0.130	0.051	-0.145	0.166	0.071
	t	1.932	**2.609***	1.735	0.571	1.489	0.707	-1.274	1.467	0.755
	Sig.	0.058	**0.011***	0.087	0.570	0.141	0.482	0.207	0.147	0.453
2	B	1.038	**0.517***	-0.196	**0.248***	0.104	-0.020	0.032	-0.003	0.095
	t	1.919	**4.429***	-1.453	**2.436***	1.089	-0.257	0.261	-0.025	0.933
	Sig.	0.059	**0.000***	0.151	**0.018***	0.280	0.798	0.795	0.980	0.354
3	B	0.053	**0.357***	**0.417***	-0.092	-0.099	0.160	0.017	0.221	0.033
	t	0.093	**2.877***	**2.905***	-0.854	-0.979	1.929	0.126	1.691	0.309
	Sig.	0.926	**0.005***	**0.005***	0.396	0.331	0.058	0.900	0.095	0.758
4	B	1.402	-0.058	**0.408***	-0.007	-0.130	**0.208***	-0.123	0.125	**0.292***
	t	2.489	-0.474	**2.904***	-0.065	-1.309	**2.570***	-0.954	0.975	**2.751***
	Sig.	0.015	0.637	**0.005***	0.948	0.195	**0.012***	0.344	0.333	**0.008***
5	B	1.16	0.286	0.043	**0.290***	-0.086	0.155	-0.065	-0.045	0.116
	t	1.705	1.947	0.253	**2.267***	-0.722	1.585	-0.417	-0.29	0.906
	Sig.	0.093	0.056	0.801	**0.027***	0.473	0.118	0.678	0.773	0.368
6	B	0.659	**0.367***	0.174	0.055	0.003	0.045	0.018	0.139	0.026
	t	1.184	**3.058***	1.253	0.523	0.029	0.558	0.144	1.100	0.244
	Sig.	0.241	**0.003***	0.215	0.603	0.977	0.579	0.886	0.275	0.808
7	B	0.918	0.090	0.286	0.201	-0.064	0.183	-0.048	0.042	0.080
	t	1.395	0.631	1.742	1.620	-0.556	1.932	-0.320	0.281	0.640
	Sig.	0.168	0.530	0.086	0.110	0.580	0.058	0.750	0.779	0.524

a. Dependent Variable: Overall elements score
*) Variable with significant positive relationship, B and t value is positive, $p < 0.05$
**) Variable with significant negative relationship, B and t value is negative, $p < 0.05$

The pedestrian space elements that influence the strength of the historical impression in the spots in this zone are dominated by Lamp Design (5 spots). The same phenomenon is observed in Zones 1 and 2, namely spots that do not have elements that influence their historical strength (see Table 5).

DISCUSSION

This study highlights that the configuration of pedestrian space elements exerts a significant influence on the historical impression of the KRC across its three distinct zones. The analysis reveals that in Zone 1, the historical impression is predominantly shaped by building color and signage, with the building façade functioning as a critical determinant of visual quality. Although recent revitalization initiatives have altered certain façade colors, color continues to act as a central factor influencing the perception of the pedestrian environment in historic urban spaces (Kurniawan et al., 2017). In Zone 2, the historical character is primarily defined by chair design and layout in conjunction with building signage. The vintage style of the chairs and their strategic spatial distribution contribute not only to the visual identity of this zone but also enhance functional comfort for visitors, providing rest areas and serving as popular photo spots (Marisa & Fuad, 2023). The concentration of commercial activities in this zone results in a greater number of building signages compared to Zones 1 and 3. Importantly, the placement of signage attached to building façades ensures that pedestrian visual corridors remain unobstructed, thereby reinforcing both spatial and visual comfort (Achsani & Wonorahardjo, 2020; Meng et al., 2024; Yang et al., 2021). In contrast, the distinctive historical impression of Zone 3 emerges from lamp design, bollard design, and building materials. The broader pedestrian dimensions in this zone allow for the installation of bollards that successfully restrict vehicular access without impeding pedestrian sightlines or movement. This arrangement contributes positively to spatial comfort while simultaneously protecting pedestrian safety (Marisa & Fuad, 2023; Meng et al., 2024; Yang et al., 2021). Furthermore, the substantial presence of Dutch colonial-style heritage buildings, alongside the visibility of their original materials, strengthens the authenticity of the historical impression in this area (Andrian et al., 2021).

To further substantiate these findings, the UVI was simulated for each zone, with the regression model incorporating the substitution of minimum values. The results are presented as follows:

$$Zone\ 1 = 0.218 + 0.203(1) + 0.221(1) = 0.642$$
$$Zone\ 2 = 0.558 + 0.251(1) + 0.180(1) = 0.989$$
$$Zone\ 3 = 0.447 + 0.354(1) + 0.352(1) + 0.299(1) = 1.452$$

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The simulation outcomes demonstrate that Zone 3 achieves the highest UVI score (1.452), followed by Zone 2 (0.989), while Zone 1 records the lowest score (0.642). These disparities highlight the fragmented nature of urban design treatment along the KRC. Such inconsistency risks undermining the unified historical image of the area and may subsequently reduce its cultural significance (Andrian et al., 2021). Hence, the results underscore the necessity of harmonizing urban design interventions across all zones to achieve spatial unity and a coherent visual identity. More broadly, the findings of this research affirm that streetscape elements and building composition play a pivotal role in determining the visual–spatial comfort of historic urban landscapes (HUL). These tangible urban attributes reinforce cultural meanings and support the interpretation of place identity (Che Amat, 2018). Moreover, the preservation of architectural elements constitutes a vital strategy in maintaining the uniqueness and authenticity of HULs while accommodating urban development pressures (Harun et al., 2015). Strengthening historical character not only safeguards heritage values but also enhances placemaking processes, which in turn improve tourist experiences and contribute to the sustainable development of heritage-based tourism destinations (Ernawati et al., 2018; Marisa & Fuad, 2023; Xiang & Mohamad, 2023).



Figure 3: Spots that have no influencing streetscape elements and building composition; (A1) Spot 6 Zone 1; (A2) Spot 7 Zone 1; (B1) Spot 2 Zone 2; (B2) Spot 6 Zone 2; (C) Spot 7 Zone 3.

In each zone, there are some spots in which the pedestrian space elements do not significantly influence its historical impression strength (see Fig. 3). There are several factors that cause this phenomenon. The strength of the historical impression of the spot is not influenced by the pedestrian space elements when the building style is not a Dutch colonial style. This is in line with the results of previous studies, which stated that the urban heritage artifacts on every scene indisputably reveal the city's socio-cultural value (Phetsuriya & Heath, 2023). The loss of the Dutch colonial style's character in several spots has diminished the HUL's character as a historic street corridor. Another factor is the absence of points of interest on the spot. No impression can be influenced because it does not have attractive elements. The attractiveness of a streetscape can affect people's preferences for a HUL's imageability (Ernawati, 2020). This phenomenon can be found in all zones in the KRC.

The placement of street furniture and building elements that obstruct people's vision and movement can affect visual-spatial comfort along the HUL. A study by Santosa et al. (2023) revealed that the visibility of landmarks of HUL from the pedestrian lane can be affected negatively by the layout of street furniture design and the placements and density of the vegetation. When people's vision is obstructed, it can reduce their comfort while walking on the road (Yang et al., 2021). Lack of space for pedestrians due to obstruction by activities other than walking or wrong placement of street furniture can reduce the spatial comfort pedestrians feel (Marisa & Fuad, 2023; Meng et al., 2024).

CONCLUSION

The result of this study suggests that both streetscape elements and building composition can influence the strength of the historical impression of a HUL according to the public's preferences, in this case, the KRC. Each zone has a different UVI, depending on each zone's characteristics and points of interest. However, some spots lack historical impression due to modern building styles, absence of points of interest, or poor street furniture layout, which can hinder pedestrian movement and obscure landmarks. These findings emphasize the need for careful design and preservation to strengthen the character of the HUL. The historical impression will be more significant when the pedestrian's visual of the road is unobstructed. Additionally, the visual composition of intact Dutch colonial-style buildings contributes to the strength of the historic impression. Therefore, the design and layout of street furniture and the preservation of the authenticity of the Dutch colonial building design are crucial considerations when designing pedestrian spaces of a HUL.

To enhance the UVI, governments should adopt cohesive streetscape designs, integrate creative architectural and street furniture elements, and leverage emerging technologies such as AI and AR, supported by community engagement and clear design guidelines. This study faced several challenges, particularly in applying regression analysis techniques to accommodate diverse data outcomes, as well as the limited scope of data collection within a single heritage area. Given that UVI remains a relatively new theoretical framework, these findings should be viewed as an initial reference. Future research should expand by comparing street furniture design styles across multiple historic corridors and by incorporating diverse respondent categories—such as researchers, policymakers, and stakeholders—to provide more comprehensive insights into UVI development.

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DISCLOSURE STATEMENT
The authors declare that they have no conflicts of interest regarding the paper's publication. All co-authors have seen and agreed with the manuscript's contents, and the authors certify that the submitted work is original and not under consideration for publication elsewhere.

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THE IMPACT OF HERITAGE TOURISM AT KAMPUNG HERITAGE KAYUTANGAN, INDONESIA: INSIGHTS FROM VISITORS' AND RESIDENTS' PREFERENCES

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Abstract

Malang City is well-known for its significant historical past from the Dutch East Indies period, which has made it a popular heritage tourism destination in East Java. Kampung Heritage Kayutangan, with its well-preserved historical buildings, exemplifies this attraction. The study explores the various factors that influence the significance of historical building tourism in shaping visitors' experiences. The research employs a mixed-methods approach, utilizing a sequential explanatory design that integrates both qualitative and quantitative assessments. The findings reveal that historical buildings significantly impact the tourist experience, with historical value, aesthetic value, and accessibility being the most influential factors. Visitors primarily emphasize the historical and cultural importance. Meanwhile, the residents emphasize the architectural aesthetic features. By embracing sustainable tourism practices and encouraging community involvement, Kampung Heritage Kayutangan can serve as a model for harmonizing heritage conservation with urban development, ensuring long-term preservation while strengthening the local cultural identity and economic growth.

Keywords: Significance, Historical building, Kampung Heritage Kayutangan, Visitors' and residents' preferences, Sustainable tourism

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INTRODUCTION

Malang City is one of the historical cities in East Java that has undergone development since the Dutch East Indies era (Tutuko et al., 2021). As a result, it has become rich in historical heritage, including its architecture and urban planning. The Malang City Government has decided to promote the city as a historical tourist destination along with the development of heritage tourism (Antariksa et al., 2024). Travelers visit historical sites in search of unique experiences and to understand the architecture, culture, and history that have shaped modern society (Timothy & Boyd, 2006). In this sense, the Kampung Heritage Kayutangan in Malang City, East Java, is one of the top destinations that provides an engaging heritage tourism experience with its well-preserved historical buildings.

The growth of the historic tourism sector is a fast-expanding trend that has become a significant emphasis in the worldwide tourist business, one of which is Kampung Heritage Kayutangan. Tourists seek unique experiences by visiting historical places to learn about the history, culture, and architecture that shape modern life. Previous studies have extensively analyzed the visual quality of buildings and architectural aspects, such as building facade assessments and 3D interactive visualizations (Santosa et al., 2016), but few have looked into visitor behavior and preferences. Additionally, residents' preferences as a part of the community in preserving the cultural heritage have been underexplored, despite their significant contributions to the heritage tourist experiences.

The significance of historical building tourism aligns with the Sustainable Development Goals (SDGs). It supports local economic enhancement and cultural preservation, particularly SDG 11, which emphasizes sustainable cities and communities (Khairunnisa & Sudikno, 2022). Incorporating sustainable tourism through community participation improves residents' quality of life and ensures environmentally sustainable, culturally sensitive activities, supporting SDG 12 on responsible consumption and production (Hu et al., 2022). By emphasizing community involvement and adopting sustainable practices, this heritage site can serve as a model for how historical tourism contributes to local economic growth while fostering environmental responsibility.

LITERATURE REVIEW

A historically developed area successfully transformed into a tourist destination must foster a positive relationship between the community and the environment to enhance its social value. Organized social activities in heritage areas are key to creating vibrant and successful sites, as these activities can build identity, a sense of belonging, and a deep meaning of place for the community (Hu et al., 2022). The transformation of historical buildings into tourist attractions supports

cultural preservation and economic revitalization of the area, as long as the historical integrity is maintained, according to UNESCO (2003). The development of facilities, such as guided tours and art attractions, must consider visitor preferences to create meaningful experiences (Chen & Chen, 2010). The main challenge is balancing cultural preservation with sustainable tourism development without compromising the authenticity of the buildings (Dutta & Husain, 2009; Liu et al., 2018).

Historical buildings play an essential role as educational tools by presenting stories of the past that enrich visitors' understanding of history and culture (Shamsuddin et al., 2024). As an educational tourist destination, this building offers an immersive, hands-on experience, enhances historical literacy, and encourages respect for cultural heritage (Vodopivec et al., 2014). Heritage tourism in Indonesia has also significantly impacted economic growth and community development. Previous research by Suprapti et al. (2019) highlights that Kadilangu Cultural Heritage Village in Demak demonstrates how the heritage tourism sector generates direct financial benefits by stimulating the local economy, creating job opportunities, and encouraging resident entrepreneurship. Similarly, research on Kampung Taman Sari in Jogjakarta by Ernawati & Moore (2014) reveals that cultural tourism educates visitors and fosters a sense of pride within the local community, as preserving cultural heritage strengthens identity and social cohesion. To maximize the advantages of heritage tourism, a comprehensive approach that integrates innovation, community engagement, and environmental sustainability is essential.

RESEARCH METHODOLOGY

This study follows a mixed-method sequential explanatory design, starting with qualitative research (Phase A) and followed by quantitative research (Phase B). In Phase A, respondents ranked registered historical buildings through a questionnaire. The findings were analyzed using score rank to identify the most interesting objects based on the preferences of visitors and residents, which would then be used as selected samples in Phase B, as shown in Figure 1.

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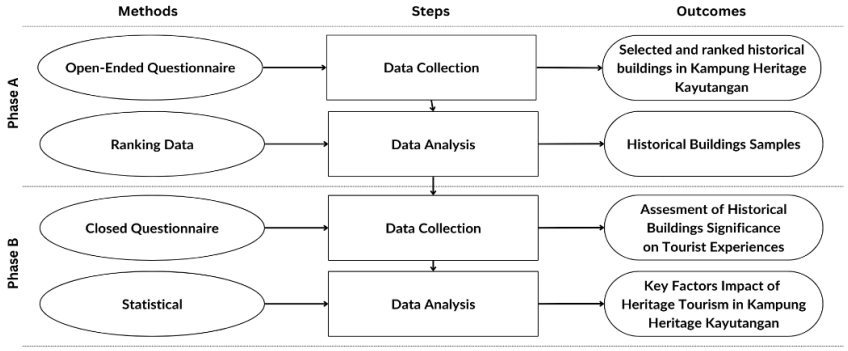


Figure 1: The Flowchart Diagram of the Research Process

The research sample was selected based on the respondents' answers on the buildings' interesting aspects as tourist destinations from the lists consisting of 10 historical buildings in Figure 2. These buildings were cataloged as assets of Malang's Heritage Buildings located in the Kampung Heritage Kayutangan: D'Penghulu, Jengki, 1870, Rindu, Nyik Aisyah, Mbah Ndut, Gubug Ningrat, Jacoeb, Jamu, and Kartini House.



Figure 2: Kampung Kayutangan's Heritage Buildings
Source: Authors

Phase B continued with an assessment of the significance of historical buildings using a questionnaire. This research used the independent variable of elements of heritage building significance. The influence of these elements was examined on the dependent variable, which is the tourism experience assessed based on the preferences of visitors and residents. The research variables, presented in Table 1, are based on studies examining the importance of building significance in heritage tourism.

Table 1: Research Variables

Variable	Indicator	Description	Source
Buildings Significance	**Cultural Value**	The ambiance of past times	Vardopoulos (2019); Nesticò & Somma (2019)
	Educational	Providing historical education experiences	Vodopivec et al. (2014); Timothy & Boyd (2006)
	Architectural Value	Having attractive building materials and colors	Pavlovskis et al. (2019); Liu et al. (2018); Chen et al. (2018); Turskis et al. (2017)
	Aesthetic Value	Having an attractive building facade	Gholitabar et al. (2018); Vodopivec et al. (2014)
		Having attractive details (such as doors, windows, etc.) and building decoration	Liu et al. (2018); Vodopivec et al. (2014)
	Authenticity	Having a fascinating architectural authenticity	Liu et al. (2018); Kutut et al. (2014)
	Historical Value	Having an encouraging history	Liu et al. (2018); Gholitabar et al. (2018)
	Accessibility	Having easy physical access Having clear and easy-to-understand information Having a multifunction that supports social activities	Doan & Nguyen (2023); Kutut et al. (2014)
	Community Value	Providing social benefits	Nesticò & Somma (2019); Pavlovskis et al. (2019)
		Providing economic benefits	Nesticò & Somma (2019); Vardopoulos (2019); Chen et al. (2018)
Tourist Experience		Giving a visitor experience	Antariksa et al. (2024); Timothy & Boyd (2006)

The questionnaire contains various assertions, and respondents react based on the relevance of the building objects to the given statements (on a 7-point Likert scale ranging from strongly disagree to agree strongly). The collected data were examined using SPSS software with mean score, correlation, and regression analysis to establish the relevance of the relationship between the building's significance and the heritage tourism experience. The mean score was calculated using the formula shown below.

$$\underline{X} = \Sigma Xi/n$$

$\underline{X}$ = mean score of variables
ΣXi = total score of variables
n = number of samples

The average score is then split into seven categories using the following formula:

$$Interval_{length} = \frac{Max\ value - Min\ Value}{Category\ size}$$

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The formula-based outcome refers to a frequency table in Table 2 for categorizing average scores.

Table 2: Mean Score Frequency

Category	Mean Score Range
Very unsuitable	1.000 – 1.857
Unsuitable	1.858 – 2.714
Quite unsuitable	2.715 – 3.571
Ordinary	3.572 – 4.428
Quite suitable	4.429 – 5.285
Suitable	5.286 – 6.142
Very suitable	6.143 – 7.000

This category was chosen to determine whether the variable values are suitable for assessing the relevance of the structures to the tourist experience in Kampung Heritage Kayutangan. Then, correlation analysis was conducted to examine relationships between variables, followed by multiple linear regression to evaluate the impact of building significance on the heritage tourism experience.

ANALYSIS AND DISCUSSION

The historical buildings in the Kampung Heritage Kayutangan have been chosen as the focus of this study. In Phase A, the data were calculated using the scoring differences when processing open-ended questionnaire data. This phase was given to 50 respondents directly. The scoring was done by assigning scores, starting with the first rank with the highest score (10 points) to the tenth rank with the lowest score (1 point). This produced the data as presented in Table 3.

Table 3: Score Ranking of Kampung Kayutangan's Historical Buildings

Name	Score										Total	Rank
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
1870 House	130*	99	80	35	18	10	4	12	2	0	390	1
Jengki House	130*	45	40	49	54	20	12	3	4	1	358	2
Mbah Ndut House	50	99	72	28	30	20	20	9	4	2	334	3
D'Penghulu House	70	54	56	56	24	10	12	12	12	3	309	4
Nyik Aisyah House	40	45	32	49	12	40	24	15	12	3	272	5
Rindu House	20	45	32	7	48	35	40	33	2	1	263	6
Gubuk Ningrat	50	18	32	35	42	30	24	12	6	8	257	7
Jacoeb House	10	27	24	56	24	40	32	15	14	2	244	8
Jamu House	0	18	24	14	30	35	28	30	26	2	207	9
Kartini House	0	0	8	21	18	10	4	9	18	28	116	10

*The highest score of the rank

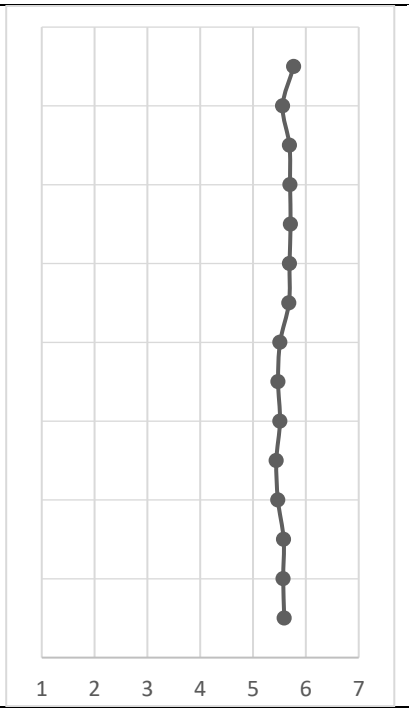
Based on the Phase A findings, the top six buildings were chosen as samples for the Phase B assessment. The results for the sample objects used are the 1870 House, Jengki House, Mbah Ndut House, D'Penghulu House, Nyik Aisyah House, and Rindu House. The research continued to the next phase, which involved giving 105 respondents (54 visitors and 51 residents). After completing the Phase B data collection, statistical analysis began with mean score analysis, correlation analysis, and regression analysis. The data passed prerequisite tests, proving that they are valid and reliable, meeting classical assumptions, and allowing for further study of regression analysis.

From all respondents, the authors looked for differences in residents' and visitors' preferences. This was done to determine whether the significant results obtained from each aspect are similar or only affect one of the two parties. This analysis was conducted using a mean score comparison of the historical building tourism significance according to visitors' preferences versus residents' preferences.

Table 4: Mean Score of Visitors' Preferences

No	Variable	Mean Score	Category	Graph
1	**Cultural Value**	5.77**	Suitable	
2	**Educational**	5.56	Suitable	
3	**Architectural Value**	5.69	Suitable	
4	**Aesthetic Value**	5.70	Suitable	
A	Visual Facade	5.71	Suitable	
B	Details & Decorations	5.69	Suitable	
5	**Authenticity**	5.68	Suitable	
6	**Historical Value**	5.51	Suitable	
7	**Accessibility**	5.47	Suitable	
A	Physical Access	5.51	Suitable	
B	Information Access	5.44*	Suitable	
C	Societal Access	5.47	Suitable	
8	**Community Value**	5.58	Suitable	
A	Social Value	5.57	Suitable	
B	Economic Value	5.59	Suitable	

* The Lowest Score
** The Highest Score



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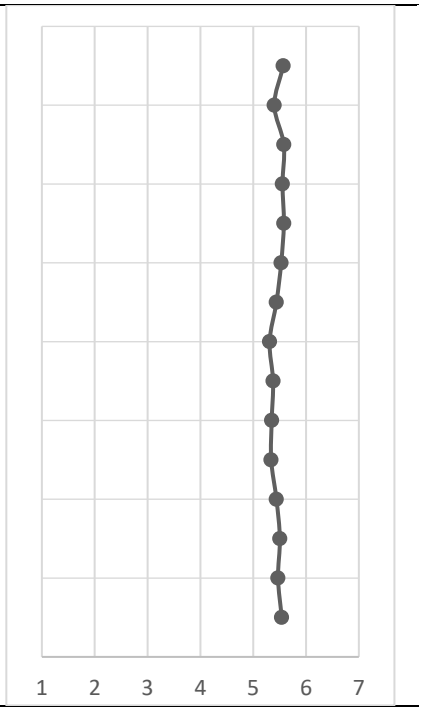
Based on Table 4, the results according to visitors' preferences show that the cultural value variable has the highest mean score with a score of 5.77, which falls into the "Suitable" category (5.286 – 6.142) for heritage tourism experiences. Cultural value shows visitors' appreciation for the buildings' significance. The societal access variable has the lowest average at 5.40, indicating visitors perceive cultural value more through buildings than local social activities. Social accessibility refers to the extent to which buildings facilitate connectivity with social activities, support community engagement, or promote interactions between visitors and existing social and cultural values (Doan & Nguyen, 2023).

Table 5: Mean Score of Residents' Preferences

No	Variable	Mean Score	Category
1	**Cultural Value**	5.57	Suitable
2	**Educational**	5.40	Suitable
3	**Architectural Value**	5.58**	Suitable
4	**Aesthetic Value**	5.55	Suitable
A	Visual Facade	5.58**	Suitable
B	Details & Decorations	5.53	Suitable
5	**Authenticity**	5.44	Suitable
6	**Historical Value**	5.31*	Suitable
7	**Accessibility**	5.38	Suitable
A	Physical Access	5.35	Suitable
B	Information Access	5.34	Suitable
C	Societal Access	5.44	Suitable
8	**Community Value**	5.50	Suitable
A	Social Value	5.47	Suitable
B	Economic Value	5.54	Suitable

* The Lowest Score
** The Highest Score

Graph



In Table 5, the results according to the local community's preferences show that the highest mean score is found in the variables of architecture value and aesthetic value by visual facade, with the same score of 5.58. This indicates that most of the objects have materials with attractive building façades as the architectural value (Turskis et al., 2017). The historical value has the lowest score

because the residents are already accustomed to the historical value of the place where they live (Gholitabar et al., 2018).

Based on the information from the mean score analysis, the authors aimed to identify differences in respondent preferences. This was done to determine whether the significant results for each aspect were similar or only affected one of the two groups, whether they were visitors or residents. The study employed a correlation analysis to examine the significance of tourism in historical buildings, comparing visitors' preferences with those of residents.

Table 6: Correlation of Historical Buildings Significance Aspects

			Historical Buildings					
			1870 House	**Jengki House**	**Mbah Ndut House**	**D'Penghulu House**	**Nyik Aisyah House**	**Rindu House**
By Visitors'	Cultural Value		0.568	0.615	0.657*	0.405	0.596	0.64
	Educational		0.493	0.699	0.5	0.667*	0.632	0.657
	Architectural Value		0.531	0.651	0.518	0.544	0.745	0.387
	Aesthetic Value	Visual Facade	0.662	0.586	0.427	0.634	0.684	0.553
		Details & Decorations	0.748*	0.658	0.433	0.51	0.551	0.54
	Authenticity		0.477	0.591	0.528	0.546	0.628	0.692
	Historical Value		0.613	0.72*	0.592	0.579	0.804	0.748
	Accessibility	Physical Access	0.313	0.67	0.419	0.508	0.677	0.678
		Information Access	0.576	0.675	0.366	0.362	0.653	0.699
		Societal Access	0.565	0.56	0.531	0.489	0.726	0.723
	Community Value	Social Value	0.47	0.497	0.638	0.633	0.694	0.587
		Economic Value	0.535	0.591	0.412	0.653	0.814*	0.763*
By Residents'	Cultural Value		0.753	0.501	0.671	0.469	0.632	0.651
	Educational		0.74	0.545	0.693	0.624	0.649	0.691
	Architectural Value		0.676	0.639	0.663	0.648	0.713	0.672
	Aesthetic Value	Visual Facade	0.812	0.722	0.74*	0.736*	0.687	0.693
		Details & Decorations	0.836*	0.822*	0.667	0.605	0.573	0.663
	Authenticity		0.586	0.664	0.609	0.512	0.644	0.669
	Historical Value		0.75	0.708	0.686	0.536	0.695	0.74
	Accessibility	Physical Access	0.678	0.348	0.575	0.446	0.705	0.589
		Information Access	0.591	0.603	0.617	0.57	0.794	0.63
		Societal Access	0.66	0.696	0.659	0.571	0.798*	0.75*
	Community Value	Social Value	0.57	0.588	0.537	0.468	0.637	0.68
		Economic Value	0.583	0.64	0.511	0.61	0.731	0.646

*The highest correlation coefficients indicate the most correlated variable

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Historical building tourism holds immense significance as it bridges the past and present, offering enriching experiences shaped by various interconnected factors, as shown in Table 6. For visitors, these experiences are deeply tied to the economic value generated by historical tourism as they promote financial benefits through activities such as guided tours, cultural events, and local craft markets. The economic impact not only supports the preservation of historical structures but also fosters community development by creating job opportunities and stimulating local economies (Nesticò & Somma, 2019).

For residents, historical building tourism presents a delicate balance between preserving cultural heritage and accommodating modern needs. This balance enhances tourism's sustainability while ensuring that historic sites' cultural integrity remains intact. Furthermore, the intricate details, artistic decorations, and visual appeal of historic architecture play a crucial role in defining a region's identity and charm, reflecting the community's pride and dedication to maintaining its cultural legacy. These elements make historic buildings not just static monuments but dynamic hubs of cultural interaction and education (Timothy & Boyd, 2006).

The existence of historical building tourism has significant effects on both visitors and the residents, shaping cultural, social, and economic dynamics. As highlighted by Vardopoulos (2019), community involvement plays a pivotal role in sustainable heritage tourism by fostering social cohesion and delivering economic benefits through locally driven activities and services. Moreover, Liu et al. (2018) emphasize the aesthetic architectural value of historical buildings, characterized by their visually striking facades, intricate details, and elaborate decorations, which enhance the overall visitor experience. This result will be further examined by investigating the significance of historical buildings on the tourist experience through regression analysis.

Table 7: Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.841[a]	.708	.702	.756

a. Predictors: (Constant), Community Value - Economic Value, Cultural Value, Accessibility - Physical Access, Authenticity, Accessibility - Information Access, Architectural Value, Accessibility - Societal Access, Aesthetic Value - Details & Decorations, Historical Value, Community Value - Social Value, Educational, Aesthetic Value - Visual Facade

According to the regression analysis using the model summary in Table 7, historical buildings are 70.8% significant overall in the visitor experience. Thus, other impactful aspects that have yet to be fully realized must be enhanced to achieve sustainable tourism. This regression continues to the F-test, which is derived from the regression model summary to show the explained and unexplained variance from the model. The regression model summary quantifies

the model's performance, while the F-test ANOVA confirms that the model is statistically valid.

Table 8: Regression Analysis of Variance

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	856.128	12	71.344	124.672	<0,001[b]
	Residual	353.080	617	.572		
	Total	1209.208	629			

a. Dependent Variable: Tourist Experience
b. Predictors: (Constant), Community Value - Economic, Cultural Value, Accessibility - Physical Access, Authenticity, Accessibility - Information Access, Architectural Value - Details & Decorations, Historical Value, Community Value - Social, Educational, Aesthetic Value - Visual Facade

In Table 8, the calculated F-value obtained is greater than the table F-value (124.672>1.983), so it can be said that the overall significance variables of historical buildings, namely community value, cultural value, authenticity, architectural value, accessibility, historical value, educational value, and aesthetic value, together have a significant influence on the tourism experience variable. The results of the analysis indicate that out of the twelve tested variables in Table 9, four have the most significant effect on tourist experience: community value (social and economic), historical value, aesthetic value (visual facade, details, and decorations), and accessibility (physical, information, and societal access).

Table 9: The Significance Coefficients of Historical Building Aspects

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.137	.154		.890	.374
	Cultural Value	.011	.045	.010	.242	.809
	Educational	.006	.052	.006	.120	.904
	Architectural Value	.001	.049	.001	.030	.976
	Aesthetic Value - Visual Facade	.169	.057	.163	2.989	.003
	Aesthetic Value - Details & Decorations	.102	.051	.101	2.005	.045
	Authenticity	-.046	.044	-.043	-1.051	.293
	Historical Value	.259	.047	.249	5.498	.000
	Accessibility - Physical Access	.073	.036	.072	2.045	.041
	Accessibility - Information Access	.060	.036	.059	1.648	.100
	Accessibility - Societal Access	.103	.045	.099	2.269	.024
	Community Value - Social Value	.064	.048	.062	1.330	.184
	Community Value - Economic Value	.197	.047	.194	4.209	.000

a. Dependent Variable: Tourist Experience

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The regression analysis reveals that historical value has the most significant positive impact on the tourist experience among the evaluated variables, with a standardized coefficient (Beta) of 0.249 and a p-value of 0.000, indicating its critical role in shaping visitors' and residents' preferences. Similarly, aesthetic value by the visual facade (Beta = 0.163, p = 0.003) and community value in economic value (Beta = 0.194, p = 0.000) are also notable contributors, emphasizing the importance of visual appeal and economic benefits in enhancing tourist satisfaction. The aesthetic architectural value, encompassing visual facades, intricate details, and decorations, significantly contributes to the overall tourist experience, as noted by Liu et al. (2018). Research by Vardopoulos (2019) also emphasized that community engagement is fundamental to sustainable heritage tourism, fostering economic benefits.

Nevertheless, variables such as cultural value, educational value, architectural value, authenticity, and community value within social value were not found to exert a statistically significant influence. These findings highlight the importance of considering historical significance, aesthetic features, and economic contributions in the development or preservation of historical buildings to optimize their appeal to visitors. Moreover, cultural, educational, and social values might require a more extended period to manifest their influence, and therefore, they might not be immediately detectable in cross-sectional studies. Research by Kutut et al. (2014) suggests that intangible factors such as authenticity and social value often have long-term effects.

The findings from the regression analysis emphasize the crucial influence of historical, aesthetic, and economic values in shaping the tourist experience, demonstrating substantial and statistically significant impacts. These factors influence visitors' experiences at heritage sites by emphasizing cultural authenticity and visual appeal, thereby cultivating meaningful experiences. The emphasis on visual aesthetics is notable as visitors prefer well-maintained environments. Additionally, the economic value associated with historical tourism, such as increased local business, reinforces the necessity of sustained preservation efforts (Ariffin et al., 2023). The results underscore the importance of strategic initiatives aimed at preserving the physical integrity of heritage sites and enhancing their social and economic significance.

CONCLUSION

Urban growth has influenced the development of Kampung Heritage Kayutangan, leading to changes in its buildings. Research on the significance of historical buildings for tourism shows that historical value, aesthetic value of the visual facade, and community value in economic aspects are the most prominent aspects experienced by visitors and residents. In contrast, authenticity is least perceived concerning heritage tourism in Kampung Heritage Kayutangan.

The differences between visitors' and residents' preferences highlight the contrasting preferences shaped by their experiences and relationships with the heritage site. Visitors tend to place the highest value on cultural significance, indicating that they appreciate the historical and cultural importance of the buildings during their tourism experience. Residents tend to exhibit a low appreciation for the historical significance, likely due to their familiarity with the historical elements of their environment, which may not evoke the same sense of novelty or emotional resonance as it does for visitors. These findings emphasize that while visitors seek heritage sites' cultural and historical aspects, residents place greater importance on architectural appeal and may perceive historical value as a more familiar, less remarkable aspect of their daily environment.

These factors create a mutually reinforcing cycle that supports heritage tourism, benefiting both visitors and residents. Thus, enhancing other impactful aspects that have not yet fully materialized is necessary to achieve sustainable tourism by integrating these aspects from the perspectives of both visitors and residents. The community can protect historical sites while providing educational value for visitors and fostering economic growth. Such an approach allows the cultural heritage to be appreciated and maintained for future generations while benefiting the local community.

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ETHICAL STATEMENT

The authors state that they have no conflicts of interest related to the publication of the paper. This study was conducted in accordance with academic research ethics. Participation was voluntary, informed consent was obtained, and confidentiality was maintained.

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IDENTIFICATION OF INFRASTRUCTURE INDICATORS IN URBAN HOUSING DEVELOPMENT IN INDONESIA

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Abstract

Urban housing development is an important aspect of sustainable spatial planning, where adequate infrastructure is a major factor in creating decent, comfortable, and safe housing. Infrastructure includes basic facilities, accessibility, security, and environmental sustainability. Semarang City, as one of the metropolitan cities in Indonesia, faces various challenges in managing housing infrastructure. Rapid population growth, limited land, and the threat of disasters such as floods are the main factors that affect infrastructure planning. Therefore, a clear parameter is needed to assess infrastructure capability in urban housing development. This research aims to identify infrastructure indicators in housing development. The results of this study have reached consensus on 23 indicators in only two rounds of Delphi, with 15 experts indicating a percentage of agreement over 75%, meaning the experts are in the agreed-upon category. The IQR≤1 value indicates a high degree of agreement. While SD<1, indicating that the experts' answers are homogeneous. In addition, the CV value obtained <0.2 or 20% indicates that stability is achieved, and there is no further Delphi round. There are four indicators of input from experts, including housing signage, a one-gate system, a jogging track, and a gathering point. However, one indicator that needs to be eliminated is the internet network, as it is not provided by housing but is instead held by each homeowner. The results of this study are expected to serve as a reference or influence existing regulations for policymakers and developers, ensuring that every housing development meets standards that support quality of life, efficiency, and sustainability.

Keywords: Indicator, Infrastructure, Housing

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INTRODUCTION

Urban housing development is one of the main challenges in spatial planning in Indonesia. Along with increasing urbanization, the need for adequate housing is increasingly urgent, so supporting infrastructure is a crucial factor in creating a comfortable and sustainable environment (Telaumbanua et al., 2024). Good infrastructure, such as transportation networks, drainage, clean water supply, sanitation, energy, and public facilities, plays an important role in supporting people's lives in urban areas. Therefore, identifying infrastructure indicators in housing development is necessary to ensure the quality of housing is up to standard (Rahadian & Oetomo, 2024).

Semarang City, as one of the metropolitan cities in Indonesia, faces various challenges in managing housing infrastructure. Rapid population growth, land constraints, and the threat of disasters such as flooding are the main factors affecting infrastructure planning. By identifying key indicators relevant to urban needs, planning for housing development in Semarang City can be more effective and sustainable. In addition, research by (Pigawati et al., 2023) highlights how land use and infrastructure growth must be aligned to reduce the negative impacts of urbanization.

Research by (Enwin & Ikiriko, 2023) highlights that inadequate infrastructure in urban areas is a significant barrier to providing affordable housing, underscoring the need for an integrative approach to develop the necessary infrastructure. It highlights the need for more attention to planning infrastructure that is both adaptive and proactive in addressing challenges.

This study aims to identify infrastructure indicators that support urban housing development to serve as a reference for developers and policymakers. It is also to ensure that every housing development meets standards that support quality of life, efficiency, and sustainability.

LITERATURE REVIEW

Housing Infrastructure

Housing infrastructure is a complex and vital system in supporting the quality of life of residents. Housing is an important aspect of modern life, not only because of its cost, but also because of its relationship with various urban challenges (Aqlima Ramli et al., 2024). The relationship between housing and infrastructure, according to (Onyejiaka et al., 2020) that the house where a person lives shows their status, a measure of achievement, community acceptance, an expression of their personality, and is a barometer that shows the way and attitude a person is perceived in society

Research (Omar et al., 2018) emphasizes that housing infrastructure is not just a physical building. However, it includes utility networks, accessibility, and support systems that are interrelated to create a decent and sustainable residential environment. (Mangalekar & Gumaste, 2021) also explained that the

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main aspects of housing infrastructure include clean water supply, sanitation, and waste management. The availability of clean water that is sustainable and safe for consumption is a top priority. According to research (Byagaba & Mukiibi, 2021), efficient sanitation systems prevent environmental pollution and disease. Effective solid and liquid waste management keeps the environment clean and healthy. Additionally, it is argued that access to reliable and affordable electrical energy supports daily activities and can improve the quality of life of residents (Ahmad et al., 2024).

According to (Intan et al., 2020), in addition to basic utilities, housing infrastructure also includes road accessibility and transportation. A well-planned road network ensures residents' mobility and access to public facilities such as schools, hospitals, and workplaces. An efficient public transportation system reduces congestion and air pollution. Last but not least, according to (Molnar et al., 2018) adequate telecommunication connectivity supports communication and access to information. Another important aspect is environmental security and safety.

In the research of (Celhay & Gil, 2020) the authors emphasized that integrated security, including adequate street lighting and neighborhood security systems, creates a sense of security for residents. Research of (Huang et al., 2019) emphasizes that infrastructure planning should also consider aspects of disaster resilience, ensuring infrastructure is resistant to various threats such as earthquakes, floods, and fires. Overall, adequate infrastructure in a housing estate is essential to support residents' quality of life.

Housing Infrastructure Indicators

Based on the review results in several journals, the following are housing infrastructure indicators in Table 1

Table 1: *Review of Infrastructure Indicator Articles*

Infrastructure Indicators	Reference
Nature / Environment	
Green open space	(Giuliani et al., 2021)
Natural Water Reservoir	(Huang et al., 2019)
Social	
Educational Facilities	(Telaumbanua et al., 2024)
24 Hour Clinic	(Zhou et al., 2020)
Mosque	(Jaffar & Abdullah, 2020)
Other worship	(Ormsby, 2021)
Shopping	(Omar et al., 2018)
Public service facilities	(Hamzah et al., 2024), (Rafee Majid et al., 2020)
Sports field	(Giuliani et al., 2021), (Hamzah et al., 2024)
Parking space availability	(Wai Lam et al., 2023)
Waste management	(Cheng et al., 2022), (Intan et al., 2020)
Security system	(Celhay & Gil, 2020), (Musa et al., 2019)

Infrastructure Indicators	Reference
Facilities and infrastructure	
Road Conditions	(Ali et al., 2023),
Lighting/PLN/Electricity	(Ahmad et al., 2024), (Graves et al., 2021)
Availability of Clean Water	(Tumwebaze et al., 2023)
Telecommunication Availability	(Graves et al., 2021), (Molnar et al., 2018)
Internet Network	(Graves et al., 2021), (Molnar et al., 2018)
Drainage network	(Pei et al., 2024), (Pigawati et al., 2023)
Wastewater network	(Cheng et al., 2022)
Availability of local transportation	(Intan et al., 2020), (Zhang et al., 2024)

Source: Review Artikel, 2024

Based on several articles from several journals, 20 indicators were obtained, of which two indicators are natural factors, 10 indicators for social factors, and eight indicators for facilities and infrastructure factors (Graves et al., 2021)

Stakeholder Analysis

Determining expert respondents is important because experience and knowledge determine the reliability and validity of the results. Therefore, expert respondents must meet four key requirements: they must have relevant knowledge and experience, be willing to participate in providing opinions or input, have sufficient time to participate, and possess effective communication skills (Giannarou & Zervas, 2014).

Table 2: *Experts (Stakeholders) involved*

Stakeholder	Role
Department of Housing and Residential Areas	Responsible for formulating policies, coordinating between sectors, implementing policies, monitoring and evaluating, and providing technical guidance related to housing and settlements
Department of Spatial Planning	Responsible for formulating policies, preparing strategic plans, coordinating programs, establishing cooperation, implementing programs and activities, as well as conducting monitoring, evaluation, and reporting related to spatial planning, building planning, development, construction services, and land.
National Housing Corporation	Organizing housing and settlements, developing housing for low to middle-income communities, and managing and planning land use.
PLN (State Electricity Company)	Provision of electricity for the community and industry in settlements
Water Company	Providing raw water for drinking and meeting community needs through a clean water distribution system.
Telkom (Telecommunication)	Providers of information and communication services and telecommunications networks in settlements
Lecturer/Researcher	Contribute to the development of new theories and methods, examine current issues, and seek innovative solutions to

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Stakeholder	Role
	improve the quality and sustainability of settlement infrastructure.
Developer	Planning, designing, and building a housing project and its infrastructure, along with permits
Social Institutions Housing Society	Monitor and provide critical input in housing infrastructure planning with a focus on environmental impact analysis, sustainability, and green technologies.

Source: survey results, 2024

Based on the results of the three stages of stakeholder analysis above, several preliminary plans can be developed to involve these stakeholder groups in the stages of the program/project. The stakeholder categories include subjects, who have high influence and low importance; key players, who possess both high influence and high importance; context setters, who have low influence but high importance; and the crowd, representing stakeholders with both low influence and low importance.

RESEARCH METHODOLOGY

This qualitative research used the Delphi method to identify housing infrastructure indicators because the topic is multidisciplinary and involves diverse views from various stakeholders. The Delphi method was chosen because it allows for anonymous input collection, thus reducing bias and encouraging a more objective consensus.

Although the Delphi method is designed to gather anonymous input (Musa et al., 2019), it highlights that the topic of housing infrastructure involves diverse views from different stakeholders. According to (Musa et al., 2019), this may pose a risk that the opinions of some influential experts may influence those of other experts, resulting in the final results not fully reflecting independent views.

This approach involves a group of experts to reach an agreement on a problem. Experts are selected based on experience, field of knowledge, and specialized expertise (Rafee Majid et al., 2020)Territorially, the Delphi process can continue to repeat until a determined consensus has been reached. The appropriate number of respondents to engage in a Delphi study, according to research (Daniel et al., 2019), is 10-15 respondents. Ten to fifteen respondents can be sufficient if the background expertise is homogeneous. The Delphi method, as described by (de Brito et al., 2017), requires three rounds to achieve its objectives. In each round, participants are given 2 weeks to respond (Musa et al., 2019).

This process uses anonymous feedback to reduce variation in answers (de Brito et al., 2017). According to (Al-Qawasmi, 2021) the Delphi questionnaire is said to be in consensus if the standard deviation value is < 1 and

the IQR value is ≤ 1. In addition, the difference coefficient of variation (CV) is determined for each indicator, which aims to provide a normalized measure of dispersion. CV is a dimensionless value (coefficient) and is calculated as the standard deviation divided by the mean. The difference is obtained by subtracting the CV from round 2 and the CV obtained in round 1, CV difference smaller than 0.2 or 20% indicates it.

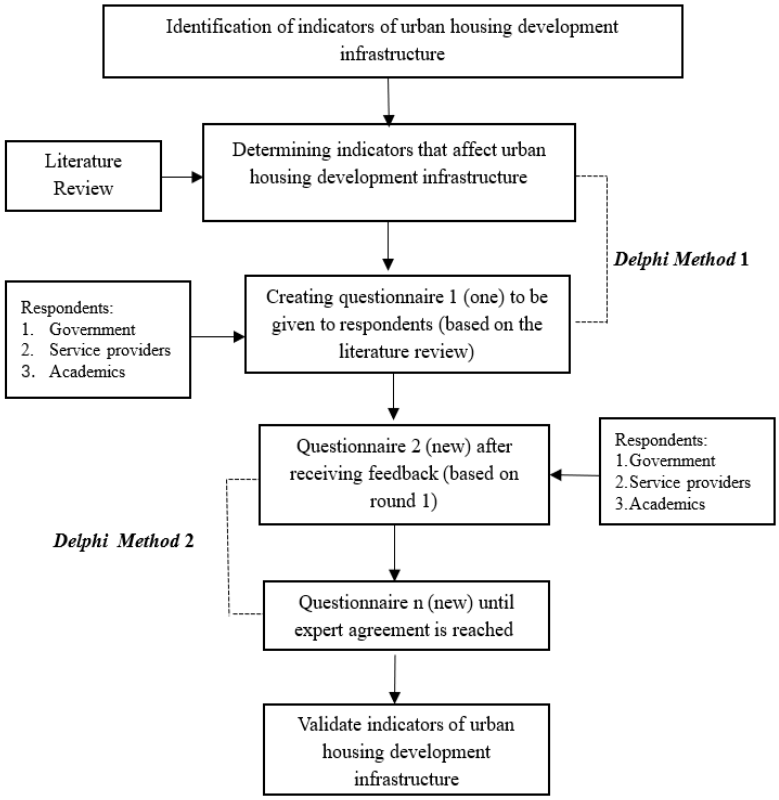


Figure 1: Research Flow Diagram
Source: Author

Figure 1 shows the flowchart of the research using the Delphi method that goes through various stages to reach the final result. First, housing infrastructure indicators were identified based on the literature review. Next, the first round of questionnaires began with closed-ended questions relating to housing infrastructure.

There were six government experts, three from academia, four from property developers, and two from the Social Institutions Housing Society, totaling 15 experts. The second round asked for responses to the indicators and

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concepts of urban housing infrastructure. It provided feedback on how to formulate indicators and improve concepts. In the next round, the questions were closed-ended, where consensus was reached on the results, indicators, and concepts. However, the Delphi rounds are not always three but usually two as long as consensus is reached.

RESULT AND DISCUSSION

Based on the Stakeholder Importance and Influence Matrix in Figure 2, it is found that stakeholders are included in the Key Player category, namely, stakeholders who have high influence and importance, so that they can be fully involved in all stages of identifying infrastructure indicators in housing development, thereby giving them confidence that the program's success is due to their support.

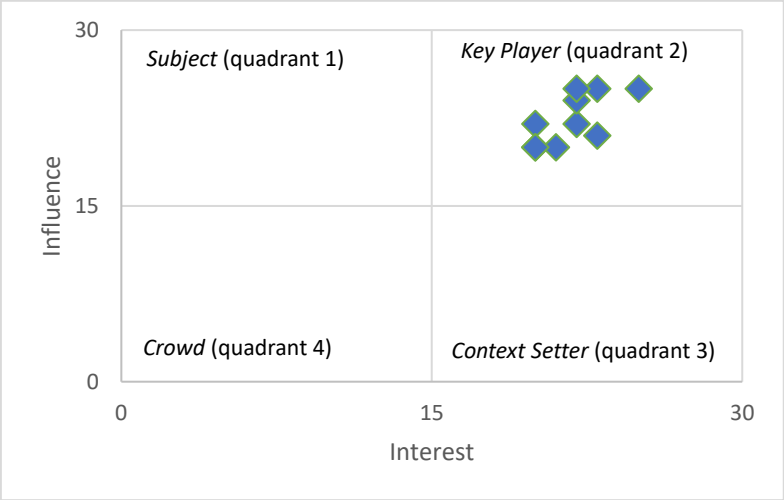


Figure 2: Stakeholder interest and influence matrix
Source: Author

Table 3 shows that, based on the review of articles and given to experts, the following results were obtained:

Table 3: *Percentage Answers 4-5, Mean, Standard Deviation, Interquartile Range, and Coefficient of Variance Delphi Rounds 1 and 2*

Indikator	Delphi 1				Delphi 2			
	% (4-5)	SD	IQR	CV	% (4-5)	SD	IQR	CV
Nature / Environment								
Green open space	100.00	0.52	1.00	0.11	100.00	0.52	1.00	0.11
Natural Water Reservoir	100.00	0.46	0.50	0.10	100.00	0.46	0.50	0.10
Social								

Indikator	Delphi 1				Delphi 2			
	% (4-5)	SD	IQR	CV	% (4-5)	SD	IQR	CV
Educational Facilities (Kindergarten & Elementary School)	100.00	0.46	0.50	0.10	100.00	0.46	0.50	0.10
24 Hour Clinic	100.00	0.46	0.50	0.10	100.00	0.46	0.50	0.10
Mosque	100.00	0.49	1.00	0.10	100.00	0.49	1.00	0.10
Other worship	100.00	0.52	1.00	0.11	100.00	0.52	1.00	0.11
Shopping	93.33	0.52	1.00	0.17	93.33	0.52	1.00	0.17
Public service facilities	93.00	0.59	1.00	0.14	93.00	0.59	1.00	0.14
Sports field	100.00	0.51	1.00	0.12	100.00	0.51	1.00	0.12
Parking space availability	93.33	0.52	1.00	0.11	93.33	0.52	1.00	0.11
Waste disposal	100.00	0.77	1.00	0.18	100.00	0.77	1.00	0.18
Security system	100.00	0.51	1.00	0.12	100.00	0.51	1.00	0.12
Jogging Track	-	-	-	-	80.00	0.52	1.00	0.17
One gate system	-	-	-	-	80.00	0.52	1.00	0.17
Housing identity board	-	-	-	-	100.00	0.51	1.00	0.12
Assembly point	-	-	-	-	80.00	0.52	1.00	0.17
Facilities and infrastructure								
Road Conditions	100.00	0.50	1.00	0.10	100.00	0.50	1.00	0.10
Lighting/*PLN*/Electricity	100.00	0.46	0.50	0.10	100.00	0.46	0.50	0.10
Availability of Clean Water	100.00	0.51	1.00	0.11	100.00	0.51	1.00	0.11
Telecommunication Availability	100.00	0.46	0.50	0.10	100.00	0.46	0.50	0.10
Internet Network	73.33	0.64	0.50	0.18	-	-	-	-
Drainage network	100.00	0.51	1.00	0.11	100.00	0.51	1.00	0.11
Wastewater network	100.00	0.51	1.00	0.11	100.00	0.51	1.00	0.11
Availability of transportation	100.00	0.46	0.50	0.11	100.00	0.46	0.50	0.11

Source: Data Processing, 2024

In Delphi round 1, the results of the article review amounted to 20 indicators and were given to experts. Indicators that have an accepted percentage> 75% are 19 indicators, and indicators that have a percentage < 75% are one indicator. Likewise, the IQR (interquartile range) value ≤ 1 indicates a high degree of agreement among experts, who agree that the 19 indicators provided can be used for housing development, except for one indicator. A value of SD (standard deviation) < 1 indicates that the expert's answer is homogeneous. It means that experts agree on 19 indicators, but there is disagreement on one. One indicator that is not agreed upon has a percentage value < 75%, an IQR value ≤ 1, and an SD < 1 is the internet network indicator because each house installs its own internet network, rather than being provided by the developer. Similar results were also reported where broadband availability is often treated as a household responsibility rather than community infrastructure (Graves et al., 2021).

In round 1, several input indicators from experts were also considered, leading to the addition of 4 indicators: housing signage, a gate system, a jogging

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track, and a gathering point. According to experts from the private sector, housing signage is a housing identity. This indicator has a vital role in building the image and pride of its residents (Intan et al., 2020). Experts from academia also pointed out that the one-gate system in this housing provides extra security for all residents. Only vehicles that are registered and have special access are allowed to enter through one main gate that is strictly guarded. Another expert from the private sector also provided input that the jogging track in this housing offers a comfortable and safe path for exercise, suitable for jogging, walking, and cycling (Intan et al., 2020) dan (Hamzah et al., 2024).

Meanwhile, the gathering point, as identified by government experts, can serve as a gathering place for residents in the event of a natural disaster or fire, provided the location is easily accessible, such as a field or or park (Omar et al., 2018). The importance of such additional livability indicators in peri-urban housing has also been emphasized in recent studies (Rafee Majid et al., 2020). Based on expert input, the indicators for Delphi round 1, which originally totaled 20, were revised to 23. One indicator was not agreed upon, and four indicators were input from experts.

In round 2, experts again rated the 23 indicators generated in round 1. After the assessment, the results of this round have reached consensus. Where all indicators have a percentage of agreement greater than 75%, so that respondents are in the agreed category. The IQR (interquartile range) value ≤ 1 indicates a high degree of agreement. While SD (standard deviation) < 1, indicating that the answers of the experts are homogeneous.

Meanwhile, the value of ΔCV (difference in coefficient of variation) has a value < 0.2 or 20%, indicating stability. Thus, no further Delphi rounds are needed for this indicator, as the level of certainty and agreement that has been reached among the experts is sufficient. The data generated from the second round can be considered as a valid representation of the experts' perceptions of the 23 indicators, with the two main indicators of natural elements being the presence of green open spaces and natural water reservoirs. This finding is consistent with other Delphi-based studies on urban quality of life indicators, which also confirmed consensus stability through IQR, SD, and ΔCV statistics (Al-Qawasmi, 2021).

Previous research, which may have involved more Delphi rounds and a larger number of respondents, aimed to achieve a higher level of consensus and reduce uncertainty in the results. However, this study, with only two rounds and 15 respondents, showed efficiency in achieving significant consensus for 23 indicators. Despite the smaller number of respondents and shorter rounds, achieving a ΔCV value below 20% in the second round indicates that the sample used is representative enough to generate a strong consensus. This efficiency aligns with findings that Delphi consensus can be achieved more quickly when expert homogeneity is high (Barrios et al., 2021).

CONCLUSION

The study achieved a strong consensus on 23 indicators in only two rounds of the Delphi study with 15 respondents, as indicated by the coefficient of variation (ΔCV) being below 20%. In the first round, there were 20 indicators, of which two were for natural factors, 10 were for social factors, and eight were for facilities and infrastructure factors. In round 2, there were 23 indicators, of which two indicators were for natural factors, 14 indicators were for social factors, and seven indicators were for facilities and infrastructure. There are four indicators of input from experts, including housing signage, a one-gate system, a jogging track, and a gathering point. However, one indicator that needs to be eliminated is the internet network, as housing does not provide it, but is held by each homeowner. The results of this research are expected to serve as a reference or influence existing regulations for policymakers and developers, ensuring that every housing development meets standards that support quality of life, efficiency, and sustainability.

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SUSTAINABILITY OF CROSS-LAMINATED TIMBER (CLT) NUSANTARA HOUSE BASED ON THERMAL COMFORT INDICATORS USING SIMULATION METHOD

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Abstract

Cross-laminated timber (CLT) Nusantara is a building model constructed to achieve the vision of a sustainable house for Indonesia. The integrated evaluation strategy of sustainable habitat systems suggests that the sustainability value can be increased through increased welfare in comfort aspect. Thermal comfort has not been measured in this building, but can be potentially improved. Therefore, this research aims to evaluate the sustainability value of CLT Nusantara building from the perspective of thermal comfort and the potential for enhancing the sustainability value of building design aspects. The adopted method used field measurements and simulation through an adaptive thermal comfort model. The results showed that the percentage of hours experiencing 'hot' conditions was more prevalent during operational hours. The design method exerted a significant influence on the augmentation of 'comfortable' hours. The addition of windows provided opportunities for air entry to increase 'comfortable' hours among the several designs applied in simulation. The shape and orientation of building had the potential to enhance 'comfortable' hours. CLT served as a building material based on the comparison applied in simulation.

***Keywords**:* Sustainability; Thermal Comfort; CLT

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INTRODUCTION

Efforts to mitigate global warming through net-zero carbon have been considered by several countries (Morris et al., 2023), such as Indonesia (Indonesia LTS-LCCR 2050, 2021). The utilization of renewable resources assumes significant importance, considering the capacity to sequester carbon over extended periods (Köhl & Martes, 2023) and lower emissions (Craig et al., 2021). Cross-laminated timber (CLT) is a rigid, slab-shaped product comprising boards/lamellas placed adjacent (Jeleč et al., 2018). This technology poses several advantages regarding mechanical properties, earthquake resistance, and potential as an alternative to concrete or stone (Jeleč et al., 2018; Sandoli et al., 2021). The expense is minimal and the environmental effect is negligible (Bahrami et al., 2021). CLT technology represents a recent innovation for Indonesia, but wood is widely found in Indonesia (Huzairin & Andini, 2022). However, research on CLT potential utilization shows that a significant opportunity has been presented as a sustainable building material (Corpataux et al., 2020).

The development potential of CLT and the efforts to achieve the vision of sustainable housing led to the construction of a building made from CLT Nusantara House. The material used for this purpose is primarily composed of acacia wood. The selection of wood species is determined by several factors, including mechanical and physical capabilities (Mohd Yusof et al., 2019) as well as the availability of local wood species (Corpataux et al., 2020). Building has been designed with various technologies to support the achievement of sustainability goals.

Sustainability in a habitat system can be assessed based on the level of reduction in environmental damage and the quality of life or welfare (Hayashi et al., 2005; Kusumawanto & Astuti, 2014; Matsufuji et al., 2004). The utilization of CLT materials necessitates an evaluation from the perspective of 'welfare,' which includes various factors. An important aspect is comfort level, which serves as a crucial element in sustainable habitat systems. The characteristics of a tropical climate with high temperature and humidity levels are different from the regions where CLT technology was first developed (Brandner et al., 2016). Thermal comfort of CLT Nusantara House building must be assessed. Thermal comfort is also recognized as a factor in determining welfare of building occupants (Li et al., 2021) and as an indicator of the sustainability of a habitat system. Therefore, this research evaluates the sustainability performance of CLT Nusantara building at Gadjah Mada University's Faculty of Engineering from thermal comfort perspective since the assessments remain unexplored. The evaluation focuses on the aspects of the current building conditions and the optimization of the design factors to enhance thermal comfort generated. The results can serve as a valuable reference point in the development of sustainable housing in Indonesia to improve sustainability value.

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LITERATURE REVIEW

Sustainable Habitat System

Hayashi et al. (2005) stated that an integrated evaluation strategy for evaluating sustainable habitat systems could be used to reduce environmental damage while maintaining an optimal level of modern quality of life. In the pursuit of enhancing the value of sustainability, concerted efforts are carried out to optimize throughput (T) by augmenting welfare (W) and mitigating environmental damage (D). Furthermore, integrated evaluation uses the 'throughput formula', where T (throughput) is the result of W (welfare) minus D (environmental damage). Welfare includes safety (Sa), relief (R), health (H), comfort (C), and sense (Se). Environmental damage comprises life cycle energy, CO2, and cost. This formulation can be used and developed to evaluate and manage sustainable habitat system development (Kusumawanto & Astuti, 2014; Matsufuji et al., 2004). Welfare, consisting of several indicators, is achieved when humans and the environment have a supportive and dependent relationship (Abu Bakar et al., 2017). The environment that affects thermal comfort is an important factor influencing the level of welfare (Li et al., 2021).

Adaptive Thermal Comfort

The adaptive model is a method that predicts thermal comfort of occupants (Solano et al., 2021). The model is considered to help design low-energy consumption building. An adaptive thermal comfort model considers local environmental factors and has an adaptive mechanism (Lakhiar et al., 2024; Yau & Chew, 2014). American Society of Heating, Refrigerating, and Air-Conditioning Engineers (2017) stated that the operating temperature acceptable to the adaptive comfort model depended on the prevailing mean outdoor air temperature (t pma (out). For the upper and lower 80% acceptance limit, the operating temperature values are obtained from t pma (out) x 0.31 + 21.3 and t pma (out) x 0.31 + 14.3, respectively.

Effect of Building Factors

The design of a building has a significant influence on thermal comfort. The materials used in the construction also have a great impact on comfort level of building. Design factors such as building height, materials, openings, and ventilation can influence thermal comfort of a building (Ariffin, 2015; Pramesti et al., 2021; Zain et al., 2007; Zulkeply et al., 2023). Meanwhile, cladding and opening are design elements considered in the context of CLT building (Husain et al., 2020).

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RESEARCH METHODOLOGY

This research used field measurements to evaluate thermal comfort. Further evaluation was carried out by simulation to predict thermal comfort conditions of building for a year. In this context, the design factors were changed from the existing conditions to determine the effect on thermal comfort in building visually represented in Figure 1.

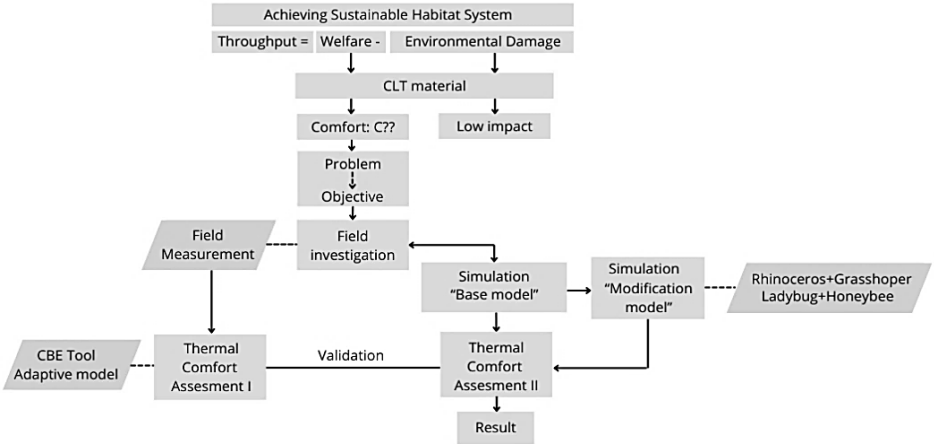


Figure 1: Schematic of Research Methods

Description of Building Model

CLT Nusantara building was located in the Faculty of Engineering campus area of Gadjah Mada University, Yogyakarta, Indonesia, at coordinates -7.765611 LS and 110.371510 BT. The construction of building primarily used CLT materials composed of acacia wood for the walls, ceilings, and floors as shown in Figure 2. In addition, CLT was planned using a 3-layered modular system. Building, with an approximate area of 27 m^2, was hexagonal and adapted to the modular dimensions of CLT material (1.2m x 2.4m per module). Various components, such as windows and terrace floors, were constructed using Bengkirai wood materials. The roof and foundation were built using a wooden roof truss with a bitumen cover and reused concrete materials from the local area, respectively. Building was designed to use natural ventilation located on the southeast and southwest sides.

Measurement Method

This research used two data collection stages, namely direct field measurement and simulation. Simulation was used as a tool to provide an overview of thermal comfort over a full year and examine the design factors affecting the performance

in CLT Nusantara. Field measurement results functioned as a validation tool for simulation used.

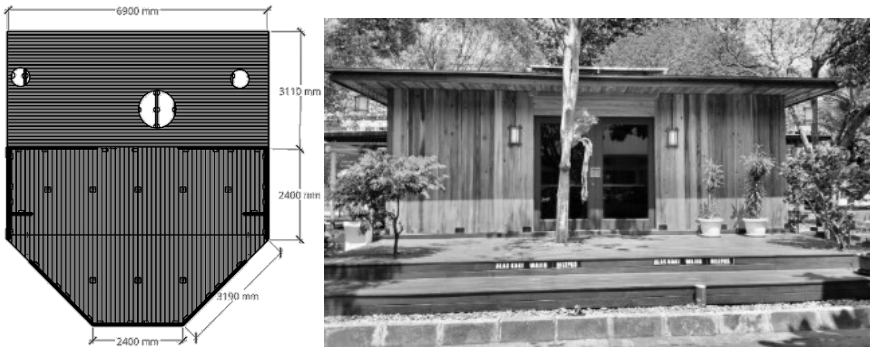


Figure 2: Plan and View of the North Facade of CLT Nusantara Building
Source: Photograph taken by the Authors, 2024

The climatic conditions of field measurements of the outdoor room were conducted from 19 October 2024 to 25 October 2024 for 24 hours over 7 days. The measurement of thermal environmental conditions was carried out during the operational hours, from 08:00 am to 4:00 pm, for 2 days. Subsequently, indoor measurements were taken to obtain air temperature, mean radiant temperature, and air speed in the room. Outdoor microclimate measurements were also conducted to obtain the prevailing mean outdoor temperature. The measurement equipment used for this purpose can be observed in Figure 3 and Table 1. The facility of the laboratory was calibrated regularly to ensure the accuracy of the measurements.

Simulation Method

Simulation used Grasshopper and Rhinoceros modeling software with Ladybug and Honeybee plugins. EPW weather data, which contained air temperature and wind speed in 5 years (2017-2021), from Adi Sutjipto monitoring station, Yogyakarta, was used in simulation. Thermal conductivity data of Acacia wood material were obtained using the results of existing research (Prasojo & Sulistyo, 2010).

Data Analysis

Thermal comfort analysis was conducted using an adaptive thermal comfort index model since CLT Nusantara Building was designed to maximise natural ventilation and empower residents to engage in adaptive mechanisms. Field measurements were analyzed using tools developed by the Centre for the Built

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Environment (CBE). Based on field measurement, simulation results are validated based on field measurement. Design factors affecting thermal comfort were also modified through simulation, and the results were compared with the base model to ascertain the effect.



Figure 3: Measurement of Microclimate of Outdoor and Thermal Environment of Indoor
Source: Photograph taken by the Author, 2024

Table 1: Specifications of Measurement Equipment.

Specifications	Type	Range of Measurements	Accuracy
Thermometer and Hygrometer (Indoor)	Hobo MX Analog/Temp/RH/Light Logger 1104	-20° to 70°C (-4° to 158°F)	±0.20°C from 0° to 50°C (±0.36°F from 32° to 122°F)
Anemometer (Indoor)	Pitot Tube Anemometer and Differential Manometer Extech advantage HD350	Air Velocity: 1 to 80.00 m/s	Air Velocity: ±1% full scale
WBGT (Indoor)	Lutron WBGT-208- Heat Index and WBGT Meter	Solar radiation: 0 to 1999 W/m²	Air temperature: ±0.8°C (±1.5°F) air humidity: ±3% RH
Weather station (outdoor)	Hobo RX3000	-40° to 60°C	±8 seconds per month in 0° to 40°C range; ±30 seconds per month in -40° to 60°C range

Source: (Flir, 2024; HOBO, 2024, 2024)

ANALYSIS AND DISCUSSION

Sustainable Assessment

The evaluation of the sustainability of CLT Nusantara House uses a tool developed for evaluating and managing sustainable habitat system development (Kusumawanto & Astuti, 2014; Matsufuji et al., 2004). In CLT Nusantara building, the environmental impact was found to be minimal. Building applies

net zero energy, uses smart light control to regulate the lighting level of LED lights, and adopts an Internet of Things (IoT) smart garden to control the watering of facade plants. CLT Nusantara building is also operated by maximizing natural ventilation, hence, the energy life cycle is considered low.

Building material used for most of the components is CLT made from Acacia wood. This wood has a very low carbon footprint compared to other construction materials that produce higher carbon emissions (Craig et al., 2021). The foundation materials utilize recycled materials, hence, the life cycle carbon of building is low. In this context, construction costs can be minimized since Acacia is a local timber. The connection system with locally produced steel plates also lowers construction costs.

Increasing welfare of CLT Nusantara House (Safety: Sa, Relief: R, Health: H, Comfort: C, Sense: Se) can maximize the sustainability value. The value of comfort must be improved to realize the vision of sustainable housing development.

Results of Field Investigations

Measurements made for 7 days of microclimate conditions in CLT Nusantara building area show temperature fluctuations in the range of 22.87^{0}C to 34.05^{0}C as shown in Figure 4. The peak temperature value occurs at 13.30 to 14.30 WIB, which decreases in the following hours. The average daily temperature based on the measurement results is 27.39^{0}C. The measured wind speed in the area is in the range of 0.5 m/s from the South.

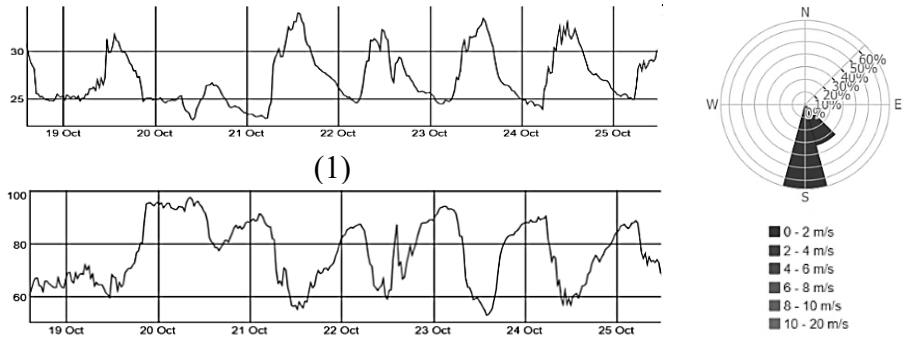


Figure 4: Microclimate Measurement Results: Temperature (1), Relative humidity (2), and Windrose (3)
Source: Author's field data

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The results of measuring thermal environment during the operational hours (08.00 a.m. to 4.00 p.m.) of CLT Nusantara House show that the peak temperature is around 2:20 p.m. The measured air and globe temperatures are in the range of 27.03^0C to 34.06^0C and 27.8^0C to 34.1^0C, respectively. Meanwhile, the air velocity in the measured room is in the range of 0.25-2 m/s.

CBE thermal comfort tool analysis shows that comfort during operational hours occurs before 10.00 WIB. The times until the end of the operational hours show that the room is 'too hot.' The percentage of hours experiencing 'comfortable' conditions compared to 'too hot' in operational hours is 27.27% and 72.73%. Based on further analysis, the percentage value of 'too hot' can be increased to 'comfortable' conditions by 6.06% through an increase in air speed from 0.3 to 1.2 m/s.

Thermal Comfort Simulation and Validation

Simulation results for the base model of CLT Nusantara building (Table 2), report that the average annual indoor and operative temperatures are 27.28^0C and 27.42^0C, respectively. Based on an evaluation over a year, 56.92% of the room conditions are in a 'comfortable' state. The onset of the 'hot' condition is observed to occur at 09.00 am or 10.00 am, with the cessation occurring at 05.00 pm visually represented in Figure 5. During operational hours (08.00 am to 4.00 pm), 33.64% and 66.36% are in 'comfortable' and 'hot' conditions. Therefore, the prevalence of 'hot' conditions was predominantly during operational hours compared to the entire day.

Table 2: Thermal Conditions of the Base Model of CLT Nusantara Building.

Variabel	**Value**
Mean operative temperature (^{0}C)	27.42
Mean air temperature (^{0}C)	27.28
Mean radiant temperature (^{0}C)	27.57
Time in Comfort (%) during 24 hours	56.92
Time in Hot (%) during 24 hours	39.28
Time in Cold (%) during 24 hours	3.80
Time in Comfort (%) during operational hours	33.64
Time in Hot (%) during operational hours	64.93
Time in Cold (%) during operational hours	1.43

Source: Author's simulation data

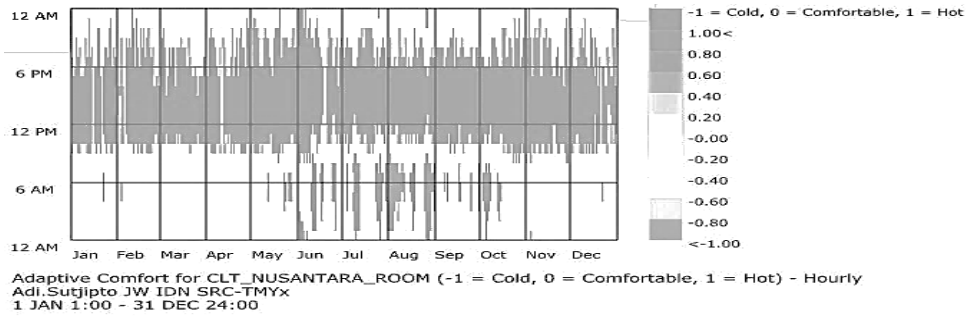


Figure 5: Adaptive Model Thermal Comfort Conditions for 1 Year
Source: Author's simulation data

This simulation shows conditions identical to field measurements and the results of the analysis. The onset of 'hot' conditions occurs at 10.00 am, with 'comfortable' hours reaching a value of 27.27%. These results show conformity with the analysis of thermal comfort conducted based on the results of field measurements.

Results of Simulation for Modified Design Factors

The design factors refer to previous literature, which include shading devices, building height and windows, materials, and building forms.

Shading Device Addition

The installation of shading devices on CLT Nusantara building includes the construction of a roof on the terrace and the roof extension. As the data in Table 3 clearly indicate, the addition of a roof on the north side in an area of 21,459 m2 enhances thermal comfort by 57.60% and 34.40% in the 24-hour state and during operational hours, respectively. The modifications, affecting changes in percentages of less than 1% by the addition of the terrace or extension of the roof, can be considered insignificant to the increase in thermal comfort.

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Table 3: Thermal Comfort Condition with Shading Modification

Model	Time 24 hours			Operating hours		
	Time in Comfort (%)	**Hot (%)**	**Cold (%)**	**Time in Comfort (%)**	**Hot (%)**	**Cold (%)**
Base Model	56.92	39.28	3.80	33.64	64.93	1.43
Modifications						
Terrace roof addition	57.60	38.52	3.88	34.40	63.93	1.67
	Increase/Decrease in Comfort Hours (%)					
	0.68	-0.76	0.08	0.76	-1.00	0.24
	Increase	Decrease	Increase	Increase	Decrease	Increase
Extension of the roof (+50 cm)	57.87	38.36	3.78	34.64	63.87	1.40
	Increase/Decrease in Comfort Hours (%)					
	0.95	-0.92	-0.02	1.00	-1.07	0.06
	Increase	Decrease	Decrease	Increase	Decrease	Increase

Source: Author's calculation

Window and Building Height Addition

The alterations include the addition of windows installed in one-third of the wall area on the south, east, and west sides. The selected additional window can be opened and closed. Simulation results show that the modifications increase thermal comfort by 6.03% and 7.12% in the 24-hour state and during operational hours, respectively. Furthermore, as the data in Table 4 clearly indicate, increasing building height from 2.4 to 3.6 m favors the time in comfort percentage for 24 hours and during operational hours by 1.85% and 1.92%, respectively.

Table 4: Thermal Comfort Conditions with Modified Openings

Model	Time 24 hours			Operating hours		
	Time in Comfort (%)	**Hot (%)**	**Cold (%)**	**Time in Comfort (%)**	**Hot (%)**	**Cold (%)**
Base Model	56.92	39.28	3.80	33.64	64.93	1.43
Modifications						
Window additions	62.95	30.14	6.92	40.76	57.29	1.95
	Increase/Decrease in Comfort Hours (%)					
	6.03	-9.14	3.12	7.12	-7.64	0.52
	Increase	Decrease	Increase	Increase	Decrease	Increase
Building height	58.77	35.70	5.54	35.56	62.59	1.86
	Increase/Decrease in Comfort Hours (%)					
	1.85	-3.58	1.74	1.92	-2.34	0.43
	Increase	Decrease	Increase	Increase	Decrease	Increase

Source: Author's calculation

Material Modifications

The materials are modified by changing the thickness of the walls, which are changed to 25 mm and 125 mm. The wall material is also changed to 100 mm bricks with two-sided plastering of 15 mm each. Simulation results show that decreasing and increasing the wall and CLT thickness reduce and improve the percentage of total 'comfortable' hours, respectively. Changes to the wall material by replacing with brick show an increase in 'comfortable' hours from the results presented in Table 5.

Table 5: Thermal Comfort with Modified Wall Materials

Model	Time 24 hours			Operating hours		
	Time in Comfort (%)	**Hot (%)**	**Cold (%)**	**Time in Comfort (%)**	**Hot (%)**	**Cold (%)**
Base Model	56.92	39.28	3.80	33.64	64.93	1.43
Modifications						
Wood (25 mm)	53.60	37.63	8.78	23.87	75.22	0.91
	Increase/Decrease in Comfort Hours (%)					
	-3.32	-1.66	4.98	-9.77	10.29	-0.52
	Decrease	Decrease	Increase	Decrease	Increase	Decrease
CLT (125 mm)	59.54	38.74	1.71	36.01	63.32	0.67
	Increase/Decrease in Comfort Hours (%)					
	2.63	-0.54	-2.09	2.37	-1.61	-0.76
	Increase	Decrease	Decrease	Increase	Decrease	Decrease
Brick with plaster	60.89	36.45	2.66	37.72	61.25	1.04
	Increase/Decrease in Comfort Hours (%)					
	3.97	-2.83	-1.14	4.08	-3.68	-0.40
	Increase	Decrease	Decrease	Increase	Decrease	Decrease

Source: Author's calculation

Building Form Modifications

Modifications to building form can investigate the sustainability potential of wider application of CLT materials. A total of three roof forms, as shown in Figure 6, with the same building mass volume were simulated with different aspect ratios of 1:1, 1:2, 1:3, 3:1, and 2:1 at heights of 2.4 m and 3.6 m.

The use of a gable and hip roof shapes provides a mean percentage of comfortable time of 56.83 % and 56.16 %, with a combination of 54.98 %. The percentage of comfortable time increases when the ratio of length to width is changed to 3:1 and 2:1. Based on building height, 'comfortable' hours increase and decrease during operating hours and 24-hour state, respectively.

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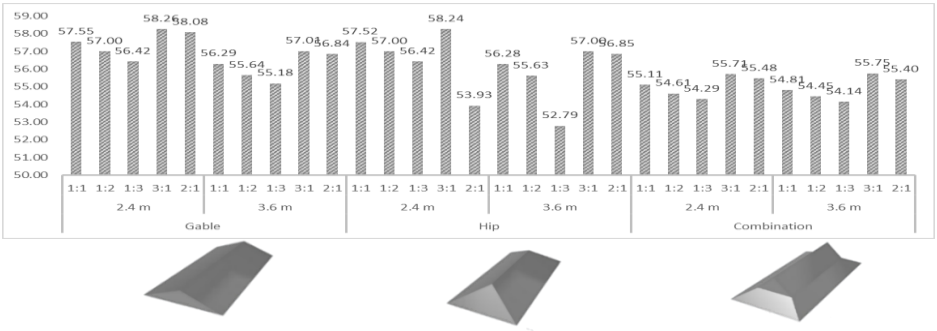


Figure 6: Total Time in Comfort (Over 24 Hours) of Modified Building Forms
Source: Author's simulation data

DISCUSSION

Some modifications to the design factors affect the value of thermal comfort and sustainability of CLT Nusantara building based on an integrated evaluation method of habitat systems (Hayashi et al., 2005; Kusumawanto & Astuti, 2014; Matsufuji et al., 2004). The modifications to building height, shading, materials, openings, and ventilation (Pramesti et al., 2021; Zain et al., 2007; Zulkeply et al., 2023) changed the percentage of 'comfortable' hours with different effects.

The addition of shading changes the percentage of 'comfortable' hours by less than 1%. The modification is influenced by the high-temperature conditions in the area during operational hours. In this research, shading was added on one north side and the entire area for the roof terrace and extension, respectively. Shading in one orientation only shows a lower comfort improvement value. This is because the effectiveness of devices is influenced by building orientation (Lau et al., 2016; Rana et al., 2022).

Modifications to the height of building and the addition of windows have a greater impact on increasing 'comfortable' hours than the addition of shading. The use of windows provides an opportunity for increased air speed to improve thermal comfort with adaptive models. The presence of sufficient air speed enhances comfortable thermal conditions (Zain et al., 2007). The material changes made to CLT Nusantara building provide interesting results. In this context, the thickness of the material influenced the change in the percentage of 'comfortable' hours. Wood possessing a thinner thickness is evaluated with a lower percentage of 'comfortable' hours than thicker types. The result is influenced by the properties of the wood, where thinner types tend to have a lower thermal resistance (R-value). Furthermore, changing CLT wall to a brick increases 'comfortable' hours. The percentage of 'comfortable' hours is close to the value of the brick wall when CLT thickness is increased to 125 mm. Assessment of thermal comfort using adaptive models (Amaripadath et al., 2023) may provide different results from other models with more variables. Therefore,

the optimal thickness to achieve a better comfort value needs to be analyzed using different comfort methods.

Increasing the width-to-depth ratio of building plan from 1:1 to 1:2 and 1:3 decreases the percentage of 'comfortable' hours. This result occurs in roof types and building heights used. Building model places the wall plane width and depth in the north-south and east-west orientations, respectively. The east-west-facing wall plane becomes larger in area when the wall depth ratio is increased. This phenomenon is also observed when the wall depth ratio is decreased to 3:1 and 2:1, showing an increase in the percentage of 'comfortable' hours. The size of the east-west-facing plane influences solar heat gain throughout the day, affecting the percentage of 'comfortable' hours. Therefore, the orientation of building and the area exposed to the sun must be considered since thermal comfort is affected (Ariffin, 2015). This research is subject to certain limitations, namely the restriction of evaluating comfort to a single model. The temporal span of the measurements needs to be addressed by future research, with particular emphasis on the development of field methods.

CONCLUSION

In conclusion, a design method can be taken to improve thermal comfort, impacting the sustainability value of CLT Nusantara building based on an integrated evaluation of sustainable habitat systems. Design aspects supporting the improvement of thermal comfort need to be considered when using CLT materials for building. Furthermore, the ratio of width and thickness of building considers the orientation, planning of windows and openings, and adjustment to the thickness of CLT materials. These materials have the potential to be used as building components in comparison with CLT and brick walls. The addition of windows and selection of the shape and orientation of building increase comfort hours more significantly than other methods. Efforts to enhance the sustainability value of building using CLT need to consider design factors affecting thermal comfort value.

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A STUDY ON SOCIAL SPACE TYPOLOGY FOR VERTICAL LIVING

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Abstract

Vertical living has been widely adopted worldwide as a strategy to address land scarcity and promote sustainable land use. However, despite its prevalence, the need for well-designed social spaces in high-rise environments remains largely similar to that in landed housing. The lack of comprehensive research on the typologies and characteristics of social spaces in vertical living presents a critical gap, particularly in understanding how such spaces contribute to community well-being and healthy living. This study aims to investigate the role and typologies of social spaces in high-rise residential developments, focusing on their contribution to social interaction and neighbourhoods' integration. A qualitative methodology was employed through a systematic review of scholarly articles, complemented by case studies of selected high-rise housing projects. The analysis highlights key design treatments and spatial characteristics that foster social interaction, inclusivity, and a sense of belonging among residents. Findings indicate that well-integrated social spaces not only enhance community cohesion but also contribute to residents' overall quality of life. This research provides valuable insights for architects, designers, and industry stakeholders, offering guidelines for designing effective social spaces that can strengthen the liveability and sustainability of vertical housing developments.

Keywords: vertical living, social space typologies, characteristics of social space

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INTRODUCTION

As urban populations grow, vertical living has become essential for sustainable land use, with projections estimating a demand for 34,000 new dwellings annually by 2030. While vertical housing reduces land conversion, it often lacks the social spaces typical of horizontal living, raising concerns about declining social interaction, which is vital for community well-being (Mahdavinejad et al., 2012). Scholars emphasize the need for well-designed social spaces in vertical housing to sustain community cohesion (Pandelaki et al., 2018; Ruiz-Tagle, 2013). This study examines social space typologies in vertical housing and their role in fostering vibrant urban communities.

BACKGROUND ISSUES

Vertical housing, particularly high-rise apartments, has become a dominant urban solution due to land efficiency and density demands. However, the absence of adequate communal spaces frequently leads to reduced interaction, isolation, and weakened social cohesion, a problem made more evident during the COVID-19 pandemic. Limited opportunities for cultural exchange, recreation, and shared experiences further erode neighborhood bonds. Social withdrawal in such environments is often linked to residents' limited control over interactions within confined settings (Rubin et al., 2009). Addressing these issues requires prioritizing inclusive and well-integrated social spaces in vertical developments. Research objectives:

1. To develop a case study on social space design in Malaysian vertical housing.
2. To identify key characteristics of social spaces in vertical living.
3. To classify typologies of social space design in vertical housing.

LITERATURE REVIEW

(Abdullah et al., 2022) analyzed numerous scholarly articles highlighting the importance of social space in high-rise housing. Their study pointed out a lack of research on the typologies and characteristics of social spaces that can foster integrated and thriving neighborhood communities. Similarly, Huang (2006), Nor Azriyati Wan Abd Aziz et al. (2014), (Sullivan et al., 2004) and (Coley et al., 1997) identified design treatments and characteristics of social space relevant to high-rise housing.

This study concludes that several features can influence social interaction, including the hierarchical structure of space, physical security, opportunities for socialization, socio-cultural behaviors, support for community needs and activities, and improved accessibility. Many studies confirm a close link between socioeconomic status and social interaction patterns in residential areas (Askew, 2019); (Masram et al., 2019); Shepherd, 2018; (Rostam et al., 1997). Moreover, (Deo*, 2021) noted that factors such as unmanaged

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environments, pollution, congestion, and indifferent or unfriendly neighbors also affect the quality of neighborhood life.

Table 1: Scholars interpretation on social space design elements and characteristics:

ITEM	AUTHOR	SOCIAL SPACE	VARIABLES
1	(Huang, 2006)	Scenic and activity spaces	Design Criteria
2	(Sullivan et al., 2004)	Greenery at social spaces	Design Criteria
3	(Coley et al., 1997)	Greenery at social spaces in a vertical neighbourhood	Design Criteria
4	(Liu et al., 2017)	Repeated visual-Social Network Theory	Design Criteria
5	(Greenbaum, 1982)	Visual connection created poor social interaction	Design Criteria
6	(Whyte, 1980)	Fascinating objects (sculpture, water fountain and others) or activities (performance, playground, mini amphitheatre and others)	Design Typology
7	(Gehl,1987)	Three types of activities: necessary, optional, and social	Design Typology
8	(Modi, 2014)	Access, participant, individuality, adaptability, and hierarchy of spaces	Design Typology
9	(Ramdhan, 2021)	Accessibility, participant, individuality, adaptability, hierarchy spaces, footprint, views, security, and pollution	Design Typology
10	(R. Maharani, 2022); (R. T. Maharani et al., 2023)	Green space	Design Criteria
11	(Anggraeni et al., 2023)	Layout	Design Criteria
12	(Abdullah et al., 2022)	'sites', 'location' and 'neighborhoods based on social cohesion' and 'quality of vertical neighbourhood design'	Design Criteria
13	(Bakar et al., 2020)	Circulation area as social space, location.	Design Typology
14	(Siew Bee & Poh Im, 2016)	Circulation area, lift lobby	Potential Social space/ Typology
15	(Wijaya Wie & Dewi, 2019)	Location-mostly located at ground floor and difficult to access	Design Criteria
16	(Abu-Ghazzeh, 1999)	Nodal spaces are most suitable	Design Criteria

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RESEARCH METHODOLOGY

This study examines design thinking as a response to contemporary challenges in vertical housing, particularly the lack of interactive spaces. The monotonous nature of vertical housing often restricts social contact, resulting in less engaging living environments. Accordingly, this research aims to enhance social quality through a thoughtful design approach.

The study follows a three-phase structure: data collection, analysis, and synthesis. A mixed-methods approach was employed, combining both quantitative and qualitative methods (Ishtiaq, 2019; Creswell, 2014; Mackiewicz, 2018). Data collection involved questionnaires and precedent analysis to evaluate social interaction in tall buildings (Groat & Wang, 2013).

- Questionnaire: Conducted via Google Forms with 53 flat dwellers, focusing on their social interaction patterns.
- Precedent Analysis: Examined Pangsapuri Desa Datuk Hajah Hasnah and Pangsapuri D'Summit (Johor) to identify issues related to social spaces and interaction.

The analysis phase employed descriptive statistics to interpret questionnaire data (Kaur & Stoltzfus, 2018; Sethi, 2017). Precedent studies were then examined using descriptive variables such as accessibility, participation, adaptability, hierarchy of spaces, footprint, views, security, and pollution to assess the effectiveness of social spaces.

ANALYSIS AND FINDINGS

The study began with a questionnaire distributed to vertical housing residents to assess their living conditions and social interactions. A Google Form survey was conducted with 53 respondents, yielding valid and reliable data (Amalia et al., 2022). The questionnaire explored occupants' behaviours, their relationship with neighbours, and the availability and effectiveness of social spaces. Additionally, precedent analysis was used to examine existing vertical housing projects, identifying both successful design elements and limitations. (R. T. Maharani et al., 2023b).

Key Findings

- Limited Neighbour Interaction: 60% of respondents do not know their neighbours due to busy schedules and a lack of necessity for interaction.
- Existing Social Relationships: 22% reported strong relationships with their neighbours.
- Lack of Social Activities: 85% indicated that their buildings do not facilitate any social activities, while 16% acknowledged that sports activities provide some opportunities for interaction.

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- Location of Social Interactions: Most social interactions occur in public facilities such as parking lots, pools, gyms, shops, and food courts, though these spaces do not necessarily encourage participation due to personal boundaries.
- Need for Dedicated Social Spaces: 81.8% of respondents believe that social interactions would significantly improve if dedicated social spaces were integrated within housing blocks.

These findings highlight the importance of intentional social space design in fostering community engagement in vertical housing. Future developments must incorporate well-planned communal areas to enhance neighbourhoods' interactions and overall social well-being.

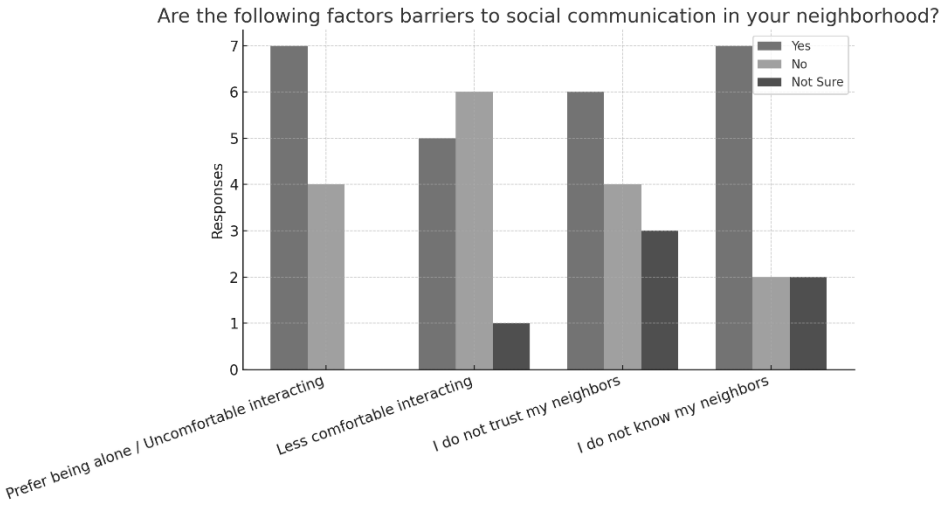


Figure 1: Barriers to Social Interaction

Respondents were asked about barriers to social interaction, such as preferring solitude, lack of time, cultural or language differences, distrust, lack of need, unfamiliarity with neighbours, and unfriendly attitudes. Most respondents disagreed with these statements, indicating generally positive attitudes toward social interaction. They showed willingness to communicate, build relationships, and engage with neighbours when opportunities are provided, supporting the potential for a healthy community.

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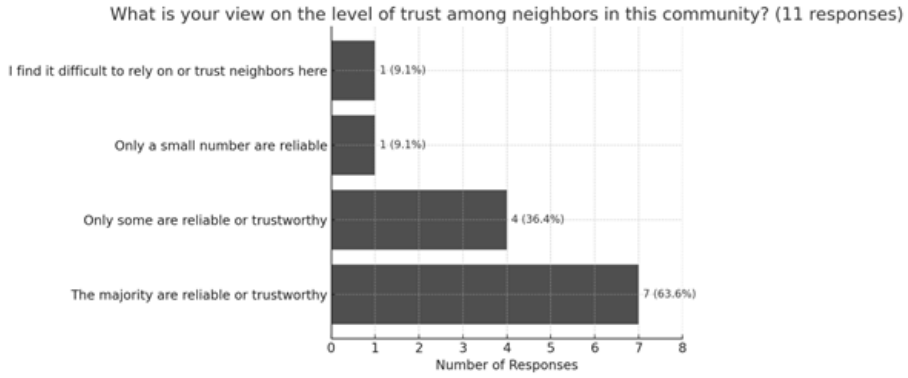


Figure 2: Level of trust among the community

About 63.6% of respondents felt their neighbours could be trusted or relied upon, while 36.4% believed some could be trusted. Only 9.1% reported trust issues with neighbours.

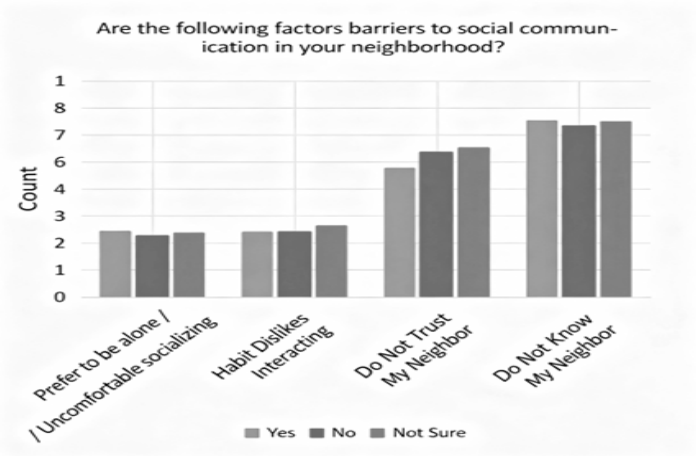


Figure 3: Factors that prevents involvement in community activities

The highest 'No' responses were for "Do not know my neighbours," indicating most do not view unfamiliarity as a major barrier, though some still see it as an issue. Overall, perceptions of social barriers varied, but most respondents felt these factors were not significant, with long working hours identified as a key limitation that social spaces should address. This suggests that the social space which should be provided for the people should respond to the limitation due to long working hours.

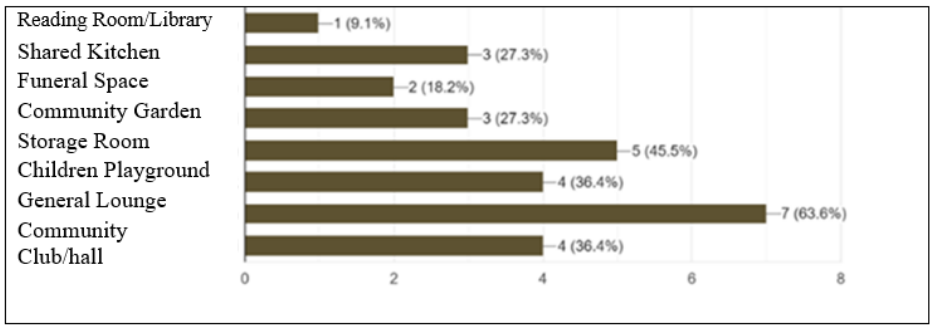


Figure 4: Social Spaces provision that influence housing choice

The respondents were asked to choose 2 types of shared spaces preferred in housing choice and 7 (63.6%) chose shared general lounge as the most preferred followed by storage space 5 (45.5%), kids play area and club house 4 (36.4%), community kitchen, community garden 3 (27.3%) and reading /library 1 (9.1%).

It shows that the respondents feel that it is necessary to provide shared resting area for the community as the internal spaces are limited for that activity to be carried out. It seems that community garden and community kitchen have less preference as they can be something new and require proper management to have it functional. The library remains the least favourable as perhaps reading is not part of Malaysian culture.

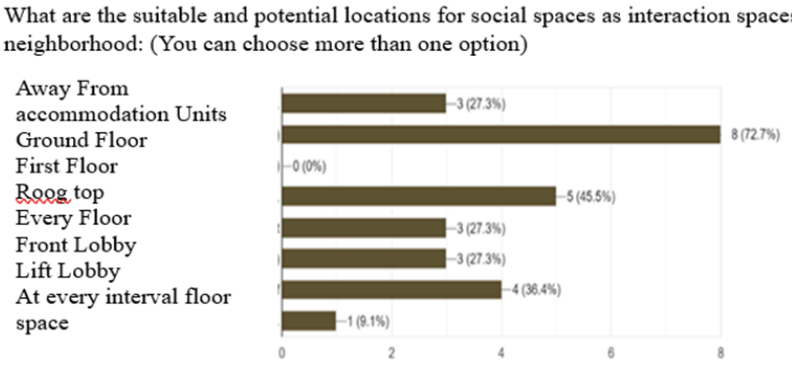


Figure 5: Potential Placement of Social Space

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The respondents were asked in Section 5 (Question 1: What is the appropriate and potential social space placement as a social interaction space in your neighbourhood). 72.7% agreed that the most suitable location is at ground floor area, while 45.5% said the rooftop area. 36.4% said the lift lobby is the suitable location for social space while 27.3% choose the frontage of the apartment and at every floor level. However, only 9.1% choose the social space to be located at a certain intermediate level.

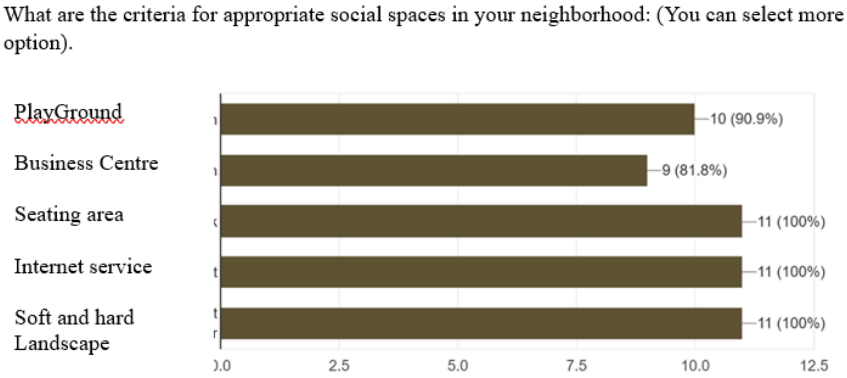


Figure 6: Social Space Criteria

When asked on the Social Space Criteria, the respondents equally agree that Social Space Criteria should be as follows: 1) Equipped with Playground, 2) Equipped with business premises, 3) Seating Areas, 4) Internet facilities and 5) Soft and Hard landscape.

Majority of the respondents (81.8%) think that the social interaction among neighbours will increase if the social spaces are provided within the housing blocks.

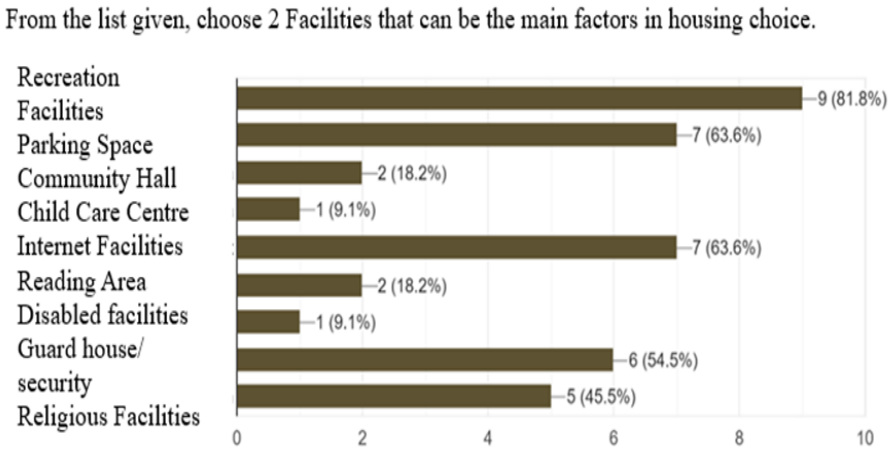


Figure 7: Main facilities that influence housing choice

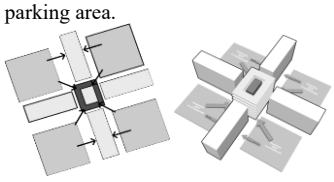
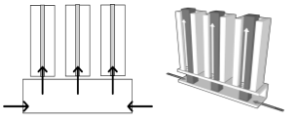
With regards to housing choice, the respondents (81.8%) prefer to buy housing units with recreational facillities, parking space and internet followed by security, religious facilities and community hall, kindergarten, and facilities for the disabled.

The data collected from the questionnaire were further analysed, a case studies and comparative studies are carried out on two (2) vertical housing in Johor Bahru, Malaysia.

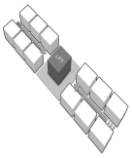
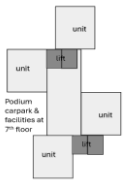


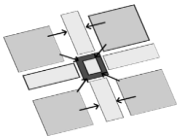
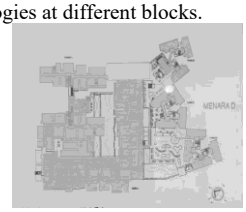
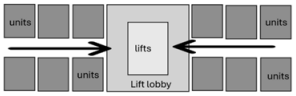
Figure 7: Condominium Datuk Hajjah Hasnah (left) and D'Summit Residence (right).

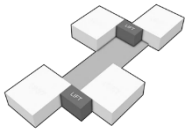
Physical observation was carried out on two (2) residential buildings of similar scale located in Johor Bahru. Datuk Hajjah Hasnah Condominium and D'Summit Residence. Although similar in scale, the residential buildings are different in the layout, facilities and foot print. The criteria are well explanatory in the table below.

CRITERIA	APARTMEN DATUK HAJJAH HASNAH	D'SUMMIT
ACCESS	The building has open access from all directions and a ground floor open parking area. 	This apartment has security access mainly through 3 guard posts. The occupants are required to use the RFID system to access and access cards for the list to the intended level. 

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<table>
<tr><td colspan="3">SYNTHESIS: Access in vertical housing is vital for inclusivity and comfort. Features like wide corridors and wheelchair-friendly lifts support mobility, while good design also improves privacy, social interaction, and overall livability.</td></tr>
<tr><td>PARTICIPANT</td><td>When all floors are accessible, corridors, pocket spaces, and commercial areas can support planned or unplanned activities, but this also allows strangers to pass by unit frontages.
  </td><td> 

Private lifts with restricted access enhance privacy and security but limit participation and reduce chances for unplanned interactions.</td></tr>
<tr><td colspan="3">SYNTHESIS: To make people as a participant the building design should provide a space to allow residents to create and involve activities.</td></tr>
<tr><td>INDIVIDUALITY</td><td>Repetitive floors-1st to top floors are identical/similar. People get together in predicted areas e.g. corridors, lift, lift lobby or public facilities.
  </td><td>Repetitive floors with different typologies at different blocks.
  </td></tr>
<tr><td colspan="3">SYNTHESIS: Layout can influence the habits of the social environment. Unique design can help people socialize even though in vertical housing</td></tr>
<tr><td>ADAPTABILITY</td><td>Fixed floor space.Environment less adaptive to dwellings. The outdoor space available is at ground floor level and corridors to the units.
 
</td><td>Fixed floor space with several typologies and access to podium facilities makes it a restricted access as each unit will be able to access to certain areas only. Although the occupants are connected to the outdoors at 7th floor facilities level. Environment adaptive to dwellings</td></tr>
<tr><td colspan="3">SYNTHESIS: Joint activities can make vertical housing spaces more adaptable. At D’Summit, privacy-focused layouts limit interaction, which occurs mainly in lifts and at the Level 7 facilities and garden.</td></tr>
<tr><td>HIERACHY OF SPACE</td><td>Open spaces are mostly at the ground floor, making them less accessible, and many remain underused due to poor management and lack of effort.</td><td>Services area at podium level accessible for all occupants and managed by the Building Management. The social spaces are limited to level 7 for privacy and security.</td></tr>
</table>

SYNTHESIS: Public spaces are usually on the ground floor, but providing varied social and outdoor spaces across different levels would give residents more choice.		
FOOTPRINT	Almost similar footprint for all blocks. 2 layout typologies and public spaces on the ground floor. Potential public space at lobby area.	4 layout typologies open for hierarchy of spaces and use. D'Summit is more complex compared to Apt Datuk Hasanah.
SYNTHESIS: The shape of footprint can influence activities on Ground Floor. (Promoto et.al,2019) There are 3 zones includes Public Zones, Service Zones and Private Zones.		
VIEWS	City View which are not exclusive	Views towards new township & highway making it an active view and gives sense of place.
SYNTHESIS: External views add little to social space but can help residents connect to their surroundings, while open spaces and landscaping are more important for success.		
SECURITY	Security is loose, where anybody can enter up to the unit's front door without going through security.	Security is very tight, where it provides 3 tier security system and the individual lift eliminate the chances for strangers to reach unit front door without proper access provision/ access card. 
SYNTHESIS: Security is a key factor in housing preferences. High-security designs are seen as a luxury, while open concepts are cheaper and allow more unplanned interactions in shared spaces.		
LANDSCAPING/ GREENSPACE	Developers often put little effort into landscaping and social space design. JMB or JMC should enhance amenities and upgrade ground floor pocket spaces to prevent neglect.	Level 7 landscaping with water features was designed for social interaction, but occupants rarely engage due to the lack of daily unplanned interaction spaces.
SYNTHESIS: Un planned social interaction space becomes an important part of the success of the social space. For eg. The occupants meet(unplanned) at the lift lobby on daily basis and connects at the social space (facilities level)		

Findings from Comparative Studies

The comparative study of Condominium Datuk Hajah Hasnah and other precedents shows that while potential spaces for social interaction exist, such as corridors, lift lobbies, and ground floor amenities, poor design planning leaves them underutilized. This demonstrates that providing space alone is insufficient; purposeful design is needed to foster engagement. Spatial hierarchy, layout configurations, and room arrangements also affect adaptability, security, and comfort, yet view placements were overlooked, limiting their contribution to social spaces. Furthermore, safety and pollution concerns remain critical for ensuring a supportive social environment.

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Key Design Recommendations

1. Optimized Layout Configuration:
   - A condensed layout (Pandelaki & Firmandhani, 2022) enhances interpersonal communication and facilitates social activities.
   - Noise reduction measures should be implemented to minimize disturbances.
2. Enhanced Common Areas:
   - Elevators and stairwells should be designed to encourage spontaneous interactions while maintaining appropriate personal space.
3. Purposeful Social Spaces:
   - Communal areas should support activities like gardening and sports, helping residents engage with their environment.
4. Improved Security Measures:
   - Centralized monitoring of public zones within the housing blocks enhances safety, encouraging participation in social activities.
5. Integration of Green Spaces:
   - Green areas improve comfort and reduce public area pollution, such as vandalism and littering.

These recommendations emphasize the importance of thoughtful spatial design in fostering a socially vibrant, safe, and sustainable vertical living environment.

CONCLUSION AND FUTURE RESEARCH

This study underscores the need for housing layouts that encourage social interaction and community building. Compact designs with green areas and strong security can enhance engagement, but excessive density may create new challenges. Findings show that the form, permeability, and use of common spaces shape social activity, as seen in Apartment Datuk Hajah Hasnah, where minimal barriers enable user-driven adaptations. Consistent with Stavrides (2015), such spatial porosity supports shared spaces, bottom-up governance, and collective urban experiences.

Future Research Directions

1. Design Innovations for Social Interaction – Exploring architectural solutions that actively encourage community engagement in high-rise housing.
2. Impact of Green and Shared Spaces – Assessing the long-term benefits of integrated green areas on social cohesion and well-being.
3. Technology and Smart Housing Solutions – Investigating how digital tools and smart design can enhance social connectivity in vertical living.
4. Cultural and Behavioural Studies – Examining how different cultural contexts influence social space utilization in high-density housing.

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By addressing these areas, future research can further refine vertical housing models, ensuring they are both functional and socially enriching.

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ETHICAL STATEMENT

This research followed the ethical standards of Universiti Teknologi Malaysia. Informed consent was obtained from all participants, and their confidentiality and anonymity were protected. Participation was voluntary, and respondents could withdraw at any time without consequence.

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A CONCEPTUAL FRAMEWORK FOR INTEGRATING COST OF QUALITY AND COST OF SAFETY IN CONSTRUCTION PROJECT

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Abstract

Project acceleration has been growing as a common demand construction projects. This creates challenges to project management in managing project budgets to ensure work quality and eliminate work accidents throughout the project. To address this issue, this study aims to offer a conceptual framework in integrating the cost of quality (COQ) with the cost of safety (COS) estimation method as a model that can be used by project management to optimize resource allocation by providing accident prevention measures and evaluating quality failures. This study conducts a qualitative method through systematic literature review about COQ and COS to formulate a conceptual framework for integrating COQ and COS using risk management framework. This paper found three major reason that integrating COS and COQ are feasible. (1) Quality failures and safety incidents have common precursor issues, (2) Quality and safety could be analyse using risk management perspective, and (3) Quality and safety cost are using similar estimation methods. This integrated COQ and COS model using risk management perspective would provide a conceptual framework for future research in integrating quality and safety management.

Keywords: cost of safety, cost of quality, integration, risk management, construction project

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INTRODUCTION

Construction projects have specific project specification demands specified in the contract related to labour, materials and equipment and have uncertainty challenges that have potential safety quality risks throughout the project (Silalahi et al., 2023). Construction industry always been known prone to high safety risk and quality failure. In US every year nearly $5 billion dollars loss due to fatality cases in construction project for covering lost family income, post traumatic suffering cost, and quality of life improvement cost (Manzo, 2017). In Australia, per project , an average $1.374,25 paid for a short absence due to accident to $4058,42 for accident result in permanent incapacitation and worker replacement (Allison et al., 2019).

Work quality failures also have a major financial impact on project management. Rework caused by poor quality supervision is key reasons for time and cost overruns in construction project (Garg & Misra, 2022). Moreover, Love et al. (2018) suggested that human error proved as a significant root cause of the work accidents and quality failures, it also mentioned that injury rate tends to be equivalent to the nonconformance rate. The incidence of work accidents and work correction demands due to poor quality impacts 3.1% to 6% of the total project cost and extends the project schedule by approximately 5.1% to 10% (Yap et al., 2017).

Project management needs a solution to overcome quality failures and work accidents. These solutions require resources to be allocated specifically to allow management to manage the risk of quality failures and safety incidents. However, project management still have to handle the fact that to perform quality and safety management effectively requires cost, and managing tight project budget that includes quality and safety cost is not an easy task (Hoonakker et al., 2010). Inadequate financial support to control quality and safety risk in an integrated manner is one of the inhibiting factors (Apriyati & Latief, 2020).

Khaled Omar and Murgan (2014) stated that cost of quality (COQ) method has been proven as a prominent method to estimate quality budget also as a method to utilise project resource based on preventive and corrective plan. Allocating strategic resources for safety investments significantly influence safety outcomes in small and medium construction company (Bachar et al., 2025). On the other hand, developing an optimum safety investment for a construction project provide many benefits such as increased worker confidence and minimise near miss incident that undoubtedly be valuable assets to the contractor (Gurcanli et al., 2015) . An accident prevention cost (APC) method has proven to reduce unforeseen cost due to fatalities of injuries in the construction industry (Ikpe et al., 2012).

Unfortunately, to this date no research has been found that addresses the integration of quality and safety management in the context of quality and safety control, resource allocation and cost calculation. Therefore, the primary

objectives of this study is to determine a conceptual framework for integrating COQ and COS using systematic literature review and descriptive analysis. To guide this research, three primary research questions formulated to investigate the possibility to integrated COQ and COS using risk management perspective.

- **RQ1**: Do quality and safety issues have the same root cause?
- **RQ2**: Can quality risks and safety risks be analyzed using the same perspective?
- **RQ3**: Can quality cost and safety cost be calculated with the same estimation stages?

This research question is structured as a guide to provide comprehensive review in findings possibility of integrating COS and COQ as an integrated cost estimation method using risk management perspective.

LITERATURE REVIEW

A. Identifying COQ and COS Components

Previous studies (Garg & Misra, 2022; Shafiei et al., 2023; Sharma & Laishram, 2024; Thabet et al., 2024) generally categorize COQ components in two main groups as shown in Table 1, namely conformance cost (CC) and non-conformance cost (NCC). Conformance cost consist of preventive cost and appraisal cost. Preventive costs defined as all costs spent by management to prevent the occurrence of non-conformities before-in-after work (Garg & Misra, 2022). On the other hand, appraisal costs are the costs that are incurred to ensure that all work products are in compliance with the expected standards including testing costs, monitoring and evaluation costs, and material inspection costs as shown in Table 2.

Non-conformance cost mostly described as costs that must be paid by the service provider if there was non-conformity/failure in a product before it is handed over to the owner (internal failure costs) or after it is handed over to the owner (external failure costs) (Heravi & Jafari, 2014). Shafiei et al. (2023) found that there are 22 factors related to CC and NCC, for example, the addition of training costs to workers has the potential to reduce the cost of rework and reduce the overall quality cost allocation.

Several previous studies categorized COS components into two parts, namely accident prevention costs (APC) and accident costs as mentioned in Table 1. APC are cost paid by contractors to prevent accidents, normally it was not included in the project budget and considered as an additional cost for contractors (Lee et al., 2022). Accident cost are costs that arise due to accidents even though prevention measures are in place (Ikpe et al., 2012).

Meanwhile, some studies classified COS as fixed prevention cost or generic cost (GC), variable prevention cost or specific cost, and unexpected

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prevention cost. GC are costs incurred by management to prevent work accidents and ensure that the work area, workforce, materials and equipment are in a safe condition and ready for use. Specific costs or variable prevention cost are costs associated with securing work areas or work methods that tend to be unique and cannot be generalized between projects, including the cost of protective equipment, safety signs, the cost of securing work methods and salaries for safety personnel (Fitriani, 2022). Security costs are example of unexpected costs which is incurred by the contractor to secure the project site, workers, materials and equipment from theft, vandalism, sabotage or disturbance of unauthorized individuals

Table 1. COQ Components

Components	Description	Reference
Prevention cost	Training of workers and staff	(Garg & Misra, 2022; Shafiei et al., 2023; Sin et al., 2024; Thabet et al., 2024)
	Suppliers quality surveys and review	
	Preparing quality system, procedures and standards	
	QC staff salaries	
	Design and specification review	
	New material storage/ inventory review	
	Equipment storage/ maintenance	
	Internal audit	
Appraisal cost	Third party audit	
	Material laboratory inspection and testing	
	Onsite inspection and testing	
	Product/ after build final testing	
	Documents review	
Internal failure costs	Defect identification	
	Scrap and demolition	
	Rework/ corrective actions	
	Re-testing	
	Re-inspection	
	Re-design/ review design	
	Materials wastage	
External failure costs	Penalties due to nonconformance	
	Warranty claims	
	Legal cost and compensations	

Table 2. COS Components

Components	Description	Reference
Generic costs	Safety training and orientation for workers and staff	(Fitriani, 2022; Ibarrondo-Dávila et al., 2015; Lee et al., 2022;
	Health and safety plan/ procedures	
	Personal protective equipment	
	Health and safety signs	
	Health and safety monitoring	
	Safety consultant/expert	

Components	Description	Reference
	General expense for health and safety inventory/supplies – first aid, hygiene related expense, fire extinguishers, emergency lighting, etc	Misnan et al., 2024; Rosmariani Arifuddin, 2023; Teo & Feng, 2011)
	Safety promotion and incentive	
	Workers and staff insurance premiums	
Security costs	Security plan – permit, security personnel, security equipment (Sc)	
Spesific costs	Health and safety staff salaries	
	Emergency response equipment/ supplies	
	Safety protection measures – fence, nets, railing, curtain, façade coating, etc	
	Traffic safety measures	
	Job/ material/ equipment/ worker permit	
Direct costs	Insurance cost	
	Uninsured medical expenses	
	Compensation for workers family	
	Fines/Claims due to safety procedure violations	
	Legal penalties and administrative cost	
Indirect costs	Work delay, productivity loss, cleanup and repair	
	Equipment failures, wasted material, raw material damages	
	Additional cost for new worker/operator recruitment	
	Accident investigation related cost	
	Penalties/ Fines due to handover delay	

B. COQ and COS Estimation Methods

Some previous studies clearly show the calculation model of quality costs and safety costs. one of the calculation models that both cost estimation methods use in common is the activity-based costing (ABC) model. The ABC could be used to identify, analyse and allocate quality costs in a detailed way, helps to manage quality costs more effectively (Schiffauerova & Thomson, 2006).

One of the most common methods of the ABC model is the preparation of work breakdown structures (WBS). WBS is used to describe each element of the project in stages into smaller items so that it is easy to manage and calculate the resource requirements for each item (Yılmaz & Kanıt, 2018). As shown in Table 3 several previous studies illustrate some similarities in the stages of the COQ and COS estimation methods.

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Table 3. Cost of Quality and Cost of Safety Estimation Phase

References	Phase 1	Phase 2	Phase 3	Phase 4	Result
(Heravi & Jafari, 2014)	Identifying and classifying quality-related activities	Collecting the cost of classified quality-related activities through survey study	Analyzing COQ data and developing the model for evaluating the COQ	Calculation of optimum level of COQ	COQ
(Rosenfeld, 2009)	Define quality failures cause and quality prevention elements	Identifying elements of quality cost (P-A-F elements)	Quantifying the cost of elements per unit		Total quality related budget
(Desai, 2008)	Identifying cost components and sub-components	Measuring and quantifying the elements	Determines quality cost scenario by analysing improvement area	Define prevention-appraisal and failures compensation measures based on quality cost scenario	COQ budget
(Fitriani, 2022)	Preparing WBS	Hazard identification and risk assessment	Determining OHS control measures	Calculating safety cost	OHS Cost
(Yılmaz & Kanıt, 2018)	Establishment of work breakdown structures	Identify possible safety hazards	Determine the protection measures and proper risk respond procedure	OHS cost estimation	OHS Cost
(Gurcanli et al., 2015)	Preparation of WBS	Analyse risk value by identifying possible safety hazards	Determination of protection measures and risk mitigation techniques	Safety cost estimation	OHS cost

RESEARCH METHODOLOGY

This study conducts qualitative research and document analysis through literature search through databases such as Scopus and Web of Science. The research problem is broken into manageable keywords such as: “cost of quality”, “quality costs”, “cost of conformance”,” cost of nonconformance”, “construction industry”, “cost of safety”,” accident cost”, “accident prevention cost”, “integration”, “integration management”.

Searching process then proceed using snowballing and trial-and-error search methods. The search was conducted between March and June 2024. The last search was performed 15 June 2024, followed by descriptive analysis on the selected articles to provide a compilation of COQ and COS factors and estimation methods which is classified into different categories using inductive content analysis.

Furthermore, the findings of the categorisation analysis provide an in-depth perspective for proposing a conceptual framework for integrating COQ and

COS as an integrated cost estimation method. The results of the literature review were then used as a reference to develop theoretical framework about COQ and COS as shown in Figure 1. The results of the theoretical framework obtained from the literature analysis are then used to develop a conceptual framework in integrating COQ and COS using WBS based on a risk management perspective as illustrated in Figure 2.

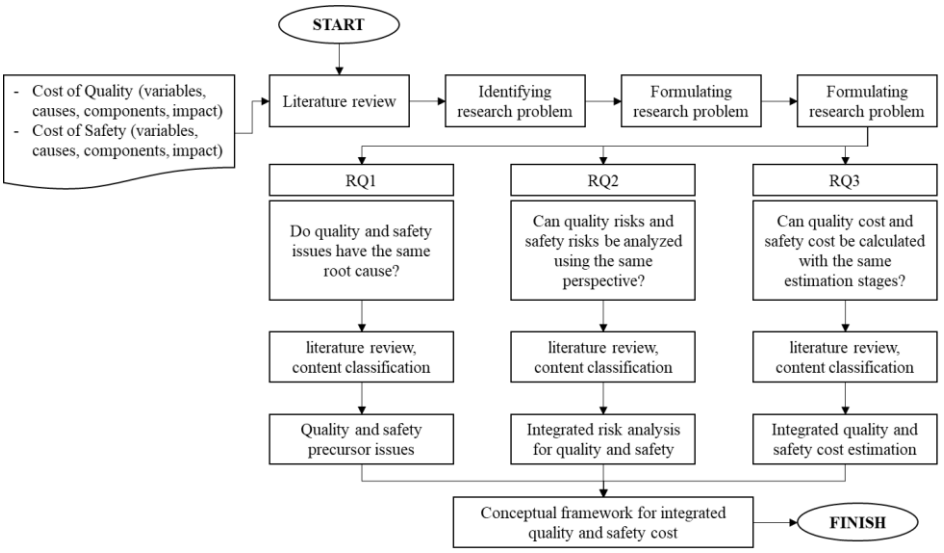


Figure 1: Research methodology

FINDINGS

A. Quality and Safety Failures Precursors Issues

Yarnold et al. (2023) state that quality control is closely related to safety control in project operations. Safety issues are often found as a consequence of poor quality. As shown in Figure 2, failure to meet specifications or requirements results in the issuance of a non-conformance report (NCR), which then requires corrective action such as rework (Love et al., 2019). Injury rate reports is positively correlated with the rework and defect rate, hence projects with poor quality performance have a higher probability to cause safety incidents (Wanberg et al., 2013). The consequence of rework is to increase safety incidents partly because rework increases working hours and increases the potential for worker fatigue (Wanberg et al., 2013).

Sadeghi et al. (2020) found that the increasing number of non-conformities found tends to lead to safety incidents or has a higher chance of potential new safety-related hazards in the work area. Prioritizing quality control in conjunction with safety control has been shown to provide significant benefits

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to project management and project operations throughout the duration of the project.

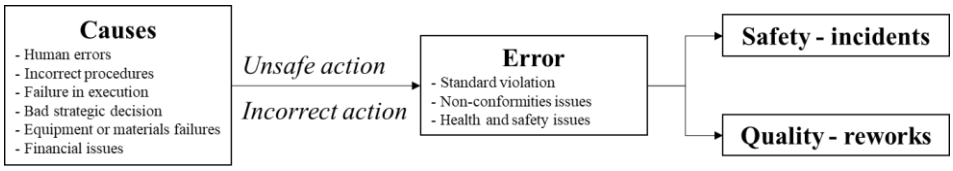


Figure 2: Quality and safety failures precursor issues
Source: Love et al. (2019)

B. Quality and Safety Risk Analysis

Previous research shows that the patterns of estimating quality costs and safety costs have some clear similarities, namely (1) determining the components or items involved; and (2) determining the potential factors that cause quality failures or safety hazards. This is relevant when associated with the stages of risk management in the construction project, namely (1) risk identification; (2) risk analysis and evaluation; (3) risk response (Fitriani, 2022).

Silalahi et al. (2023) shown that using risk management perspective proven highly relevant to provide detailed quality or safety plan. Quality and safety plan that comprise selected resources efficiently to ensure cost effective strategic decision as shown in Figure 3.

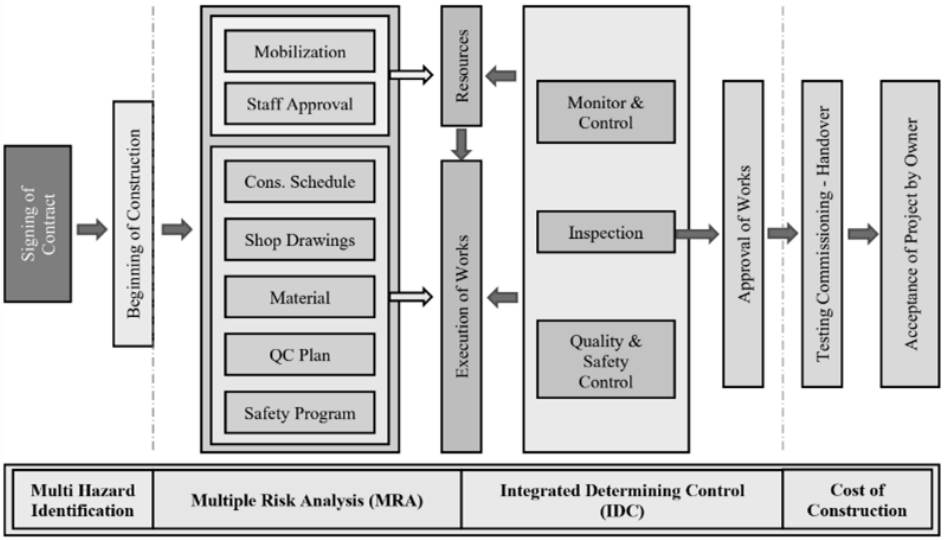


Figure 3: Quality and safety analysis model using risk
Source: Silalahi et al. (2023)

C. Quality and Safety Cost Estimation Method

Studies on OHS costs in the construction industry have been conducted since the 1990s. Tappura et al. (2015) introduced cost-benefit analysis of accident prevention method and incorporated the fatality factor as a critical risk into this model. Gurcanli et al. (2015) estimated COS contained in project costs and using the activity-based risk assessment method along with activity-based cost analysis to calculate COS. Fitriani (2022) included the element of security cost as a new variable in calculating the safety cost component.

On the other hand, Desai (2008) used the conventional method of quality costing approach on six construction companies in India from various levels (local, regional, national to multinational). Rosenfeld (2009) used the total quality related cost (TQRC) approach by comparing historical data of nine construction companies in Israel to serve as a basis for estimating COQ in percentage form. Heravi and Jafari (2014) used the method of decomposing all quality-related activities associated with the level of conformance to quality and the COQ elements.

From literature mentioned above that COQ and COS estimation method provide quite similar pattern and stages as shown in Figure 4.

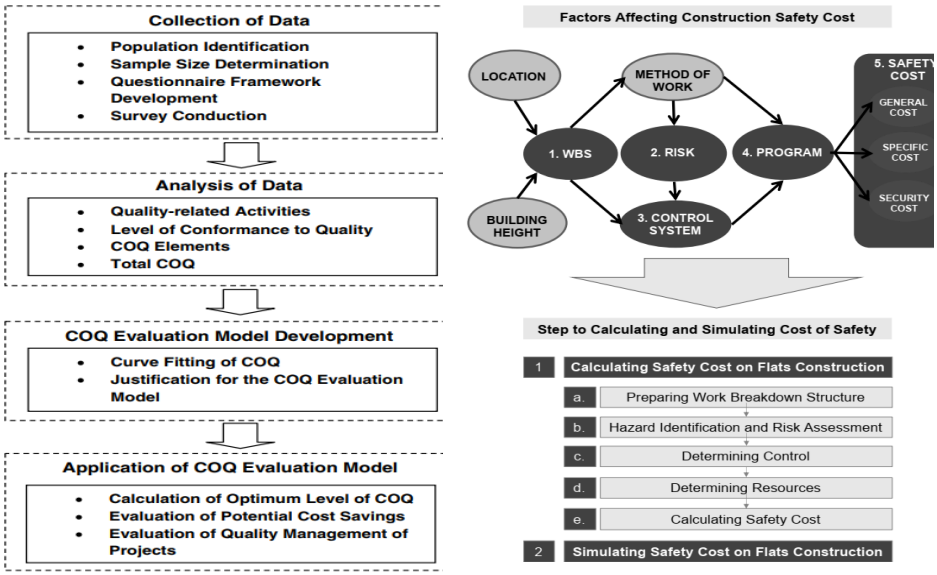


Figure 4: COQ and COS estimation method comparison
Source: (Fitriani, 2022; Heravi & Jafari, 2014)

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ANALYSIS AND DISCUSSION

Using the risk management point of view as illustrated in Figure 5, the steps of integrating quality costs with safety costs can be described as follows,

1. Using systematic activities breakdown as a starting point followed by determining all activities in detail grouped by project stages (preparation, mobilization, implementation, testing and handover);
2. The next step is identifying the potential quality and safety hazards simultaneously in each activities;
3. Followed by analyze the probability and impact value of each potential hazard that has been determined using risk analysis (quality+safety) matrix;
4. After that proceed with establishing an integrated quality and safety control measures based on the risk value analysis results.
5. Lastly, determine quality and safety control measures to estimates integrated COQ and COS according to local/national cost standard.

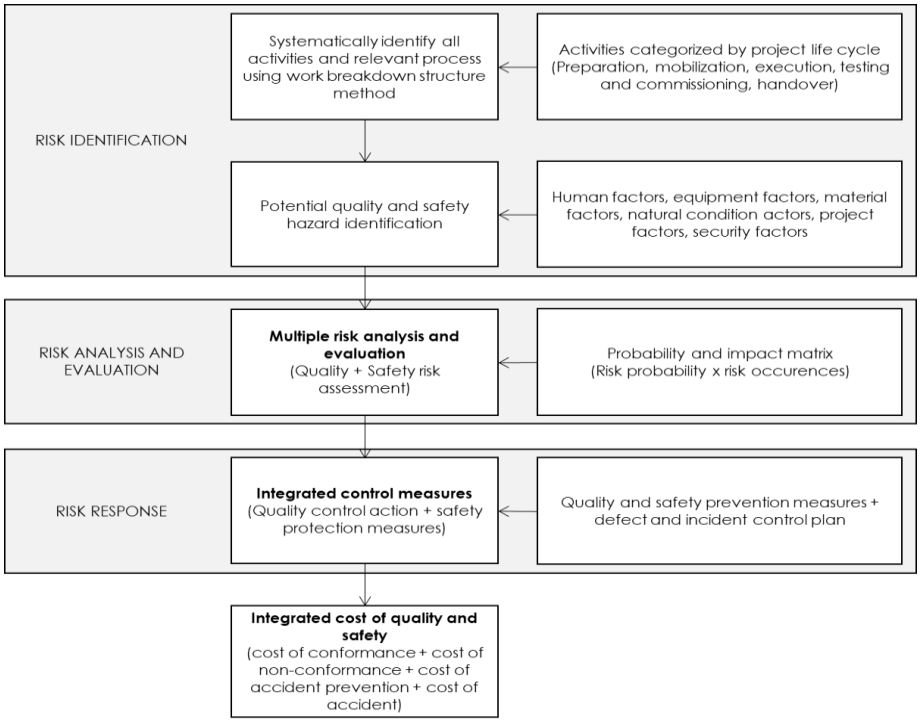


Figure 5: COQ and COS integration conceptual framework using risk management perspective

CONCLUSION

We found there are three major highlights that led us to conclude that the integration of COQ and COS is feasible using a risk management perspective. Those highlights are:

(1). COQ and COS have common precursor causes such as human error, equipment and material failures, and incorrect procedures;
(2). COQ and COS component that tend to be similar grouped into two main components as preventive components such as training for workers, providing safety/quality plan, scheduled quality and safety inspections and corrective components such as direct expenses for medical expenses, cost for rework-retest-reinspection; and
(3). COQ and COS common estimation stages/method.

Estimating COQ and COS are proven relevant when associated with the risk management framework as stated by Love et al. (2018) that conducting risk assessment before project begins to anticipate potential errors that may cause NCR or safety incidents. Application of risk management framework in conducting integrated estimation of quality costs and safety costs expected to result in detailed breakdown of COQ and COS components, a better and comprehensive risk analysis because the probability level and impact value are calculated from the quality and safety perspectives simultaneously, and quality and safety risk control measures could be applied in effective and efficient manner resulting in optimum cost allocation (Silalahi et al., 2023).

LIMITATIONS AND FUTURE RESEARCH

While this research provides valuable insights in integrating COQ and COS. This research scope is still limited to a literature review with descriptive analysis so that it still needs further follow-up to prove the proposed conceptual framework. This conceptual framework can serve as a baseline for further research to validate each of step of risk analysis for COQ and COS integration. This integration process will be very efficient if assisted by information and communication technology (ICT) innovations such as Building Information Modelling (BIM) in its future research methods which could help to provide an efficient and better cost estimation methods.

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ASSESSING THE TYPOLOGY OF FALLEN TREES RISK IN SURAKARTA CITY, INDONESIA

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Abstract

Surakarta City has a significant risk of fallen trees. Because of its long urban history, it has many old, diverse, and historic trees. On one side, it indicates the existence of historical urban vegetation, but on the other side, the old trees have a high risk of falling. The tropical climate causes extreme weather risks that have often occurred in recent eras. The urban stakeholders seek to keep the diverse trees to ensure the urban vegetation proportion in the city. This article explores the typology of fallen tree risks in Surakarta. The research used the spatial analysis of the geographic information system. It was supported by historical data on fallen trees in Surakarta compiled from urban institutions and electronic newspapers over the last three years. The correlation analysis supported this research in exploring the relationship between the level of fallen tree hazard, the existence of main roads impacted by the fallen trees, and the existence of urban green space. The occurrences of fallen trees were dominated along the main streets in the city, including primary and secondary roads. Furthermore, there is a correlation between the hazard of fallen trees and urban green space in the city. The sub-districts have a high proportion of urban vegetation in a linear relationship to the risk of fallen trees in the city. These results could be the implications of the Surakarta urban planning policy for disaster risk management.

Keywords: Fallen Trees, Urban Green Space, Urban Disaster Risk, Surakarta

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INTRODUCTION

Urban vegetation is an essential element in a city. It has several functions, including reducing carbon emissions, reducing the city's heat island effect, improving the urban climate, and supporting urban health to support the urban ecology. It is a critical issue in urban management. The law of the Republic of Indonesia No. 26 of 2007 concerning spatial planning mentions that a city's ideal proportion of open space, including green and water spaces, is about 30 % of the total area. However, many cities in Indonesia have difficulties in achieving this proportion (Yusuf et al., 2023). The existence of green open space for local climate instruments in Indonesian Cities is one of the three lowest countries in Southeast Asia (Priyanta & Zulkarnain, 2024). Based on this situation, many Indonesian cities seek to preserve the existence of urban vegetation to avoid reducing open space in the city. Commonly, one type of urban vegetation is the trees along the urban streets. The urban trees functioned as reducing land surface temperatures, carbon emissions, inundations, urban greening, and the city's beautification (Guo et al., 2023; Grote et al., 2016; Ow & Ghosh, 2017; Olawuyi, 2019; Hamzah et al., 2024). The high density of urban trees is what we refer to as the optimum functional system of urban vegetation. Conversely, urban trees pose a disaster risk due to the fallen trees, particularly during the rainy season. Frequently, storms occur in the cities during the rainy season (Huo & Chen, 2020) and produce fallen trees in the city, consequently causing urban damage and human deaths. Not only does the fallen tree risk occur due to the storm, but several factors contribute to the fallen tree risk, such as the problem of the tree's condition, including branches, roots, and trunk; the tree species; and the tree's age (Mendes et al., 2024; Ardestani et al., 2020). Research on fallen tree risk is needed to improve urban management, particularly urban risk reduction and ecological landscape systems (Hui et al., 2022; Delshammar et al., 2015; Abdullah et al., 2024). Urban tree management is a crucial issue, not only in Indonesia but also in other countries in Southeast Asia, such as Malaysia, Thailand, and Singapore (Kanniah, 2017; Nor and Abdullah, 2019; Intasen et al., 2017; Tan et al., 2021; Lazim and Misni, 2016; Srinurak et al., 2024). Our research limits the spatial perspectives seeking to understand the fallen tree risk toward the existence of urban green spaces in the city, including along roads and urban parks. The problem of the tree's condition is not a focus of this research, and the tree's condition factors and extreme weather are considered potential confounders.

Surakarta, as a historical Javanese city, has a high density of urban trees along the urban streets. Many trees are old and need regeneration (Indrawati et al., 2021). Nevertheless, Surakarta also has the problem of limited green open spaces. Surakarta's Green spaces are approximately 9 (nine) % of the city's area. They are under standard from the ideal proportion of open green space based on the law of spatial planning in Indonesia (Absori et al., 2020; Harahap et al., 2021). The limitation of green spaces produces an ecological function problem. The

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existence of urban parks and urban vegetation should be improved in Surakarta (Suhardono et al., 2024; Zaky et al., 2023; Nurhayati et al., 2024). On the other hand, fallen trees often occur in Surakarta. The last occurrence of the critical fallen trees disaster in Surakarta occurred during a rainstorm on January 3rd, 2024. At that time, dozens of fallen trees caused urban damage, including several vehicles being hit by the fallen trees and damage to urban electricity. This situation produces insecurity in society due to the risk of falling trees (Camacho-Cervantes et al., 2014; Portoghesi et al., 2023). These facts indicate that Surakarta has a high risk of falling trees, but this city also needs to increase the number of green space areas. Based on these situations, this research assumed that the existence of urban green zones directly correlates with a higher probability of fallen tree occurrences. It assesses the typology of urban fallen tree risk to improve urban planning, mainly urban mitigation towards the fallen tree risk, and also the perspectives for the appropriate increase of urban green space in Surakarta.

RESEARCH METHODOLOGY

This research uses a case study concerning Surakarta City. It has a high-density population and is a historic city in Central Java, Indonesia. This city has existed and been planned by the Mataram Kingdom since the 18th century. Surakarta City area is about 4672.00 hectares, divided into 54 sub-districts. Rapid urbanisation has produced a massive reduction in green space in Surakarta. The research focuses on the typology assessment of fallen tree risk in this city. It uses the quantitative method supported by the spatial analysis of geographic information systems (GIS) and the correlational statistical analysis. The spatial analysis uses the open-source Quantum GIS (QGIS), and the correlation analysis utilises the open-source statistical program, namely JASP. QGIS was used to identify the locations of fallen trees and how they have spread in the city over the last three years. From the identification of fallen tree locations, the number of occurrences in each sub-district could be calculated to assess statistically and spatially the levels of fallen tree risk in Surakarta. Meanwhile, JASP revealed the correlation between the risk of falling trees and the existence of open green spaces and urban vegetation in Surakarta. The data, including fallen trees, areas of urban green space, and impacted main roads by fallen trees, were analysed using the correlation analysis supported by the JASP tool. This research uses a quantitative approach supported by the statistical and spatial data retrieved from the agencies of Surakarta Municipality, particularly the environmental office and the regional disaster management agency. The data collection was based on secondary data from local institutions and newspapers. The data and information on fallen tree occurrences provided by the local institutions, including Surakarta Disaster Management Agency and the official website of municipality data (https://solodata.surakarta.go.id/), were combined with the information on fallen

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trees in the local newspapers (Solopos, Portal Berita RRI) during the last three years. The interviews of officials and field observation are needed to support data triangulation.

The research process is conducted in several phases, including identifying fallen trees in the city and conducting hazard analysis of fallen trees. Then, this research determines the typologies of fallen tree risks based on the level of fallen tree hazard and the existence of urban green space. The first step was exploring the historical and statistical data on fallen tree occurrences. The records of fallen tree occurrences were converted into frequency and aspatial data. The second step was the spatial mapping of fallen trees in the city. GIS was utilised to indicate the location and spatial data of fallen trees in the city. In this step, the main roads impacted by the fallen trees were also identified. Ground checking was also carried out to verify the fallen trees, particularly recently. The third step was the analysis of the fallen tree hazard level. This phase classified the potential hazard of fallen trees into three levels: low, medium, and high. The level classification was calculated from each sub-district's average maximum and minimum fallen tree incidents. The fourth step was identifying green space areas in the city based on its sub-districts. The fifth step is to determine the typology of fallen tree risk based on the hazard level, the main roads impacted by the fallen trees, and green space areas in the city. Correlation analysis was implemented in this research to prove the relationship between those factors. The standardisation of correlation analysis was used for the interpretation of statistical results. The research result will reveal the typology of fallen tree risk in Surakarta. This finding reinforces the appropriate urban management for mitigating fallen tree risk.

Table 1: The scoring technique

Criteria	Range/ Value	Scoring	Classification
Level of fallen tree hazard	$= \frac{Highest\ Value - Lowest\ value}{number\ of\ class}$ (3)	$0 - 1^{st}$ range	Low
		2nd range	Medium
		3rd range	High
Percentage of main roads impacted by fallen trees	$= \frac{Number\ of\ fallen\ trees\ occurrences\ on\ main\ roads}{Number\ of\ fallen\ trees} x$	Percentage (%)	
Percentage of urban green space	$= \frac{Total\ area\ of\ green\ space\ in\ each\ sub-district}{Total\ area\ of\ sub-district} x\ 10($	Percentage (%)	

Source: Author's identification (2024)

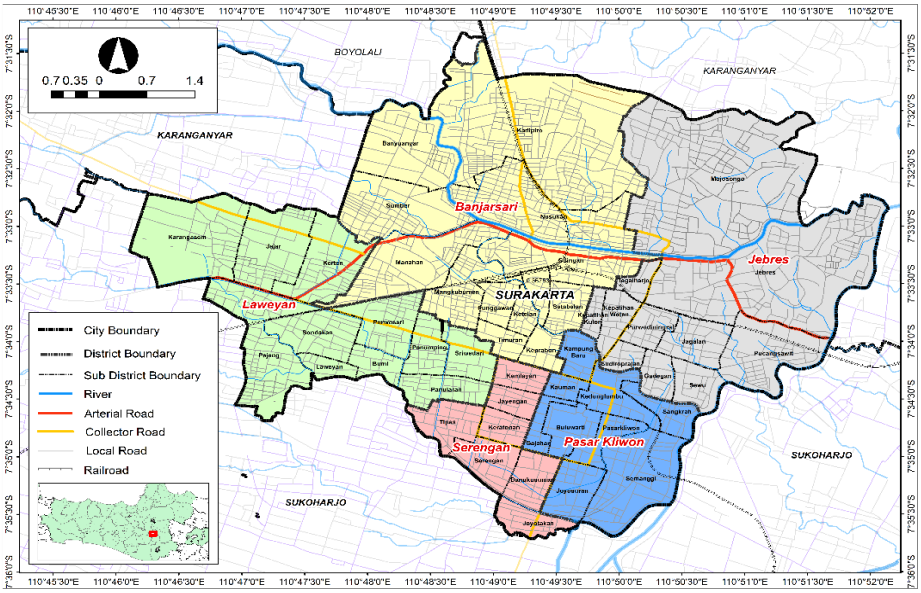


Figure 1: The Administration of Surakarta City
Source: Municipality of Surakarta, 2023, with the author's modifications

ANALYSIS AND DISCUSSION

Fallen Trees Occurrences during the Last 3 Years

Surakarta has frequently experienced incidents of fallen trees over the past three years, from 2021 to 2023. It has been recorded that 34 out of 51 sub-districts in Surakarta have experienced at least one fallen tree incident during this period. These incidents mainly occur at the beginning of the rainy season, especially when strong winds accompany heavy rain.

Based on data gathered from various sources, such as the Surakarta Disaster Management Agency and the Surakarta Municipality Data Website (https://solodata.surakarta.go.id/), combined with information on fallen trees from local newspapers (Solopos, Portal Berita RRI), there were 93 fallen tree occurrences during three years (data from 2022 to mid-2024). 34 from 54 sub-districts of Surakarta City experienced fallen trees. 20 sub-districts that have not experienced any incidents of fallen trees in the past three years. This situation indicates that the majority of sub-districts have fallen tree risks. Manahan Sub-District in Banjarsari District has recorded the highest number of fallen tree incidents over the past three years, with 8 (eight) incidents. Of these eight incidents, six occurred around the Manahan Stadium and the adjacent city park. Another sub-district in Banjarsari District with many incidents is Nusukan, which experienced 6 (six) incidents. However, the difference is that in Nusukan, the trees fell in residential areas and main roads. This number resembles several other sub-districts, such as Tipes (in Serengan District), Sriwedari (in Laweyan

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District), and Jebres (in Jebres District). However, there were many sub-districts where the fallen tree took place one time, including Sudiroprajan, Sewu, Serengan, Semanggi, Punggawan, Panularan, Kepatihan, Kemlayan, Karangasem, Joyosuran, Jayengan, Jajar, and Jagalan. The number of fallen tree occurrences during the last three years can be seen in Figure 2.

Most tree-fall incidents occurred in the central part of Surakarta, characterised by dense land cover. Meanwhile, the sub-districts that have experienced few or no incidents are mainly located on the outskirts of Surakarta, such as Joyotakan, Danukusuman, Laweyan, Sumber, and Sangkrah. During the three years, 20 incidents of fallen trees occurred in 2022, 43 incidents in 2023, and at least 30 incidents in 2024 (until mid-2024). The distribution and location of fallen tree accidents during the last three years can be seen in Figure 3.

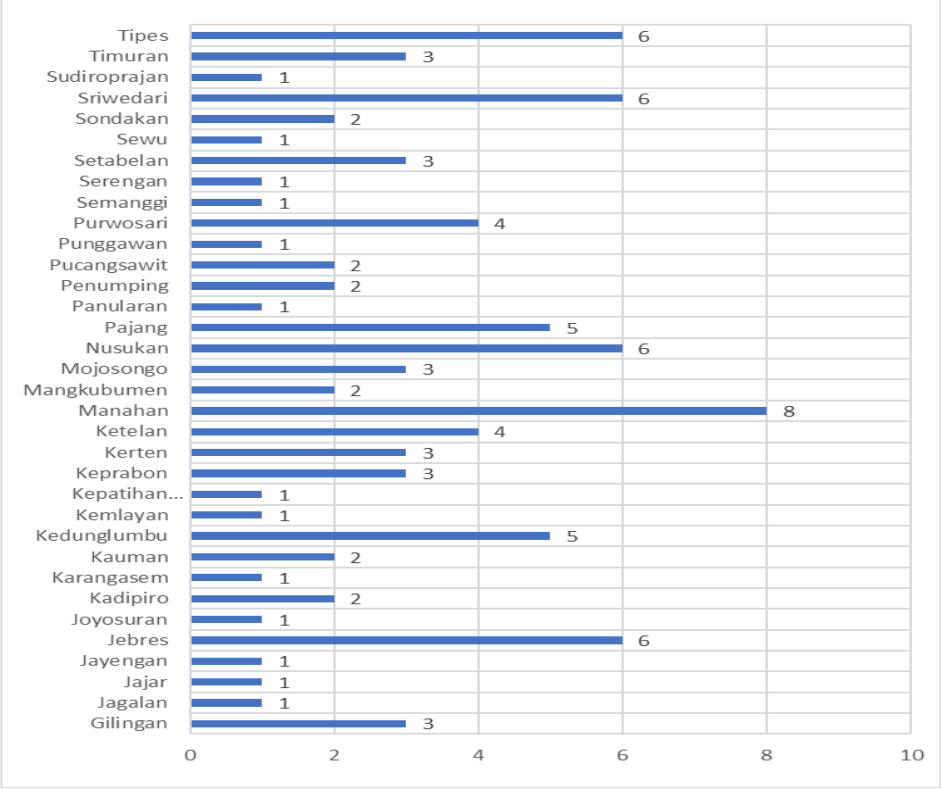


Figure 2: The number of fallen trees in each sub-district in Surakarta City during the last 3 years (2021-2023)
Source: Surakarta Disaster Management Agency, 2022; Municipality of Surakarta, 2023; local newspapers (Solopos, Portal Berita RRI)

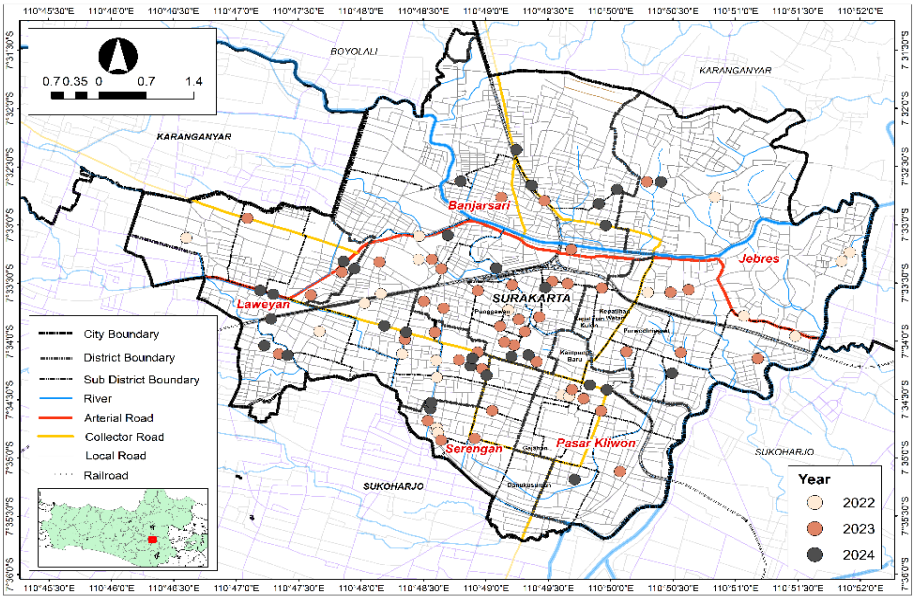


Figure 3: The distribution and location of fallen trees during the last 3 years
Source: Surakarta Disaster Management Agency, 2022; Municipality of Surakarta, 2023; Local newspapers (Solopos, Portal Berita RRI)

The Level of Fallen Tree Hazard

Like in many urban areas, fallen trees pose significant hazards in Surakarta that can impact public safety, infrastructure integrity, and environmental health. So, it is essential to identify the level of fallen tree hazards over the past three years. The level is determined by how many times fallen trees occur in each sub-district. Table 2 describes the frequency and location of fallen trees during the last three years.

Table 2: The frequency and location of fallen trees in Surakarta during the last 3 years

Frequency of Fallen Trees over 3 Years	Level of Fallen Tree Hazard	Sub-district
0-2	Low	Sudiroprajan, Sondokan, Sewu, Serengan, Semanggi, Punggawan, Pucangsawit, Penumping, Panularan, Mengkubumen, Keplatihan, Kemlayan, Kauman, Karangasem, Kadipiro, Joyosuran, Jayengan, Jajar, Jagalan, *No occurrence*: Banyuanyar, Banjarsari, Joglo, Kestalan, Ketelan, Sumber, Gandekan, Kepatihan Kulon, Purwodiningratan, Tegalharjo, Laweyan, Bumi, Baluwarti, Gajahan, Kampung Baru, Mojo, Pasar Kliwon, Sangkrah, Danukusuman, Kratonan
3-5	Medium	Pajang, Kedunglumbu, Purwosari, ketelan, Timuran, Setabelan, Mojosongo, Kerten, Keprabon, Gilingan
>5	High	Tipes, Sriwedari, Nusukan, Jebres, Manahan

Source: Author's Calculation (2024)

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The Main Roads Impacted by the Fallen Trees

Fallen trees cause direct losses, such as physical damage to buildings and vehicles, and can lead to macroeconomic losses if they occur on major roads that drive urban mobility. The impact is such infrastructure damage to traffic congestion and errors that disrupt public and private transportation mobility, reducing productivity. Based on this situation, the identification of main roads impacted by the fallen trees is needed to assess the risks of the fallen trees in the city. The main roads are the essential elements of the city, so when fallen trees occur on the main roads, their impact is higher than when fallen trees occur on streets in settlements. The percentage of main roads impacted by fallen trees can be shown in Table 3 as follows.

Table 3: Percentage of main roads impacted by the fallen trees

Sub-district	Number of fallen trees	Number of fallen tree occurrences on main roads	Percentage of main roads impacted by fallen trees
Manahan	8	3	38%
Pucangsawit	2	0	0%
Kedunglumbu	5	3	60%
Sriwedari	6	2	33%
Jebres	6	4	67%
Kestalan	0	0	0%
Kampungbaru	0	0	0%
Sewu	1	0	0%
Gilingan	3	2	67%
Mangkubumen	2	2	100%
Pajang	5	2	40%
Sangkrah	0	0	0%
Nusukan	6	3	50%
Jagalan	1	1	100%
Purwosari	4	3	75%
Sondakan	2	1	50%
Setabelan	3	2	67%
Semanggi	1	0	0%
Tegalharjo	0	0	0%
Gandekan	0	0	0%
Kerten	3	1	33%
Joyosuran	1	0	0%
Joyotakan	0	0	0%
Buluwarti	0	0	0%
Kadipiro	2	2	100%
Tipes	6	4	67%
Karangasem	1	0	0%
Serengan	1	0	0%
Laweyan	0	0	0%
Sumber	0	0	0%
Sudiroprajan	1	1	100%

Sub-district	Number of fallen trees	Number of fallen tree occurrences on main roads	Percentage of main roads impacted by fallen trees
Ketelan	4	2	50%
Mojosongo	3	2	67%
Panularan	1	1	100%
Purwodiningratan	0	0	0%
Bumi	0	0	0%
Punggawan	1	1	100%
Penumping	2	2	100%
Kepatihan Wetan	1	1	100%
Danukusuman	0	0	0%
Jayengan	1	1	100%
Pasarkliwon	0	0	0%
Keprabon	3	2	67%
Banyuanyar	0	0	0%
Kepatihan Kulon	0	0	0%
Jajar	1	0	0%
Kauman	2	2	100%
Gajahan	0	0	0%
Timuran	3	2	67%
Keratonan	0	0	0%
Kemlayan	1	1	100%
Total area	**93**	**53**	**57%**

Source: Author's Calculation (2024)

As previously described, more than half (57%) of fallen tree occurrences in Surakarta City occurred on main roads, which can cause traffic and potentially macro-scale economic disruptions. Manahan sub-district, which experienced the highest amount of fallen trees, only had three incidents on the main road. Meanwhile, sub-districts such as Jebres and Tipes each had four incidents of fallen trees on main roads. Only 7 (seven) sub-districts, such as Pucangsawit, Sewu, Semanggi, Joyosuran, Karangasem, Serengan, and Jajar, experienced fallen trees where main roads were unaffected.

The Existence of Urban Green Space

The urban green space in Surakarta includes the railway buffer zone, the river buffer zone, and urban parks and forests. The sub-district of Jebres has the highest urban green space area in Surakarta, with 74.29 hectares. Green space is one of the important urban elements. The ideal area of urban green space is more than 30 %. However, this number is difficult to implement in Indonesian cities, including Surakarta. The urban green space of Surakarta is only 426.80 hectares or 9.14 % of its total area. The sub-district of Manahan has the highest proportion of green space, about 30.22 %, in Surakarta. On the other hand, 5 (five) sub-districts, including Kauman, Gajahan, Timuran, Kratonan, and Kemlayan, have a proportion of green space under 1 (one) %. The classification and proportion of

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urban green space in Surakarta can be detailed in Table 4. This situation indicates that urban green space is not evenly distributed in the city.

Table 4: Classification and Percentage of Urban Green Space

Sub-district	Area of rail-way buffer zone (Ha)	Area of river buffer zone (Ha)	Area of urban parks and forests (Ha)	Total area of urban green space (Ha)	Area of sub-district (Ha)	Percen-tage of urban green space (%)
Jebres	2.77	12.95	58.56	74.29	432.24	17.19
Manahan	3.57	3.29	40.13	46.99	155.50	30.22
Pucangsawit	5.61	6.20	2302	3483	128.14	27.18
Kadipiro	6.70	7.67	13.86	28.24	506.06	5.58
Mojosongo	0.00	8.16	18.24	26.39	545.41	4.84
Nusukan	6.15	8.01	7.07	21.23	196.09	10.83
Pajang	2.83	9.17	7.13	19.13	164.25	11.65
Gilingan	10.18	3.05	2.94	16.17	125.98	12.83
Kedung lumbu	1.80	1.39	12.89	16.08	59.34	27.10
Semanggi	4.22	3.64	3.19	11.05	159.99	6.91
Mangkubumen	6.04	3.24	1.72	11.00	87.04	12.64
Karangasem	0.00	3.40	7.09	10.49	193.25	5.43
Sriwedari	0.00	1.22	9.27	10.48	54.08	19.39
Sumber	0.00	6.57	0.83	7.40	146.94	5.04
Purwosari	2.89	2.43	1.52	6.84	80.27	8.52
Kerten	0.00	3.85	2.96	6.81	111.73	6.10
Sondakan	1.90	2.03	2.80	6.73	80.63	8.34
Sewu	0.00	1.68	4.68	6.36	47.40	13.42
Jagalan	1.63	4.10	0.32	6.05	61.90	9.78
Kampungbaru	0.00	1.16	3.68	4.83	35.73	13.53
Sangkrah	1.86	2.32	0.27	4.44	41.04	10.83
Banyuanyar	0.00	2.22	1.67	3.89	145.83	2.67
Joyosuran	0.00	2.83	0.71	3.54	59.18	5.99
Kestalan	2.44	0.83	0.11	3.39	24.29	13.94
Tipes	0.00	1.42	1.85	3.27	59.76	5.48
Setabelan	0.00	0.59	2.58	3.17	44.40	7.15
Baluwarti	0.00	0.00	3.12	3.12	54.10	5.76
Serengan	0.00	2.61	0.44	3.05	56.62	5.38
Panularan	0.00	1.04	1.59	2.63	56.30	4.68
Joyotakan	0.00	1.12	1.30	2.42	41.50	5.84
Gandekan	0.00	2.16	0.00	2.17	34.52	6.28
Jajar	0.00	0.52	1.61	2.13	122.09	1.74
Danukusuman	0.00	1.85	0.00	1.86	52.98	3.51
Penumping	0.00	0.81	1.01	1.82	48.16	3.77
Purwodiningratan	1.12	0.62	0.00	1.74	38.86	4.47
Tegalharjo	1.45	0.00	0.00	1.45	22.62	6.42
Bumi	0.00	1.11	0.33	1.44	32.77	4.40
Kepatihan Wetan	0.69	0.34	0.41	1.44	39.56	3.64
Punggawan	0.00	0.26	1.01	1.28	33.77	3.78

Sub-district	Area of rail-way buffer zone (Ha)	Area of river buffer zone (Ha)	Area of urban parks and forests (Ha)	Total area of urban green space (Ha)	Area of sub-district (Ha)	Percen-tage of urban green space (%)
Pasarkliwon	0.00	1.18	0.07	1.25	37.74	3.31
Sudiroprajan	0.00	1.18	0.00	1.18	23.51	5.03
Laweyan	0.00	0.42	0.74	1.16	22.91	5.06
Ketelan	0.00	0.72	0.41	1.13	23.25	4.87
Keprabon	0.00	1.03	0.00	1.03	33.61	3.07
Jayengan	0.00	0.00	1.00	1.00	29.97	3.33
Kepatihan Kulon	0.00	0.27	0.12	0.39	18.92	2.08
Kauman	0.00	0.00	0.00	0.00	20.72	0.02
Gajahan	0.00	0.00	0.00	0.00	25.02	0.00
Timuran	0.00	0.00	0.00	0.00	28.56	0.00
Kratonan	0.00	0.00	0.00	0.00	33.58	0.00
Kemlayan	0.00	0.00	0.00	0.00	32.67	0.00

Source: Author's Calculation (2024)

The area of urban parks and forests is the most common type of green space in Surakarta City, offering residents essential environmental benefits and recreational opportunities. Sub-districts like Jebres and Manahan even have urban parks and forests spanning more than 40 hectares, and overall, their urban green space areas are about 74.29 hectares and 46.99 hectares, contributing to over 28.41% of the total green space in Surakarta City (see Table 3). However, its proportion of green space area is only 17.19 % of the Jebres sub-district area, which is relatively low. These expansive areas enhance the quality of life and play a crucial role in maintaining ecological balance in densely populated urban settings. Conversely, sub-districts with smaller urban parks and forests tend to have less overall green space. Each sub-district in Surakarta has a different distribution of urban green space characteristics. In the middle of Surakarta, the urban green space mainly consists of city forests and parks. Meanwhile, the urban green space primarily consists of a cemetery in the northern part, which contains some of the Banjarsari Sub-district and Jebres Sub-district. The location of fallen trees and green space in Surakarta can be shown in Figure 4.

The Typology of Fallen Tree Risk

One key factor in urban risk management is understanding urban disaster risk typology. In this context, exploring fallen tree hazard typology is essential in mitigating and managing Surakarta's urban fallen tree risk. Table 5 describes the typology of fallen tree risk relating to the urban green space and the main road impacted by fallen trees.

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Table 5: Typology of fallen tree risk

Sub-district	Total area of urban green space (Ha)	Percentage of urban green space (%)	Percentage of main roads impacted by fallen trees	Level of fallen tree hazard
Jebres	46.99	30.22	38%	High
Manahan	34.83	27.18	0%	Low
Pucangsawit	16.08	27.10	60%	Medium
Kadipiro	10.48	19.39	33%	High
Mojosongo	74.29	17.19	67%	High
Nusukan	3.39	13.94	0%	Low
Pajang	4.83	13.53	0%	Low
Gilingan	6.36	13.42	0%	Low
Kedung lumbu	16.17	12.83	67%	Medium
Semanggi	11.00	12.64	100%	Low
Mangkubumen	19.13	11.65	40%	Medium
Karangasem	4.44	10.83	0%	Low
Sriwedari	21.23	10.83	50%	High
Sumber	6.05	9.78	100%	Low
Purwosari	6.84	8.52	75%	Medium
Kerten	6.73	8.34	50%	Low
Sondakan	3.17	7.15	67%	Medium
Sewu	11.05	6.91	0%	Low
Jagalan	1.45	6.42	0%	Low
Kampungbaru	2.17	6.28	0%	Low
Sangkrah	6.81	6.10	33%	Medium
Banyuanyar	3.54	5.99	0%	Low
Joyosuran	2.42	5.84	0%	Low
Kestalan	3.12	5.76	0%	Low
Tipes	28.24	5.58	100%	Low
Setabelan	3.27	5.48	67%	High
Buluwarti	10.49	5.43	0%	Low
Serengan	3.05	5.38	0%	Low
Panularan	1.16	5.06	0%	Low
Joyotakan	7.40	5.04	0%	Low
Gandegan	1.18	5.03	100%	Low
Jajar	1.13	4.87	50%	Medium
Danukusuman	26.39	4.84	67%	Medium
Penumpng	2.63	4.68	100%	Low
Purwodiningratan	1.74	4.47	0%	Low
Tegalharjo	1.44	4.40	0%	Low
Bumi	1.28	3.78	100%	Low
Kepatihan Wetan	1.82	3.77	100%	Low
Punggawan	1.44	3.64	100%	Low
Pasarkliwon	1.86	3.51	0%	Low
Sudiroprajan	1.00	3.33	100%	Low
Laweyan	1.25	3.31	0%	Low
Ketelan	1.03	3.07	67%	Medium
Keprabon	3.89	2.67	0%	Low
Jayengan	0.39	2.08	0%	Low

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Sub-district	Total area of urban green space (Ha)	Percentage of urban green space (%)	Percentage of main roads impacted by fallen trees	Level of fallen tree hazard
Kepatihan Kulon	2.13	1.74	0%	Low
Kauman	0.005	0.02	100%	Low
Gajahan	0.00	0.00	0%	Low
Timuran	0.00	0.00	67%	Medium
Kratonan	0.00	0.00	0%	Low
Kemlayan	0.00	0.00	100%	Low

Source: Author's Calculation (2024)

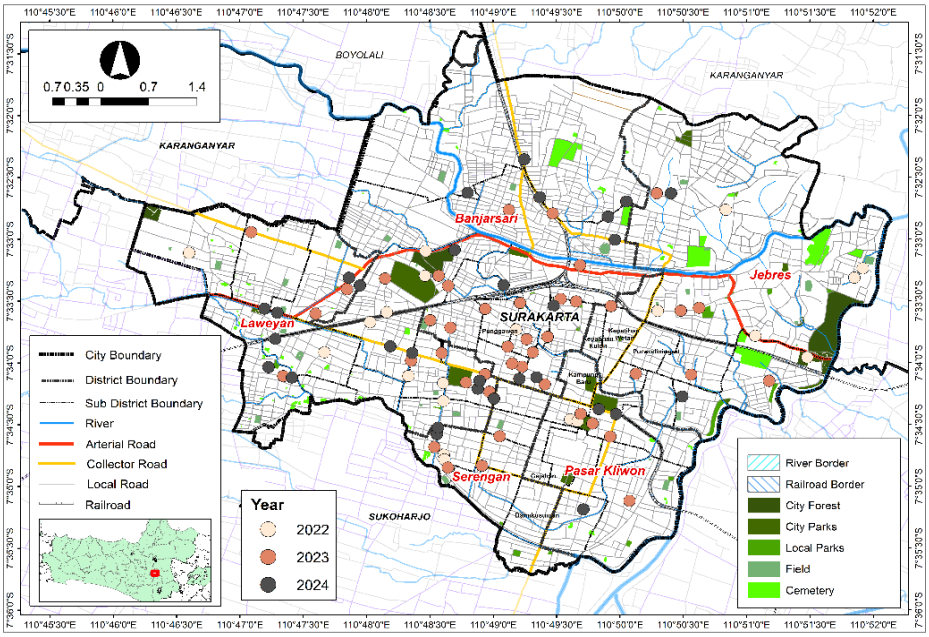


Figure 4: Green space and location of fallen trees in Surakarta City
Source: Surakarta Environmental Agency (2023), Author's Identification (2024)

Using correlation analysis in JASP software, the typology of fallen tree incidents in Surakarta City can be identified by examining the relationship between variables such as the total area of urban green space, the percentage of main roads impacted by fallen trees, and the level of fallen tree hazards. The analysis tries to determine whether there is a statistically significant relationship between these variables, which can provide valuable insights into the patterns and risk factors associated with fallen trees in urban environments. The result of the correlation analysis can be described in Table 6.

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Table 6. Pearson's Correlation

Variable		V1	V2	V3	V4
V1	Pearson's r	-			
	p-value	-			
V2	Pearson's r	0.648	-		
	p-value	< .001	-		
V3	Pearson's r	0.112	-0.051	-	
	p-value	0.432	0.723	-	
V4	Pearson's r	0.539	0.441	0.233	-
	p-value	<0.001	0.001	0.1	-

V1: Total area of urban green space V2: Percentage of urban green space
V3: Percentage of main roads impacted by fallen trees V4: Level of fallen tree hazard
Correlation coefficient interval: 0.00-0.199 (very low), 0.20-0.399 (low), 0.40-0.599 (medium), 0.60-0.799 (strong), 0.80-1.00 (very strong)

Source: Author's Analysis (2024)

Based on the correlation analysis table above, it is known that the correlation between the total area of urban green space and the level of fallen tree hazards has a Pearson's r value of 0.539, with a significance level of <0.001. This indicates a positive, significant, and medium correlation between the total area of urban green spaces and the level of fallen tree hazard in each sub-district. The positive and significant correlation means that if there is a correlation between those factors and an increase in the total area of urban green space, the level of fallen tree hazard will also increase. The medium correlation means those factors are moderately correlated, and others probably have a strong correlation. Meanwhile, the correlation between the percentage of urban green space and the level of fallen tree hazard has a Pearson's r value of 0.441, with a significance level of <0.001. This indicates a positive, significant, and medium correlation between the percentage of urban green space and the level of fallen tree hazard. In other words, an increase in the percentage of urban green spaces in a sub-district is associated with a higher level of fallen tree hazard. The logical statement concerning the percentage of urban green space is interpreted as the total area of urban green space towards the level of fallen tree hazard. Conversely, the correlation between the percentage of the main roads impacted by fallen trees and the level of fallen tree hazard has the p-value of these two variables is 0.1 or more than 0.005. It indicates no correlation between the percentage of main roads impacted by fallen trees and the level of fallen tree hazards in each sub-district.

More green space is correlated with the fallen tree risk predicted by the existence of old trees' ages in Surakarta. Many trees have existed since the kingdom's era. The trees along the main roads and those in urban parks are dominated by mature trees. However, further research could concern the potential confounders, including the tree specification, such as species, age,

root failure, and structural defect, influencing the fallen tree risk. Furthermore, the effects of climate change on extreme weather could be a factor that could be assessed in further studies.

CONCLUSION

The risk of fallen trees is an essential challenge in urban management in Surakarta City. The research described the increase in fallen tree risks during the last three years. The occurrences of fallen trees were dominated along the main roads in the city, including primary and secondary roads. Several sub-districts have high fallen tree hazards, including Tipes, Sriwedari, Nusukan, Jebres, and Manahan. Furthermore, the research demonstrates that urban green space is not evenly distributed in the city. The research findings conclude that the fallen tree hazard level correlates with the existence of urban green space. Most sub-districts have a high proportion of urban green space and a high risk of fallen trees. By addressing these challenges, urban stakeholders can enhance the resilience of fallen trees through proactive and integrated approaches to urban risk management. The number of green spaces in Surakarta City needs to be increased, but it needs to be balanced by managing urban trees. The mitigation of fallen trees should be done by identifying urban trees. Regularly monitoring and maintaining urban trees proactively should support the tree identity cards developed by urban stakeholders recently. The existence of tree identity cards should inform the specific tree species and tree ages so that preventive maintenance can be carried out well. It relates to the implications of urban planning and management policy that could improve the resilience of urban environments to natural hazards.

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RISK FACTORS IN LIFE CYCLE PHASES OF INDONESIA GEOTHERMAL POWER PLANTS PROJECT

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Abstract

The project life cycle must be managed by carrying out a series of project management activities, which are generally known as the project management process. Each project management process generally produces one or more outputs, including the implementation of the Geothermal Power Plant Project in Indonesia. It can be seen that, as of now, the development of several Geothermal projects in the country is at risk of delay or loss. This is most likely caused by several risk issues that arise throughout the project life cycle. Therefore, this study aims to identify various obstacles that contribute to the risks that interfere with the success of the project. This study is a descriptive study where the research method is intended to overcome existing risks, which still happen today, with a description of Geothermal Project Development activities. The Statistical Package for the Social Sciences (SPSS), a statistical method, was used to analyse various risk factors. The results of processing the discussion data from 17 risk factors revealed the 5 greatest risk factors in sequence, namely X2 (Exploration), X3 (Drilling Test), X4 (Feasibility Study), X11 (Actual Volume Estimation), and X17 (Risk Management).

Keywords: Project Life Cycle, Construction, Geothermal, Power Plant Project

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INTRODUCTION

Indonesia is currently implementing the 20-year development plan, starting from 2005 to 2025. One of the programs is carried out with the intention of expanding the electricity plants to meet the demand for electricity, which increases by 10% every year (Kashem, 2021). In essence, electricity consumption will encourage economic growth in a country (Mohammed, 2023). One of the significant components of energy consumption is electrical energy. In fact, the importance of electricity for economic growth has been recognised by economists, engineers, and various government agencies.

Based on the energy sector, Indonesia has the largest capability to advance geothermal energy as it has the largest geothermal resources in the world. In other words, Indonesia is endowed with 35% – 40% of the world's geothermal resource potential (Fan & Nam, 2018). One of the biggest advantages of geothermal energy is that geothermal power is a very predictable and reliable energy source, especially compared to other renewable energies (Energy Sage, 2021).

Fan and Nam (2018) found that significant social change requires systematic development of Indonesia's geoscience sector through improvements in economic, social, environmental, legal, and regulatory contexts. GeothermEx (2010) reports that the high project risks in geothermal development create the main hurdle preventing the expansion of such projects since developers must accept substantially greater risks when compared to other investments (Castlerock, 2010; International Finance Corporation, 2013; Nur et al., 2023). According to JICA (2009), the main resource-related challenges and the initial investment burden are the key obstacles to geothermal development in Indonesia (Nur et. al., 2023).

LITERATURE REVIEW

GEOTHERMAL

Geothermal can be defined as hot steam that originates from beneath the earth's surface, which can be utilised as one of the potential sources of renewable energy. Basically, geothermal energy originating directly from the earth's crust comprises an estimated 20% of the new formation of the core of the earth and 80% of the materials under the crust and radioactive disintegration (Kashem et al., 2021). Although magma is a mixture of liquid or semi-liquid rock located beneath the earth's crust, it is also active. Magma generates heat through the continuous radioactive decay of naturally occurring radioactive substances like uranium as well as potassium.

Besides, Kashem et al. (2021) list some practical applications of geothermal energy in one's daily life. In winter, it is necessary to wash using hot water. Hot water from a geothermal pump can heat the whole bathroom when, for instance, someone is taking a bath. In order to receive hot water instantly from

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below the surface of the earth, several countries construct geothermal water reservoirs. Some of the reservoirs are employed for industrial and commercial uses as well as residential use.

GEOTHERMAL ENERGY

In modern usage, hot water is obtained from geothermal reservoirs. Hot water is often required for many processes that need heating. In this case, a well is made to the geothermal reservoir in order to draw hot fluids from the earth's interior through a pipeline in a closed-loop geothermal heat pump. In general, its mechanical system includes a piping system, a heat exchanger, and some controllers. Besides transferring the water through the well mechanism, this type of mechanical system can be applied as a direct heat distribution system for other purposes. To minimise the flow rate of cold water from the system, a discharge system is incorporated to return the cold water to the ground or discharge it to the surface of the earth (Kashem et al., 2021).

On the other hand, in some countries, geothermal energy potential is utilised for greenhouse and aquaculture purposes. These two are the primary ways that geothermal energy potential sources are utilised within agribusiness. This is so because geothermal resources can substitute the use of traditional energy sources by 80%. This is very important because, in the past, the use of conventional energy resources like fuel energy could have polluted the environment in many ways, and it was also cheaper to use geothermal energy than to use some of these conventional sources of energy. Geothermal energy in remote geographical regions can mean clean air and water, fewer disease incidences, and opportunities for stable employment for those living in such regions (Kashem et. al., 2021).

GEOTHERMAL POWER PLANT PROJECT

A power plant is an installation that generates electrical power from some form of primary energy. The majority of power plants rely on one or more generators that turn mechanical energy into electrical energy, so that they pull power from the electrical grid needed by the community. The only exception is the solar power plants that source this electricity with the help of photovoltaic cells, not turbines (Atkins & Escudier, 2013).

During the implementation of the geothermal project development, there are several risks and obstacles that occur in several stages, which must be managed properly. Cost overruns occur when actual project expenditures exceed initial cost estimates, thereby causing financial stress, delays in completion, and stakeholder dissatisfaction (Sondakh & Palsson, 2021). In general, the average magnitude of cost overruns in the construction industry depends on various project characteristics, including project location, project type, industry, and construction time (Habibi et al., 2019).

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Several contingencies in a few activities of the Geothermal Project development phase in Sarulla have led to the prolongation of time and cost. While drilling, the drill pipe becomes lost in the borehole; hence, formation irregularities or the drill pipe could not maintain the right mud pressure, which leads to a blowout (Schlumberger, 1999). On the other hand, in the construction phase, the developer relies on the contractor, asserting that the factory will be constructed by the contractor and its subcontractors in accordance with the design and timeline within which the project is developed, and that the key components of the technology will operate as anticipated (Rakhmadi & Sutiyono, 2015).

PROJECT LIFE CYCLE

The project life cycle is controlled through the performance of project management activities referred to as Project Management Processes. Each of the project management processes results in an output or multiple outputs from one or more inputs by employing project management tools and techniques. It can be a deliverable or an output. Outcomes are a terminal condition, as they are the culmination of something. Project management processes are used universally across organisations (PMI, 2017). Project management processes are sequentially integrated because of their deliverables.

The Project Management Process Group is a collection of processes that apply to a certain project purpose. Process groups do not correlate with project phases. There are five major Project Management Process groups that categorise project management processes. The EPC project problems and challenges are segregated for each phase of the project for better understanding (Akhtar, 2020).

Based on interviews with experts, some reasons attributable to EPC project cost overruns include inadequate resource commitment to actual activities, a limited budget, inapplicable resources, and resource procurement problems that do not meet project goals or objectives. Thus, safety, time, quality, and cost are the four key PSs for evaluating the success of project performance of all the projects being managed by the project management regardless of the type of project and the different phases of the project from initiation to project completion in accordance with the contractual terms (Mairizal et. al., 2020; Roshdi et. al., 2023).

The composition of development costs for geothermal power plant projects varies greatly in each project's life cycle. The probability of success rate is very low in the initial stages of development, particularly in the exploratory stage, wherein there is still a high degree of risk. The upstream initiation stage, especially the test drilling stage, is generally considered the most risky in the development of a geothermal power project (Gehringer & Loksha, 2012). The risk is relatively lower after test drilling, but the cost is equally high since SAGS and power plant construction costs can amount to 60% or more of the total project cost (Sondakh & Palsson, 2021).

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Initiating Process Group
Procedures executed to establish what a given project entails or a given phase of a project following the acquisition of approval to commence the project or phase (PMI, 2017).

1. Front End Engineering Design (FEED) Readiness & Endorsement
2. Inherited Bidding Inaccuracies and Estimation Mistakes
3. Aggressive Un-realistic Schedule

Planning Process Group
The specific activities are those that are needed to define what the project will encompass, what is to be accomplished within the processes, and the action plan for achieving the goals for which the project was done (PMI, 2017).

1. Changes in Rely Upon Data/Information
2. Engineering & Design Deliverables Late Submission & Approval
3. Weak or Poor Project Planning
4. Non-receipt of NOC Or Permits from statutory authorities after the due date
5. Delay in Developing Project Management Team & Relevant Inadequacies
6. Team Competency Gaps
7. No Consideration of the Previous Project's Lesson Learn

Executing Process Group
As per those processes that are carried out to deliver the work that has been specified in the project management plan to meet the requirements of the specific project (PMI, 2017).

1. Engineering Query and Resolution: The following complicated the process by delaying response time.
2. Engineering/Design Issues and Changes
3. This has led to ineffective leadership and poor decision-making: This has made leaders ineffective and caused them to make poor decisions.
4. Lack of project workforce, tools, and other equipment
5. Delay in Materials Ordering, especially LLI's
6. Delay in Manufacturing and Delivery of Materials (incl. LLIs)
7. Poor Cash Flow
8. Serious HSE Violations and Accidents
9. Construction Implementation Failures
10. Delay in Permit to Work (PTW) issuance and compliance

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Control & Monitoring Process Group
Those processes needed for monitoring, controlling, and documenting the project's progress and performance; determining which aspects of the plan require modification; and implementing such modifications (PMI, 2017).

1. Lack of proper supervision and legislative measures during the implementation process of a project.
2. As mentioned above, poor Interface Management also includes poor communication in project management.
3. Lack of Risk Identification, Analysis, and Assessment for Project Risks

Closing Process Group
Adaptive: Those processes performed to formally complete or close the project, phase, or contract (PMI, 2017).

1. There was an inadequate inclusion of provisions for feedstock for commissioning and start-up.
2. This is due to either a delay in the finishing of the item. Project As-built activities are taking longer to complete.
3. Around the prevention of early demobilisation of the project management team
4. Delay in punch list clearance
5. Incomplete, inadequate, or untidy close-out report
6. Delay in punch list clearance
7. Delay in provisional acceptance certificate issuance

RISK FACTORS

Power plant construction encompasses elaborate and sophisticated mechanical, electrical, and civil works together with highly related technical, environmental, social, and political factors (Islam et al., 2023). This makes projects a bit risky, especially where the cost overruns are frequent and sometimes highly charged. For instance, in their review of 401 power infrastructure projects across the globe, they discovered an average cost overrun of 66%. However, according to another study, this figure was as high as 200% for power plant projects in Europe and North America, as ascertained by HIS in 2014. Hence, the advice to lessen overruns is often to assess the possible risks implicated and their consequences carefully (Islam et al., 2023).

A major problem in doing this for complex projects is that there is little information concerning project uncertainties and incomplete knowledge of the project, implying that project complexity in general raises the level of information uncertainty. Lack of understanding of the interactions between risks during risk assessment is also one of the key reasons for producing an incorrect risk

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assessment in projects of various kinds of complex nature. However, it is always difficult to get the full picture of prospects of large and complicated projects in terms of objectives, resources, environment, and project risk, owing to their specificity. Regarding interdependencies between power plant project risks, it has to be remembered that they are high and the practitioners must keep this in mind when deciding on the cost of the project and its risks (Islam et. al., 2023). Below are several risk factors during the project life cycle of a geothermal development project, as outlined in some literature (Table 1).

Table 1: Risk Factors during Project Life Cycle from literature.

	Initiating	**Planning**	**Executing**	**Control & Monitoring**	**Closing**
Oishi (2000) Setiawan (2014) IAEA (2015) Zhu et. al.(2015) Rera et.al. (2021) Aziziah et. al. (2023)	Pre-survey	Pre-survey			
Oishi (2000) Setiawan (2014) Zhu et.al. (2015) Rera et.al (2021) Aziziah et. al. (2023)	Exploration	Exploration			
Oishi (2000) Setiawan (2014) Zhu et.al. (2015) Rera et.al (2021) Igwe (2021)	Test Drilling	Test Drilling			
Oishi (2000) Setiawan (2014) IAEA (2015) Zhu et.al. (2015) Rera et.al (2021) Aziziah et. al. (2023)	Feasibility Study	Feasibility Study			
Oishi (2000) Setiawan (2014) Zhu et. al. (2015) Rera et. al (2021) Igwe (2021)	Drilling	Drilling			
Setiawan (2014) Zhu et. al. (2015) Igwe (2021) Negara et. al. (2022) Putri & Sulhan (2023)		Construct-ability	Construct-ability	Construct-ability	Construct-ability
Setiawan (2014) Sahdarani et. al. (2020) Negara et. al. (2022) Aziziah et. al. (2023) Negrin (2024)					Start-up
Sovacool et. al.(2014a) Valipour et. al. (2015) PMI (2017)		Working Items Complexity	Working Items Complexity	Working Items Complexity	Working Items Complexity

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	Initiating	**Planning**	**Executing**	**Control & Monitoring**	**Closing**
Eash-Gates et. al. (2020) Islam et. al. (2023)					
Oishi (2000) PMI (2017) Wahyudi et.al. (2019) Sarbini et.al. (2021) Yudha et.al (2022)		Working Detail Understand	Working Detail Understand	Working Detail Understand	Working Detail Understand
Zhu et. al. (2015) Yudha et. al (2022) Negara et. al. (2022) Negrin (2024)			Design Change	Design Change	Design Change
Zarrouk & Simiyu (2013) Bilqist et. al. (2018) Dewi et. al. (2022) Negrin (2024) Pambudi & Ulfa (2024)			Actual Volume Estimation	Actual Volume Estimation	Actual Volume Estimation
Zarrouk & Simiyu (2013) Bilqist et. al. (2018) van Wees et. al. (2020) Sarbini et. al. (2021) Dewi et. al. (2022)		Complexity of Work Method	Complexity of Work Method	Complexity of Work Method	Complexity of Work Method
Mairizal (2021) Sarbini et. al. (2021) Kashem et. al. (2021) Karytsas et. al. (2022) Dachyar et. al. (2023)		Inspection Test Plan	Inspection Test Plan	Inspection Test Plan	
Setiawan (2014) Zhu et. al. (2015) Rera et. al (2021) Mairizal (2021) Aziziah et. al. (2023)	Site Investigation	Site Investigation			
Zarrouk & Simiyu (2013) PMI (2019) Mairizal (2021) Dewi et. al. (2022) Larasati et. al. (2024)		Resources Availability	Resources Availability		
PMI (2019) Mairizal (2021) Yudha et. al. (2022) Aziziah et. al. (2023) Larasati et. al. (2024)		Contractor Planning			
PMI (2019) Mairizal (2021) Karytsas et. al. (2022) Yudha et. al. (2022) Aziziah et al. (2023)	Risk Management	Risk Management	Risk Management	Risk Management	Risk Management
Total frequency	**7**	**14**	**9**	**8**	**8**

RESEARCH METHODOLOGY

This study is descriptive research, and its purpose is to address existing risks associated with the Geothermal Project Development activities. The author used the Statistical Package for the Social Sciences (SPSS) statistical method to analyse various risk factors that cause cost overruns in the construction of the Geothermal project. The following explains the methodological steps used and the risk factors that caused excess costs, as shown in Figure 1 and Table 2.

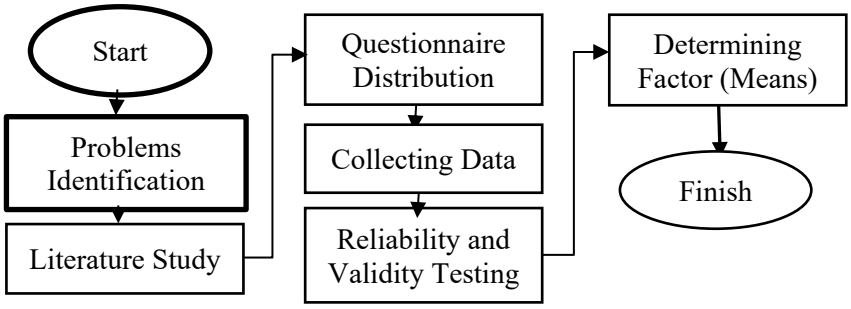


Figure 1: Research Methodology

This study produced 17 risk factors in 5 project cycle phases and tested them on 18 respondents (n+1) taken from investor companies and EPC contractors using the purposive sampling method. Based on the description of the 17 risk factors in Table 1, data processing was carried out using SPSS to evaluate the reliability and validity outcomes. The results of the data processing are sorted from the highest to the lowest mean value.

In this study, data collection was conducted on 18 geothermal development companies in Indonesia. Data were collected using questionnaires from those who are very influential in the development of geothermal projects and who have more than 20 years of experience.

They were given a questionnaire related to 17 factors that determine the sustainability of geothermal development in Indonesia. In its implementation, all of them responded based on their experience in developing geothermal-based power plants in Indonesia.

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Table 2: Risk Factors During Project Life Cycle (summary)

	Initiating	**Planning**	**Executing**	**Control & Monitoring**	**Closing**
Pre-Survey (X1)	/	/	-	- -	-
Exploration (X2)	/	/	-	-	-
Test Drilling (X3)	/	/	-	-	-
Feasibility Study (X4)	/	/	-	-	-
Drilling (X5)	/	/	-	-	-
Construct Ability (X6)	-	/	/	/	/
Start-up (X7)	-	-	-	-	/
Working Items Complexity (X8)	-	/	/	/	/
Working Detail Understand (X9)	-	/	/	/	/
Design Change (X10)	-	-	/	/	/
Actual Volume Estimation (X11)	-	-	/	/	/
Complexity of Work Method (X12)	-	/	/	/	/
Inspection Test Plan (X13)	-	/	/	/	-
Site Investigation (X14)	/	/	-	-	-
Resources Availability (X15)	-	/	/	-	-
Contractor Planning (X16)	-	/	-	-	-
Risk Management (X17)	/	/	/	/	/
Total Schemes	**7**	**14**	**9**	**8**	**8**

ANALYSIS AND DISCUSSION

The study starts its analysis section by validating reliability scores with alpha values > 0.70 and validity standards that exceed r-table values. Pearson coefficient characteristics show r-table = 0.4000 according to Pearson's Product-Moment r-table with a significance level of 0.05. Next, the study establishes its research beginning with the analysis section by validating reliability scores that exceed 0.70 values and demonstrating validity standards higher than r-table benchmarks.

The results of data processing carried out using the statistical program of social sciences version 24.0, recommending r-table = 0.4000 (r-table for Pearson's Product Moment significant level = 0.05). Data was analysed by SPSS, whereby the minimum r-count result was 0.404 (X3) for the test drilling factor. Meanwhile, for the reliability test, the Cronbach's Alpha value ranged from 0.938 to 0.951 (Table 2). In addition, the highest mean calculation result was 4.0556 (X2 or exploration), and the lowest mean was 3.3333 (X15 or resource availability).

Table 3: Item Statistics

	Mean	Std. Deviation	N	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
X1	3.7222	.82644	18	.729	.941
X2	4.0556	.72536	18	.529	.945
X3	3.8333	1.04319	18	.404	.951
X4	3.8333	.70711	18	.479	.946
X5	3.7222	.82644	18	.807	.940
X6	3.5556	.85559	18	.858	.938
X7	3.3333	.68599	18	.894	.938
X8	3.6667	.68599	18	.718	.942
X9	3.3889	.91644	18	.852	.938
X10	3.6667	.59409	18	.805	.941
X11	3.7778	.64676	18	.702	.942
X12	3.3889	.91644	18	.617	.944
X13	3.6111	.69780	18	.583	.944
X14	3.6111	.60768	18	.747	.941
X15	3.3333	.68599	18	.761	.941
X16	3.4444	.78382	18	.775	.940
X17	3.7778	.64676	18	.734	.942

As can be seen from the factor analysis highlighted in Table 3 above, the seventeen risk factors can be ranked as determining risk factors that have an impact during the project life phase, as shown in Table 4 below.

Table 4: Determinant Risk Factors during Project Life Cycle

	Mean	Std. Deviation	N	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
X2	4.0556	.72536	18	.529	.945
X3	3.8333	1.04319	18	.404	.951
X4	3.8333	.70711	18	.479	.946
X11	3.7778	.64676	18	.702	.942
X17	3.7778	.64676	18	.734	.942
X1	3.7222	.82644	18	.729	.941
X5	3.7222	.82644	18	.807	.940
X8	3.6667	.68599	18	.718	.942
X10	3.6667	.59409	18	.805	.941
X13	3.6111	.69780	18	.583	.944

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	Mean	Std. Deviation	N	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
X14	3.6111	.60768	18	.747	.941
X6	3.5556	.85559	18	.858	.938
X16	3.4444	.78382	18	.775	.940
X12	3.3889	.91644	18	.617	.944
X9	3.3889	.91644	18	.852	.938
X7	3.3333	.68599	18	.894	.938
X15	3.3333	.68599	18	.761	.941

When looking at the results of the ranking of the determining factors in Table 4 above, it can be seen that the Exploration factor is ranked at the top. This is in accordance with research by Pálsson (2017), which states that the composition of geothermal power plant project development costs varies greatly in each project life cycle. The exploration stage is the one that still has a very low success rate in development.

The second rank is Test Drilling, which is also in accordance with research by Gehringer & Loksha (2012), which states that the upstream initiation stage, especially the test drilling stage, is usually seen as the riskiest part of geothermal power project development.

Meanwhile, the third rank, namely the Feasibility Study, is also a determining factor according to Kashem et al. (2021). There are several challenges in the development of geothermal energy in Indonesia that need a highly detailed analysis of the feasibility study. The obstacle is the high operational costs. As for the risk distribution level, the highest percentage is observed at the exploration stage. As a result, more funding is required from the owner for the advancement of geothermal energy.

CONCLUSION

Referring to the results of the previous discussion, X2 (Exploration), X3 (Test Drilling), X4 (Feasibility Study), X11 (Actual Volume Estimation), and X17 (Risk Management) were the most significant factors that contributed to the highest risk. Due to the limitations in terms of opportunities and writing space, this research was developed in a broader direction with more detailed data processing steps.

Geothermal investment development requires multiple years for implementation, along with substantial financial costs. This initiative presents both dangerous conditions and five crucial alerting results according to the study findings. Results from the investigated cases established that exploration

processes take excessive durations, while drilling tests require substantial financial investments. Consistent geological research conducted repeatedly escalates drilling expenses and results in operational unpredictability. Initial investments in geothermal development need precise underground event prediction data at project initiation; thus, this study serves as an essential tool for new geothermal ventures. Nevertheless, the research constraints require strict research expansion among all participating programs.

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MALAYSIA GREEN HIGHWAY INDEX: THE ESG QUADRUPLE HELIX JOURNEY

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Abstract

This paper highlights the Malaysia Green Highway Index (MyGHI) as a national index that evaluates the Highway Infrastructure responsible for green initiatives. The index offers a measurable system for assessing the highway operation and services that reflect on Environmental, Social, and Governance (ESG) factors. To evaluate and promote the sustainability of the life cycle of highway projects, the MyGHI assessment focused on the sustainable practice from design, construction, operation & maintenance of highways in Malaysia, which entails reducing carbon footprint, conserving resources, and environmental conservation. The study explores how a green policy is connected to green rating tools developed to meet governmental priorities for enhanced national sustainable development. The MyGHI ESG journey is a step-by-step process of government agencies and universities collaborating on the Quadruple-Helix Methodology. MyGHI elevates social factors concerned with sustainability, which creates rest and service areas and safety for the community, engaging the community in meaningful ways and achieving equitable allocation of comfort and safety benefits. As a result, this paper expounded on MyGHI ESG's road map from the cradle to the present.

***Keywords*:** Environmental Social Governance, Green Highway Index, Sustainable Leadership, Quadruple Helix

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INTRODUCTION

What is the Green Highway Index? The Malaysia Green Highway Index (MyGHI) is a green rating tool for sustainable practice measurement that reflects the presence of green infrastructure in any highway. The MyGHI measures sustainable highway infrastructures and analyses the highway projects based on environmental impact, society, and governance factors. The index aims to make highway design, construction, operation, or maintenance compliant with Malaysia's or even international sustainable development objectives, where ESG factors are involved.

The road map began in late 2011 when Lembaga Lebuhraya Malaysia (MHA) invited Universiti Teknologi Malaysia (UTM) for a research and consultation courtesy visit to prepare for this research. The first briefing of the project to the MHA Department of Planning and the Department of Expert Services & Technical Collaboration (KPKT) received a positive reception. Both entities showed keen interest in possible cooperation in the Quadruple-Helix activities concerning several avenues for cooperation towards the development and innovation of the highway sector. Therefore, this paper is inquisitive about how green policies and green rating tools, such as MyGHI, were developed to match government attention to elevating the sustainable development of the country.

From the potential of collaboration, the Quadruple-Helix concept became a pivotal model to address the multifaceted and interconnected processes of academics and highway authorities involved in innovation, knowledge formation, and sustainable development. Specifically, the model's focus on the co-evolving and co-generative nature of knowledge, technology, and social change is well aligned with the multifaceted systems thinking because the sustainability transformation in the construction industry demands, by nature, a 'wicked', integrated approach. The driving of the Quadruple-Helix model concerning sustainable development and innovation was discussed in this paper, which presented the perspectives of green highway practices.

PROBLEM BACKGROUND

Malaysia Green Highway/Road Research

Malaysia has been at the forefront of encouraging sustainable development, primarily through the implementation of the MyGHI. The MyGHI is a tool to facilitate the adoption of green protocols in the planning, design, construction, management, and maintenance of highways in Malaysia. The index was commissioned by the Malaysian Highway Authority (LLM) to achieve green roads and provide more sustainable highways in terms of carbon footprint and transport infrastructure. The MyGHI also checks and ensures the environmental sustainability of highway projects to meet the country's sustainability goals on ESG factors. In short, it is a framework that aims to determine the sustainability

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of highway infrastructure within the country. The MyGHI established stakeholder values and the principles and/or objectives deemed necessary by the MHA, and further discussed sustainability and the issues encountered by the construction industry in Malaysia in the broader context. Several researchers have explored the comparison of green highway criteria. For example, a comprehensive survey of green highway assessment frameworks appeared in Husin et al.'s (2024) work. Their assessment checked the requirements within five vital components to develop green highways, which include sustainable design and construction operations, energy efficiency, environmental and water stewardship, materials technology, and social security measures.

Table 1: Green Highway Road/Research Project of Quadruple Helix Collaboration from 2011-2025

Year of Project Granted	Title of Research Project	Collaboration Team
2011	Malaysia Green Highway Index (MyGHI)	MHA-UTM
2017	Carbon Calculator of Malaysia Green Highway Index (MyGHI) Web-based	MHA-UTM
2018	Cost-Benefit Analysis of Malaysia Green Highway Index (MyGHI)	MHA-UTM
2019	The development of Malaysia Green Rural Road (MyRRI) for neighbourhood socio-economic benefits	JKR- UTM - UITM - UPNM
2024	MHA Green Policy	MHA-UKM
2024-2025	UTM- Universitas Semarang Green Highway Joint Research	UTM-USM-LLM

Transitioning effectively towards the environmental, social, and governance aspects of green highways/roads from a concept to reality has been a complex process that requires the adoption of the Quadruple-Helix approach. To include civil society in the model, which focuses on the participatory engagement of stakeholders and democratic views for the actualisation of innovation, the existence of civil society as a stakeholder was recognised. Furthermore, the Quadruple-Helix model has been considered one of the strategies for attaining the Sustainable Development Goals (SDGs). In light of Table 1 above, it is necessary to describe the journey of MyGHI and MyRRI research implementations.

Adopting the whole-of-nation approach is crucial for SDG implementation in accordance with the "leaving no one behind" principle. The MHA adopted SDG principles and responded as the catalytic policy enablers. With the inspiration of enhancing connectivity and transport infrastructure focused on being responsible for SDG Principle 9: Industry, Innovation, and

Infrastructure, combined with SDG Principle 11: Sustainable Cities and Communities, MHA embarked on its journey of responsive, sustainable efforts and green technology. The first output was a book entitled "*Preliminary Guide to Nurture Green Highway in Malaysia.*" This book aided the planning and execution of environmentally friendly road projects in Malaysia. The handbook provided a fundamental resource for engineers, developers, contractors, and other stakeholders engaged in Malaysia's design, building, and upkeep of highways. In line with international and national sustainability goals, it aimed to encourage the highway industry to embrace green practices.

Research and efforts to identify the relevant green highway elements and the possibility of applying the green concept in highway development have been undertaken to achieve a green highway with proper assessment. The creation of the MyGHI green rating tool in 2014 was a good fit for Malaysian highways since it addressed the shortcomings of existing worldwide highway green technologies. The MHA of Malaysia initiated several projects to use MyGHI to ensure more sustainable highways and marked a notable advancement in green technology (Gara et al., 2021). When built to the standards of the concept, a green highway produces invaluable environmental benefits. A green highway needs more consideration from all parties concerned. As a policymaker, the government provides the rules and regulations to be practised by the concession companies and highway users (Uchehara et al., 2022). Awareness among the highway users and stakeholders is essential to ensure that the equilibrium between development and sustainability is maintained

As the Ministry of Works (MoW) and MHA successfully integrated sustainable practices into their core activities, they actively collaborated with a wide range of government, academic, civil society, and business actors to achieve meaningful and sustainable progress to safeguard the sustainability of their ESG efforts (Institute for Capital Market Research Malaysia, 2023). The 'Quadruple-Helix' model has helped MyGHI understand how best to implement the ESG model. Having other participating organisations from the government agencies, academic institutions, and other industry peers allowed them to gain full access to knowledge and resources. It shared best practices that made the ESG highly resilient. This was in line with findings from current studies that argued that companies that integrate ESG factors into their management and operation frameworks are likely to realise numerous opportunities and efficiencies (Wang et al., 2025).

LITERATURE REVIEW

Environmental Social Governance (ESG)

ESG is the abbreviation for Environmental, Social, and Governance. Over the last few years, ESG factors have become crucial for investors and firms. In general, ESG factors potentially affect the company's reputation, business processes, and

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financial results (Che et al., 2024). While using ESG criteria, investors seek better returns on investment since they know that organisations with good ESG performance indicators have higher chances of outcompeting their counterparts in the long run.

The organisation of a company needs to incorporate sustainability strategies into their current operations since the complexity of the environment demands improvements in environmental laws, consumer requirements, and community standards. ESG data disclosure can also assist firms in improving their prospects in terms of brand image, financing, and financing cost, which is a positive contribution to their valuation. In the past decades, managers adopted radical changes in their goals, where they used to work more in the quest for making higher profits in the short run, as demanded by shareholders and investors. However, given the increasing awareness of corporate responsibility toward the environment and civil society, promoted by diverse actors, including the government, they were forced to shift their paradigms (Sideri, 2021). Consequently, ESG disclosures were made to align corporate social responsibilities and corporate governance to facilitate the presentation of companies' claims that their business operations were environmentally friendly and had no negative impact on civil society; The board of directors was more involved in active discussions with civil society (Dwekat et al., 2020; Ebaid, 2022).

ESG-focused sustainability leadership with a profound commitment to actualisation is significant in guiding organisations and communities toward embracing and imbuing sustainable business management and development principles and practices in their business. This type of leadership sustains a focus on generating sustainable business value over the long term regarding ecological sustainability, social responsibility, and the principles of good corporate governance (Brühl, 2023). Regarding the advancement of sustainable development, the Malaysia SDG Council is a key institutional structure set to lead, monitor and facilitate the UN-SDGs across the nation (Pawar et al., 2020). This council has an important role in coordinating the alignment of Malaysia's national development priorities with the international SDG framework to improve progress towards achieving the goals set for 2030, as indicated in Figure 1 below. The formation of the SDG Council in Malaysia is an aspect of the focus towards the realisation of the SDGs as championed in the United Nations 2030 Sustainable Development Agenda. The 17 SDGs outlined several environmental, social and economic goals for countries of different stages of development, stating that every country should do its part in their implementation. As a member of the United Nations, Malaysia has made a global commitment to the SDGs, and the SDG Council serves as the primary mechanism for coordinating and overseeing the country's efforts to fulfil this commitment.

From the SDG council, it sparked the continuity of the sustainability mission and was being taken by the ministerial and private sectors, including the construction industry sector.

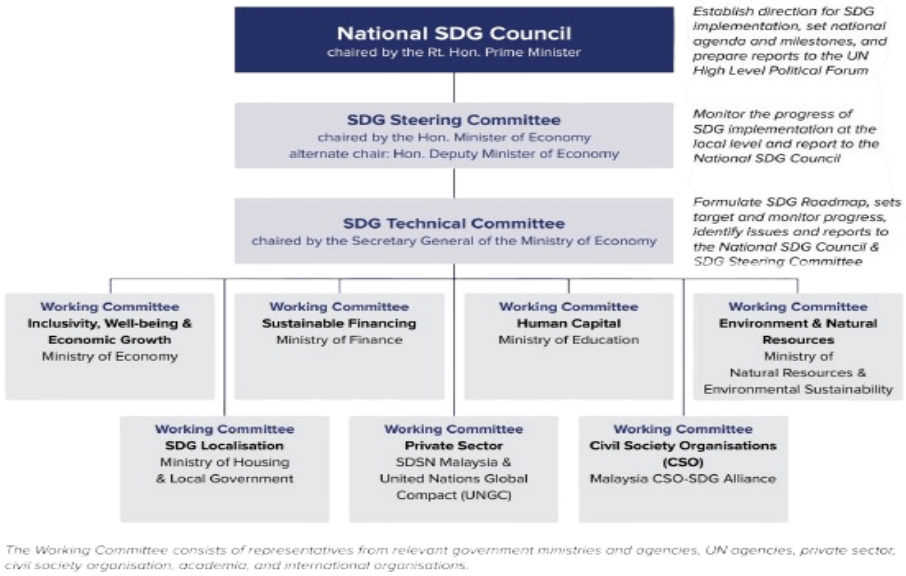


Figure 1. The National SDG Governance Structure of Malaysia
(Source: Economic Planning Unit, 2018)

From the SDG council, it sparked the continuity of the sustainability mission and was being taken by the ministerial and private sectors, including the construction industry sector. Thus, the National Construction Policy was established with six core areas (i) Quality and safety project performance, (ii) Embrace Sustainable Built Environment, (iii) Improve construction productivity, (iv) Strengthen infrastructure maintenance, (v) International competitiveness, and (vi) Strengthen good governance and adoption of best practices (Ministry of Works Malaysia, 2021).

The MoW, whereby it took further strategies and actions, the Highways Planning Division published an apparent reference to the Highway Network Development Plan (HNDP). The HNDP is a national master plan of road infrastructure developed by the MoW. Its aim is to create a national highway network that complements the national economic development plan and considers several factors, including the volume of traffic, land use, socioeconomics, and financial and environmental factors. The earlier HNDP was HNDP 2010: duration from 2010 to 2025. The efforts will continue to evolve with HNDP 2030: duration from 2020 to 2030, consisting of Part 1: Peninsular

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Malaysia and Part 2: Klang Valley & its conurbation, as shown in Figure 2. The MoW is studying the HNDP 2040 (HNDP 2040).



Figure 2: Highway Network Development Plan (HNDP 2030) Part 1 &Part 2
(Source: Ministry of Works Malaysia, 2020)

Malaysia SDG Council and the Key Roles and Responsibilities

The Malaysia SDG Council has a crucial role in advancing the country towards the challenging goalpost outlined in the United Nations SDGs (Sahimi et al., 2018). Being an institutional arrangement that is responsible for the coordination of the processes of implementation of the SDGs, the council is responsible for the integration of the strategies for the development of the country with the global idea of sustainable development (Johan et al., 2017; Sahimi et al., 2018). To do this, Malaysia needs to determine which particular objectives and goals need more input from the country. Consequently, plans must be developed and executed to achieve the aforementioned goals more effectively. Many other countries are also taking the same strategic approach, such as St. Lucia, which has established the National Coordinating Mechanism to oversee the implementation of the 2030 Agenda and the 17 SDGs (United Nations Office for Barbados and the Eastern Caribbean, 2023). Another example is Jamaica, whose national coordination mechanism for the 2030 Agenda includes the National 2030 Agenda Oversight Committee (NAOC) (Planning Institute of Jamaica, 2019). The roles and responsibilities of the five roles are explained below:

Role 1 - Strategic Coordination and Oversight
The role of the Malaysia SDG council is to devise and develop the national framework for implementing the SDGs, which is ensured to be integrated into Malaysia's coherent development framework and agendas. The council also supervises and disseminates data concerning the implementation of the SDGs in Malaysia and shares this information with local and international parties.

Role 2- Policy Guidance and Integration
Guaranteeing consistency of these policies with the national strategies of Malaysia and the commitments at the global level, the council provides consultation on establishing the policies that contribute to the SDG achievement. To this end, the council collaborates with various ministries, agencies, and government sectors to develop cooperation in establishing the integration of all SDG goals in the country's overall development framework.

Role 3- Stakeholder Engagement
The council is mandated to promote sustainable development across all societal strata and ensure that the understanding of the SDGs increases. The SDG council can engage with various stakeholders from the government, commercial, academic, civil society, and foreign sectors. This ensures that there will be a favourable approach in achieving the set common development goals and objectives.

Role 4- Resource Mobilisation and Capacity Building
The council mobilises funds and other resources from the corporate sector and international organisations for funding SDG endeavours. In the same regard, capacity building is stressed across various sectors to ensure that other players equally have the necessary capacity in terms of knowledge, technologies, and financial enablers required to support the achievement of the SDGs. For example, a study by Mohamed Anuar and Abdullah (2021) investigated methods of transforming underused areas beneath urban highways into sustainable functional space using green infrastructure approaches. This article showed the economic and urban lifestyle enhancements that resulted from implementing such programs.

Role 5- International Collaboration and Reporting
The Malaysian SDG council is responsible for ensuring that Malaysia fulfils its international reporting obligations for the SDGs by providing Voluntary National Reviews (VNRs) to the UN. To share and acquire knowledge of experiences of other countries and organisations in implementing the SDGs, the council supports cooperation with other countries and international and global educational networks.

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An organisation implementing sustainability at the centre of its business strategies will likely handle different risks effectively. In this sense, the integration of sustainability practices within the organisational structure and supply chain, as written in the conceptual framework, implied that such companies could improve their capability to address current and future environmental, social, and economic issues (Schulte & Hallstedt, 2018). Sustainable risk mitigation requires a holistic approach that considers risks within and outside the organisation, affecting all supply chain partners and stakeholder groups. Adopting a multi-dimensional framework for sustainability risk management can enable firms to systematically identify, assess, and address various risks, from technical and operational to regulatory and reputational.

RESEARCH METHODOLOGY

There were several steps of methodology to generate much interest in the possible partnership on the Quadruple-Helix agenda, especially regarding innovation and sustainable development in the green Highway initiative. The MyGHI ESG journey was a step-by-step process of the above collaboration on the Quadruple-Helix Methodology. The following are the steps that were taken:

Step 1: It started with the inauguration of a shared vision and mutual benefit aligned with all parties' objectives. This stage was to make academia understand SDG's vision and mission, which were governed by the SDG Council and translated via the MoW through the Malaysian Highway Authority. UTM and other universities were invited and welcomed to share their research idea and innovations in improving highway operation and services.

Step 2: There were consultative meetings with all parties to discuss the Quadruple-Helix agenda. It started with a meeting to nurture the SDG agenda in highway development, and several more presentations to pitch the research idea, as well as a Focus Group Discussion (FGD) with the road and highway industry experts. Workshops and seminars were also organised with industry experts, researchers, and policymakers to discuss and exchange ideas on key topics, such as sustainable materials, green construction practices, and technological advancements. UTM, as the academic counterpart, played a significant role in giving the training and upskilling assessment for the MyGHI Auditor.

Step 3: Roles and responsibilities were clearly defined to ensure everyone was aware of how their efforts would advance the project's objectives and how to utilise their own abilities optimally. MHA sought to upskill the staff and the highway concessionaires' sustainability officer so that they could understand the implementation of MyGHI, how it was assessed in terms of audits, and define how vital data is as evidence of sustainability. MHA established a cooperative

framework that described the processes for making decisions, allocating resources, and monitoring progress with the use of the MyGHI tool.

Step 4: In demonstrating the early wins, 10 sectional highways were selected as the pilot project. The initiation of pilot projects was the showcase of the Quadruple-Helix collaboration. The 10 sectional highways received awards for initiating green highway achievement as the early success story.

Step 5: MHA made an effort in a public relations campaign to inform people about the Quadruple-Helix partnership. The initiative's significance and each stakeholder's part in promoting sustainable growth in the highway industry were emphasised through social media, the media, and public events. An example was MHA Green Day, which encouraged highway concessionaires to make continuous improvement efforts to demonstrate their resilience in SDG responsibility.

Step 6: The MHA expanded the research funding based on the outcome of MyGHI for the Carbon Calculator of the MyGHI Web-based system. This suggested that Malaysia's green highway is not about the score but responsive to its responsibility for carbon reduction, and the assessment is computerised and achievable via a web-based system.

Step 7: The journey continued with a MOU signing and one research project to another with a memorandum of agreement to create a system for ongoing improvement, whereby all parties involved evaluated the relationship's progress regularly, exchanged insights, and modified plans of action in response to new problems that arose.

ANALYSIS AND DISCUSSION

Developing sustainable and resilient infrastructure requires a collaborative approach that aligns the goals and objectives of diverse stakeholders, including government agencies, academia, industry, and civil society (A. Bhattacharya et al., 2019; Acuña-Coll & Sánchez-Silva, 2023). This journey established a shared vision aligned with all parties' objectives, including government organisations, educational institutions, businesses, and civil society. It emphasised how the partnership can support the accomplishment of shared goals, like promoting innovation, enhancing infrastructure resilience, and increasing sustainability. For example, the first collaboration between MHA and UTM was presented as the project background in Table 2.

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Table 2: 1st Collaboration Research Project for Green Highway Assessment

A Collaboration Project between Malaysia Highway Authority (MHA) and Universiti Teknologi Malaysia (UTM)	
RESEARCH TITLE	The Development of An Assessment Framework for Green Highways in Malaysia
RESEARCH DURATION	2 Years
START- END DATE	25 November 2011 - 25 November 2013
GRANT DETAILS	The Research Project is divided into two Project Leaders and produces 2 capacity buildings. (Refer to MOA: 1 Postgraduate Student from LLM and 1 postgraduate student from FKA)

Collaboration among stakeholders could lead to significant benefits for all parties involved. Collaborative partnerships positively impacted individual organisations and the broader value chain, enabling system-wide changes and addressing complex social and environmental challenges (Green & Johnson, 2015). The benefits that each stakeholder would gain from the collaboration were clearly outlined. For instance, government agencies could gain better governance support, the highway concessionaires could find new markets, academic institutions could promote research and innovation, and civil society could receive better public services.

The Grant Details

Cooperation was fortified via official contracts, including partnership agreements or Memoranda of Understanding (MoUs). These agreements spelt out long-term obligations and guaranteed that everyone was on the same page regarding the objectives and results. Securing financing for research and development initiatives associated with the Quadruple-Helix agenda could foster innovation. This could entail providing funding to academic institutions and research centres so they could work on initiatives that further the collaboration's objectives, as shown in Table 3.

Table 3: Grant Funding and Division of Research Projects

Grant	**Project Title**	**Project Leader (Research Supervisor)**	**Capacity Building (Students)**
1 (4B055)	The Development of a Framework for Green Highway in Malaysia	Prof. XXX	Student PG 1 (LLM)
2 (4B056)	Weightage Factors for Malaysian Green Highway Assessment	Assoc. Prof. YYY	Student PG 2 (UTM)

The Research Flow

This journey clearly explained each stakeholder's obligations within the Quadruple-Helix framework. The framework flowed from Phase 1: Confirmatory of green highway assessment elements; Phase 2: Determination of criteria and sub-criteria of green highway assessment; Phase 3: Data collection and data analysis; Phase 5: Presentation and data validation; Phase 6: Green highway manual and publications. It was also crucial for everyone to understand how each contribution would help achieve overall goals and how one might leverage one's talents to further the cause of the initiative. Developed a system that provided structure to the cooperation between groups and explained how material resources, power delegation, and information would be divided, and how any achievements would be measured. This promoted trust and facilitated productive cooperation.

The Project Progress and Monitoring

Consultative meetings offered a forum for setting this shared strategic direction and ensuring that organisational goals were in harmony with those of stakeholders. Frequent conference sessions were set up with all stakeholders, especially regarding the green highway Quadruple-Helix actors. Such an integrated approach, involving the governmental and non-governmental actors, required solid knowledge of the best teamwork practices and the willingness to share information (Green & Johnson, 2015). It was advised to take advantage of such meetings to gather feedback, address and solve problems, and ensure all participants were part of the decision-making on how the collaboration would be conducted.

In addition, workshops and seminars were working meetings that allowed for the presentation of key trends, discussion of best practices and outcomes, and development of recommendations for further industry development. Besides, they attracted the attention of experts, researchers, and policymakers to sustainable materials, green construction practices, and innovative technologies. As such, these meetings could be used to create impactful activities and to show that collaboration is relevant and beneficial.

The Quadruple Helix Research Outcome:

Demonstration projects were launched to highlight the Quadruple-Helix collaboration's potential. These include modest-scale but significant highway projects that highlighted the advantages of creative problem-solving and sustainable methods. Success stories of such partnerships in other areas or industries were also presented. Emphasising successful results increased confidence and excitement about the possibilities of this partnership. A system for ongoing enhancement was also provided, whereby involved parties regularly evaluated the collaboration's progress, exchanged insights, and modified tactics

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to remain adaptable and sensitive to new problems. The outcome of 13 years (from 2011 to 2024) of trust in the Quadruple-Helix collaborative journey of Malaysia's green highway/road is portrayed in Table 4.

Table 4: Quadruple Helix Research Outcome (2011-2024)

Year of Project Granted	Title of Research Project	Capacity Buildings	Publications (Journals/Manuals/ Guideline)
2011	Malaysia Green Highway Index (MyGHI)	4-PhD 5-Masters	9-Journals 1-Preliminary Guidelines 1- MyGHI Index
2017	Carbon Calculator of Malaysia Green Highway Index (MyGHI) Web-based	1-PhD 4-Masters	10-Journals 1-Guidelines 1- Manual
2018	Cost-Benefit Analysis of Malaysia Green Highway Index (MyGHI)	1- PhD 2-Masters	
2019	The development of Malaysia Green Rural Road (MyRRI) for neighbourhood socio-economic benefits	3- PhD 6-Masters	7–Journals 2–Guidelines 2– Manual 1–MyRRI Index

CONCLUSION

Assuring that Malaysia makes significant progress towards accomplishing the SDG Agenda by 2030, the SDG Council plays a key role in ensuring that Malaysia's national development strategies align with the global SDG agenda. Transparency in sustainability reporting has become increasingly important as organisations seek to demonstrate their commitment to environmental and social responsibility. Transparency helps to build trust with stakeholders, such as investors, customers, and the general public, by providing reliable and verifiable information about an organisation's sustainability performance (Auger, 2014).

The Quadruple-Helix framework is a booster for an ESG comprehensive approach to innovation and problem-solving that involves the collaborative efforts of four key stakeholders: academia, industry, government, and civil society. Each stakeholder played a crucial role in driving the initiative forward and leveraging their unique strengths to contribute to the overall goals.

(i) **Academia** - The academic sector, comprising universities and research institutions, served as the knowledge hub within the Quadruple-Helix framework. Their primary duties were to produce quality research, generate new ideas, and offer conclusions based on scientific facts to encourage people to make informed decisions. Academia also played a huge role in training the workforce for the

community's future needs to ensure that knowledgeable human resources fit for the initiative are available.
(ii) **Industry** - The stakeholders of private firms, start-ups, and multinational industries contributed to the practical experience, market intelligence, and capacity for commercialisation in the Quadruple-Helix framework. Their responsibility was to transform the science created in universities into solutions that can be successfully adopted in the market, including offerings and business models.
(iii) **Government** -The local, regional, and national government stakeholders were expected to provide the necessary environment to develop the Quadruple-Helix initiative. This involved creating guidelines, rules, and resources that nurture innovation and entrepreneurship and stakeholder cooperation. To this end, the government played a significant role in ensuring that the initiative addressed overall social, economic, and environmental objectives.
(iv) **Civil society** -The community, through people in the civil society, such as groups and individuals, acts as the middle link between the initiative's implementation and the beneficiaries or the users. Their responsibility was to represent the needs and demands of the initiative, to assess and provide feedback on the effects of change or innovation, and finally to apply the innovation through the implementation of change in solving societal issues.

These ESG journey examples provided a comprehensive set of processes and steps spanning environmental, social, and economic dimensions, which can be customised to align with an organisation's unique sustainability objectives.

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INTERVENTIONS FOR STABILITY: PLACEMAKING STRATEGIES FOR UNDERUSED SPACES IN THE HISTORIC MINING DISTRICT OF SAWAHLUNTO, WEST SUMATRA, INDONESIA

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Abstract

COVID-19 pandemic has emerged as a crucial catalyst for a reassessment of the roles of public spaces in urban environments. This transformation is particularly noticeable in sectors such as city regeneration and tourism, both of which have experienced instability. There is a notable lack of research addressing the application of placemaking theory, particularly within historical contexts. This study examines the potential of underutilized spaces in historic mining districts as part of tourism infrastructure. It aims to explore how placemaking theory can be applied to these areas to revitalize them as tourist destinations, with a focus on both the physical characteristics and social dynamics they foster. Qualitative research was employed, utilizing field observations and space mapping as the primary data collection methods. These techniques enabled a comprehensive analysis of the underutilized spaces, focusing on their fundamental features. The data was analysed through contextual and thematic analysis to identify patterns and draw meaningful insights. The study identified seven (7) distinct types of underutilized spaces within the historic mining districts. Three (3) of these spaces are currently in use, while four (4) are underperforming but exhibit significant hidden potential. The findings suggest that revitalizing underutilized spaces in historically significant mining districts requires a holistic approach that integrates placemaking principles with local sociability and activities. Additionally, the study uncovers five (5) thematical emerging placemaking strategies including indigenous, celebratory, diversity, welcoming, and pride. By focusing on the interconnectedness of these attributes, it is possible to achieve urban stability and enhance the tourism infrastructure in these areas, thereby unlocking their full potential as vibrant tourist destinations.

Keywords: Placemaking, Sociability, Creative Strategy, Historic Mining District, Urban Stability, Tourism Infrastructure

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INTRODUCTION

The COVID-19 pandemic has significantly disrupted the functions of public spaces, particularly outdoor areas that rely on social engagement, proximity, and user diversity. During the pandemic, widespread social distancing and lockdown measures led to a cessation of communal activities, undermining the vibrancy and stability of these spaces. As Kortelainen & Albrecht (2021) note, such disruptions can cause public spaces to lose their connection to people, resulting in underutilized areas that no longer serve their intended social functions. Hansasooksin & Tontisirin (2021) further emphasize that a space's ability to attract people depends on its sociability and the recognition of its broader spatial functions, which were severely impacted during that time.

In the post-pandemic context, restoring the "sense of place" has become crucial for revitalizing these underutilized spaces. Khalaf et al. (2022) argue that fostering a deeper attachment between people and the spaces they occupy is key to restoring their vitality and sociability. Revitalization efforts must go beyond mere physical refurbishment; they must focus on enhancing both the tangible and intangible qualities of spaces, including community engagement, cultural events, and ongoing activities. Wan Ismail et al. (2020) stress that maintaining the identity of these spaces through such practices helps reintegrate them into the fabric of urban life, fostering a vibrant and connected community. Thus, a holistic approach to placemaking—one that blends physical rejuvenation with social and cultural reintegration—is essential for ensuring the long-term stability and success of public spaces in a post-pandemic world.

PROBLEM BACKGROUND

Shifting vision and paradigm in public spaces

The continuity of space functions often depends on the transformation of physical, economic, historical, and socio-cultural attributes that ensure the stability of these spaces. However, many of these attributes have been overlooked or degraded, especially in the face of disruptive events such as the COVID-19 pandemic, which challenged traditional perceptions and uses of public spaces. The pandemic exposed the vulnerability of public spaces, where functionality has been eroded due to degrading infrastructure and shifting societal needs. As Zhou et al. (2021) note, space utilization is inextricably linked to time and the trajectory of its socio-cultural context, and these influences can significantly affect how people engage with and utilize spaces.

Sawahlunto, a historic mining district inscribed on the UNESCO World Heritage list in 2019, offers a unique case study in this context. The district's exceptional urban characteristics, historical significance, ethnic diversity, and remarkable landscapes make it a potential hub for tourism (Cheris et al., 2020; Rosa et al., 2023; Cheris & Rosetia, 2022). Despite its inherent potential, the

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district has yet to fully capitalize on these attributes, with its public spaces underutilized and disconnected from the broader community. This study aims to explore the fundamental features of public spaces within Sawahlunto's historical district, focusing on the integration of sociability and the typology of public spaces. The research will also propose a checklist of requirements to enhance people's engagement with these spaces, helping to transform them into vibrant tourist destinations that reflect the district's rich heritage.

LITERATURE REVIEW

Public spaces in historic districts

Public spaces in historic districts play a pivotal role in presenting and embodying cultural identity, as they are often sites where the past and present intersect, creating a tangible sense of place (Widodo, 2012; Kapoor et al., 2022). The complexity of the human-nature relationship contributes to the development of a transactional connection between people and their environment, where the identity of a space becomes evident through interaction and experience (Ogborn, 1996). In these spaces, diverse activities and social interactions occur, which, together with the narrative urban elements and interpretive settings, create a distinct character unique to the area. This character is shaped by a rich historical evolution and the impact of human activity, resulting in a space that reflects the intersection of time, culture, and community (Rosley et al., 2024).

Through public spaces, the past is not only preserved but also actively interpreted, providing an opportunity for current and future generations to engage with the history and identity of a place.The dynamic process of selecting, interpreting, and representing aspects with culture induces identity stories (Rosa et al., 2023). They contest time and space, advertising dominant and imaginative geographies that delve into character inside their urban element and public spaces. Nowadays, heritage objects thrive by community embezzlement along with creative activities (Soedarsono et al., 2021). Dwelling on layers of historicity, the measurement took deeper key factors in making strategic practice on how to keep the space stable (Sills, 2021). Traditional practices may be found to be imbalanced with current progressive impact, and lead to gentrification instead (Lew, 2017). Developing places for commercial and tourism consumption may have fractured their cultural existence and degraded their identity.

Strategy driven by specific space typology

The strategy for enhancing public spaces is often driven by the specific typology of the space, which directly influences its liveability, sense of well-being, and the rootedness of community members within a place (Ellery & Ellery, 2019). The decision-making process that shapes space typology, including the designation of functions, layouts, and spatial distributions, plays a critical role in boosting the

vibrancy and vitality of a place, creating a positive feedback loop that fosters continued engagement. According to Relph (2007), the articulation of space typology encompasses not only the functional aspects of a space but also its layout and distribution, which together define how a space is used and experienced. The intimate relationship between these three elements-space function, layout, and distribution-correlates strongly with individual experiences of activity engagement, mobility, and familiarity with a space's physical properties, social interactions, and cultural presentation (Lanham, 2007). When these elements are thoughtfully integrated, they can enhance the overall experience of the space, making it more meaningful and connected to the community it serves.

Sociability in placemaking strategies for space stability

Sociability plays a crucial role in placemaking strategies, as it helps build a strong sense of connection between people and the places they inhabit, turning the community into a valuable asset for space utilization (Crisman, 2022). In placemaking theory, sociability is recognized as a key factor in enhancing and developing urban design by fostering social interactions that strengthen the overall stability of public spaces (Soedarsono et al., 2021). By promoting friendly and diverse interactions, volunteerism, and a sense of local pride, sociability contributes to creating a vibrant community that is invested in the space's well-being. These attributes encourage engagement and support, nurturing the development of spaces that are not only functional but also meaningful, reinforcing the value of the place to its users (Ellery & Ellery, 2019).

The element of placemaking strategies values people as the asset (PPS, 2016) not only in the quality of the setting, i.e. material, shape, colour, order, harmony-, but also in the spirit that pervades the place (Kortelainen & Albrecht, 2021). There is an auto-correlation between urban function and community preservation (Zhou et al., 2021). The ability of people and community to create a quality in a space is beyond socio-cultural trajectory (Relph, 2007). Through sociability attributes in placemaking, places not only can carry their function but also revive spirit, meaning, experiences, and emotion.

Among the four (4) strategies of placemaking, sociability has the capability to cover the most intangible attributes that a place needs. They are: diversity, stewardship, cooperation, neighbourliness, pride, friendliness, interactivity, and a welcoming. Every one of these elements supports a tangible attribute among women, children, and the elderly, creating a social network, supporting volunteerism, and integrating evening use with street life. As long as the attributes are interconnected with other strategies in placemaking - namely, Uses & Activities, Comfort & Image, as well as Access & Linkages, attributes from Sociability strategies empower the making of a place, enhancing public

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spaces' identity and pride (Frenette, 2017). The degree of public space can be sustained to become successful when it reaches existence flow continuously, coordinating within the socio-cultural axis that strengthens connection to the spirit and emotion of the place.

RESEARCH METHODOLOGY

The site of the study is located in the historical district of Sawahlunto city, West Sumatra, Indonesia. It encompasses a diverse range of characteristics related to rural and urban places with historical value. The study begins with a literature review on public spaces in historic districts and the sociability characteristics in placemaking theory. Site observation and space mapping were used in this study. The old town was easy to navigate, as each landmark was only a 15-minute walk away, and the observation process took only half a day.



Figure 1: Location of Sawahlunto old town
Source: Author

During the observations, areas were designated utilizing the map and images, which aided in our identification of the several sorts of public spaces in the old town. Underutilized spaces, both heavily and minimally used, can be found via the map and analyzed based on their quality according to specified typologies in spatial arrangement, distribution, and function. Additionally, this paper utilizes sociability key metrics from placemaking theory to bolster the context and thematic analysis by leveraging the interconnected tangible and intangible attributes.

ANALYSIS AND DISCUSSION

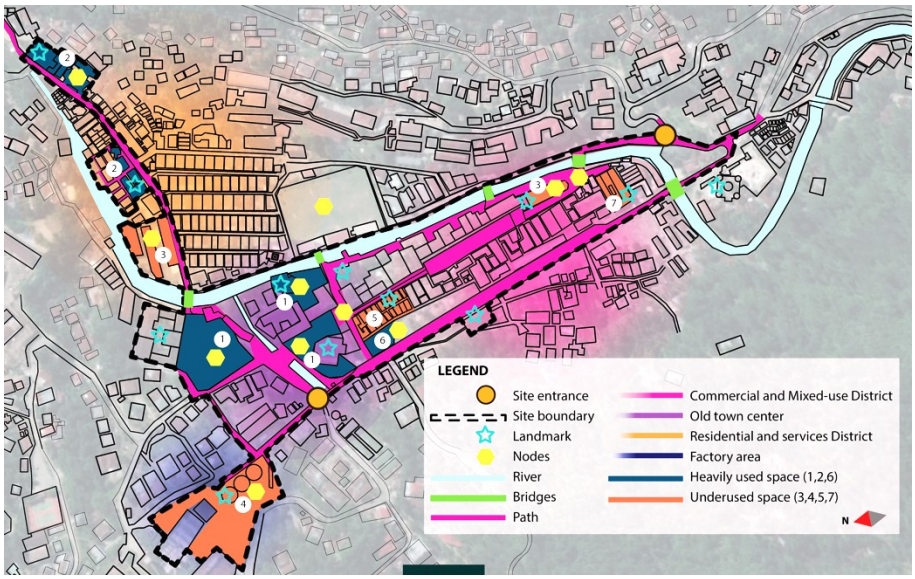


Figure 2: Land use map and 7 Identified spaces
Source: Author

Identified space 1: Plaza

The two plazas (Figure 3), strategically located opposite each other, are framed by significant landmarks that reinforce their distinct identity within the historic town of Sawahlunto. As shown in Figure 2, together, these plazas reflect the strong historical identity of Sawahlunto, with monuments and symbols of its authentic history serving as their backdrop. While these spaces function as lively hubs, enhanced by the surrounding natural environment that provides a serene and comfortable atmosphere, they fail to fully preserve or complement the continuity of the town's historical narrative. Although both plazas symbolize Sawahlunto's liberation, they lack the emotional resonance necessary to foster a deeper connection to the town's heritage. Details of the quality of the spaces are identified in Table 1 below.

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Figure 3: Two plazas of two interpretive settings
(PT. Bukit Asam office and Gedung Pusat Kebudayaan)
Source: Author

Table 1: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Plaza	SF	Public	Communal event, Daily activities
	SL	Open Layout	Iconic and vital by interpretive settings Celebratory history Natural settings Lively street life during night
	SD	Dispersed	High accessibility Low continuity

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function

Identified space 2: Inner court

Museum Goedang Ransoem stands out as one of the most notable museums in the historic town of Sawahlunto. The space between the museum's compound (Figure 2, space number 2) creates an inviting and welcoming atmosphere, reflecting the neighborhood's multi-functional character. The museum not only serves as a cultural space but also functions as a gateway to the old industrial area, with its proximity to a historic tofu factory at the back (Figure 4). The significance of the museum's historical narrative, along with the connection to the tofu factory, led the preservation team to ensure the factory's retention as part of the site. This decision highlights the vitality of the space, reinforcing a strong sense of place and deepening the community's attachment to both the museum and its history. By preserving this local landmark, the museum effectively bridges the past with the present, fostering a tangible link between the community and its heritage (Table 2).

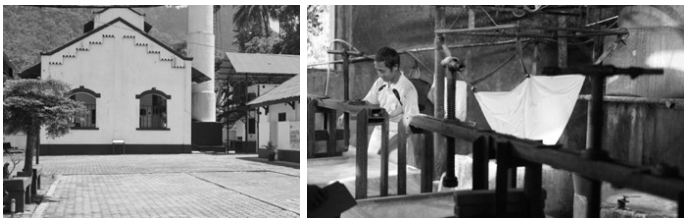


Figure 4: Inner court at *Goedang Ransoem* museum and the handmade tofu factory attached to it
Source: Author

Table 2: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Inner court	SF	Public Semi-Public Semi-Private	Special event Museum activity Factory activity, Daily activity
	SL	Compound	Layers of historical events Relevant to community Stewardship
	SD	Clustered	High accessibility

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function

Identified space 3: Terminal

The space possesses essential qualities that contribute to communal well-being, particularly through its integration of artistic and cultural activities. When utilized as a venue for recounting the historical activities of the ancient town, the terminal takes on a more meaningful role (see Figure 5), progressively strengthening its connection to the community. With prime location in the centre of Commercial and Residential district (see Figure 2), this sense of continuity helps foster a communal atmosphere, encouraging a shared spiritual bond among individuals and cultivating a deeper sense of belonging within the space, as detailed in Table 3).



Figure 5: Public transport terminal and communal garage for local residents
Source: Author

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Table 3: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Terminal	SF	Public	Communal activity, Specific activity
	SL	Semi-Open	Seasonal high mobility Historic gateway
	SD	Clustered	Moderate accessibility

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function *Source: Author*

Identified space 4: Playground

The playground (Figure 6), though designed to cater to children, adults, and the elderly, is fully occupied with interactive activities but fails to fully fulfil its intended functions. This failure undermines its role as a societal connector, leading to a general lack of appreciation for the space as a recreational area. While the interpretive settings in the area could serve as a strong symbol of the old town's history, their potential is weakened by poor accessibility. In Table 4, specific typology of space distribution depicts a contradictory quality. To address these issues, the space should be reimagined to prioritize comfort, safety, and a stronger sense of connection.



Figure 6: The Silo Playground only accessed by local residents
Source: Author

Table 4: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Playground	SF	Public	Specific activity
	SL	Open Space	Convenient landscape amenities Linked social space Interpretive settings
	SD	Clustered	High visibility Low accessibility

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function

Identified space 5: Intersection

As illustrated in Figure 2, the interspersed rows of shophouses create a network of alleys, pedestrian pathways, stairs, and ramps. These spatial layouts, combined with the heritage facade character, contribute to fostering a convivial and communal atmosphere within the town. The intersections and corners within this area serve as points of engagement, capturing the attention of individuals and

encouraging exploration of the local nuances that define the town's unique identity (Figure 7). The daily activities and interactions that take place in the town's limited spaces reflect the depth of social connections among its residents (Table 5).



Figure 7: Potentials urban element such as path, underpass, alleys, and stairs
Source: Author

Table 5: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Intersection	SF	Public Semi-Public	Communal activities Daily activities
	SL	Alley Stairs	Associates with interpretive settings Dynamic street art Fun linkages
	SD	Dispersed	High accessibility and continuity

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function

Identified space 6: Park

The park plays an important role in the daily activities of the community, offering a welcoming atmosphere and a comforting sense of belonging when people stroll through the town. Despite its significance, its secluded location means that many individuals do not notice its availability. From images in Figure 8, the park is characterized by mature vegetation and functional landscape features, such as pergolas and benches, contributing to its calm and composed design. By increasing its visibility, the park can further enhance its role in promoting cultural identity and supporting creative endeavours, ultimately elevating its impact on the community (Table 6).

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Figure 8: Community park near to residential
Source: Author

Table 6: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Park	SF	Public	Daily activities
	SL	Open Space	Convenient landscape amenities Manmade settings Linked social space
	SD	Clustered	Low visibility Moderate accessibility

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function *Source: Author*

Identified space 7: Rooftop

Despite its utilitarian function, this rooftop holds significant potential due to its strategic location, which strongly aligns with the visual continuity of the town's environment. It could serve as a dynamic creative platform for the local community. The adjacent spaces, with their multiple functions, contribute to the vibrancy of the area (see Figure 9). Given its low accessibility, introducing art-led initiatives such as creative installations or a progressive cultural tour could help infuse vibrancy into the space, gradually transforming it into a more engaging and culturally rich environment (Table 7).



Figure 9: Rooftop at the market
Source: Author

Table 7: Quality of the identified space towards specific typology

Space typology	Code	Type	Quality
Rooftop	SF	Public	Communal event, Seasonal
	SL	Semi-Open	Dynamic visual relationship to surround old town
	SD	Clustered	High visibility Low accessibility

*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function

Specific typology-led special object setting

The identification of underused spaces within the historic district revealed how specific space types intersect with sociability attributes from placemaking, particularly in relation to their uses, linkages, activities, and cultural value. These spaces were then analysed through thematic emerging strategies based on placemaking principles. Drawing from the literature, it is clear that sociability, as an attribute of placemaking, plays a pivotal role in fostering regenerative strategies. Sociability is deeply interconnected with other placemaking attributes, including activities, images, and connections, which collectively inform the development of revitalization methods. While the distinctive typology of each space largely determines its potential and quality, the rising qualities of sociability within placemaking strategies can stimulate the reinvention of these spaces. The following provides a thematic examination of these emerging strategies and outlines their practical contributions to enhancing the space's functionality and relevance in the community.

Table 8: Thematic and Context analysis on underused spaces in historic mining district
*) Specific typology code: SL=Space Layout; SD=Space Distribution; SF=Space Function

Placemaking attributes interconnected strategy with sociability and activities	**Identified 7 underused spaces in historic mining district according to specific typology*)**														
	Plaza			Inner court		Park	Playground		Intersection			Terminal		Rooftop	
	SD	SL	SF	SF	SL	SF	SL	SF	SL	SD	SF	SL	SF	SL	SF
Pride in historical and spiritual value		√			√										
Multi-ethnic diversity preservation		√			√	√				√			√		
Neighbourly community					√	√		√		√					√
Celebratory attraction/event		√			√			√					√		√
Indigenous properties and welcoming street life		√			√	√				√					

Source: Author

The revitalization of historic districts through place-making strategies represents a significant intersection of urban planning, community development, and cultural heritage preservation. The findings from the analysis reveal a multifaceted approach that emphasizes the importance of sociability, space

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typology, historical narratives, and the preservation of original characteristics in creating vibrant urban environments (Ja'afar & Harun, 2018). This discussion will synthesize these elements into a cohesive framework for understanding the revitalization process in historic districts.

Public spaces such as plazas and inner courts serve as vital arenas for social interaction, fostering community ties and a sense of belonging among residents. The table illustrates that space with all attributes from placemaking emerging strategies construct a higher quality. In this context of study, Inner court serves all the attributes of placemaking, however, its secluded location causes it to be wearisome. Compared to Plaza with its great typology of distribution and layout, even though lacking community engagement, the space appears vibrant and lively.

The work of Gehl (2010) adequately underscores the necessity of designing public spaces that encourage social engagement, which is essential for building resilient communities. By preserving the indigenous character of these spaces, urban planners can enhance their cultural significance, thereby reinforcing local identity. As exhibited in Table 8, the least associated thematic strategy assembles three (3) most underused spaces in a historic mining district, namely: Playground, Terminal and Rooftop. Their space quality and typology validating the underlying emerging strategy of placemaking did not cater to the poor visibility. This is particularly important in historic districts, where the character of the area is often closely tied to its cultural heritage (Ja'afar & Harun, 2018).

The analysis indicates that while certain areas, such as intersections, may lack specific revitalization strategies due to their limited spatial configurations, they still contribute to the overall identity of the district. Rosley et al. (2024) emphasize the importance of diverse uses in urban spaces, arguing that such diversity contributes to the vitality and character of neighbourhoods. The integration of small paths and connections to adjacent parks not only enhances the overall design but also fosters connectivity, which is crucial for urban vitality. Lynch's (1960) concept of legibility in urban design further supports this notion, as easily navigable spaces encourage exploration and interaction.

Incorporating dynamic features, such as historical storytelling, into the design of public spaces can significantly enrich user experiences. Wan Ismail et al. (2018) highlight the importance of place attachment and the narratives that shape our understanding of spaces. By embedding historical narratives into the design, urban planners can create environments that resonate with both residents and visitors, enhancing the cultural richness of the area. This approach not only educates the public about the history of the district but also fosters a deeper emotional connection to the space (Akbar & Edelenbos, 2020).

The potential for development in underutilized spaces, such as parks, playgrounds, terminals, and rooftops, is significant. These areas, while less frequented, can serve as vital components of the urban fabric. Carr et al. (1992) argue that parks and recreational spaces contribute to the quality of urban life and can be designed to reflect historical continuity. The visual connections between these spaces and the overall city atmosphere can enhance the urban experience, as noted by Whyte (1980). By revitalizing these spaces with thoughtful design and programming, planners can create inviting environments that encourage community engagement and recreational activities.

CONCLUSION

Sawahlunto, with its rich historical legacy, diverse identity, industrial aesthetics, and walkable environment, holds significant potential as a tourist destination. By leveraging the city's unique attributes and fostering special and thematic tourism, Sawahlunto can enhance its appeal and ensure the long-term sustainability of its tourism infrastructure. A strategic approach that incorporates sociability, distinctive activities, functional infrastructure, and a dynamic cultural and arts scene will be crucial in ensuring the preservation of the city's historical significance and maintaining its position as a vibrant and sustainable tourist hub. Furthermore, this study highlights the substantial potential of underutilized spaces, particularly those located in less frequented areas, which, if strategically developed, can be as valuable as more heavily trafficked spaces. The findings from this study emphasize the importance of integrating historical land use, cultural events, ethnic diversity, spiritual significance, and community engagement to effectively revitalize public spaces, particularly within historical contexts. This research demonstrates that sustainable urban development in historically significant mining districts can be achieved by focusing on the interconnectedness of placemaking, social interaction, and local activities. Theoretically, this study contributes to the placemaking discourse by emphasizing the need to address both tangible and intangible qualities of public spaces, particularly in historical areas. Practically, it underscores the importance of creating spaces that are not only functional but also socially engaging, thereby fostering community attachment and contributing to urban stability.

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ACOUSTIC AND MECHANICAL PERFORMANCE OF STYROFOAM-BASED LIGHTWEIGHT CONCRETE

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Abstract

Noise pollution and the growing issue of Styrofoam waste are major environmental concerns in urban areas. This study investigates the potential of utilizing Styrofoam as a partial aggregate in lightweight concrete to address both challenges. Styrofoam, a non-biodegradable material, contributes significantly to environmental pollution, while noise pollution impacts public health and productivity. Incorporating Styrofoam into concrete mixtures offers a dual benefit of reducing waste and enhancing acoustic insulation, especially for non-structural applications. The research evaluates the mechanical and acoustic performance of Styrofoam-based lightweight concrete, with a focus on mixtures with varying Styrofoam content. Results show that the incorporation of Styrofoam reduces the concrete density to a range of 1000–1300 kg/m³, with the lightest mix yielding a density of 1097.88 kg/m³. While the addition of Styrofoam significantly improves sound absorption—especially in mid-frequency ranges—there is a notable decline in mechanical properties, particularly flexural strength, which limits its application for structural purposes. The highest flexural strength observed was 44.12 kg/cm², significantly lower than that of conventional concrete. The findings indicate that Styrofoam-based lightweight concrete, particularly with a thickness of 15 cm and high Styrofoam content, is well-suited for non-structural applications such as partition walls due to its favorable acoustic performance and reduced weight. However, to enhance its mechanical properties, future research is recommended to explore reinforcement techniques. This study fills a critical gap by simultaneously addressing the environmental concerns of Styrofoam waste and the need for effective sound insulation in urban development.

Keywords: Lightweight Concrete, Styrofoam, Noise Reduction, Compressive Strength

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INTRODUCTION

Noise pollution and Styrofoam waste represent two significant environmental challenges in today's urban development. Noise pollution—driven by transportation, industrial activity, and urbanization—poses serious health risks and affects human productivity (Daigle, 2001; Finegold & Schomer, 2001). International and national institutions such as I-INCE have stressed the need for innovative noise reduction solutions (Boué, 2025; Chen et al., 2023). For instance, studies in Malaysia have documented excessive noise levels near hospitals, raising urban planning concerns (Mohd Nasir et al., 2024), while limited public participation further complicates sustainable development (Marzukhi et al., 2022). At the same time, the reuse of non-biodegradable materials such as Styrofoam in concrete and landscape elements has emerged as a cost-effective and sustainable approach (Ahmad et al., 2022).

Styrofoam (expanded polystyrene, EPS), due to its durable and non-biodegradable nature, contributes significantly to global environmental pollution by accumulating in landfills and ecosystems (D. Kumar et al., 2024; Siyal et al., 2012). Traditional disposal practices like incineration or landfilling are increasingly seen as environmentally harmful, prompting exploration of reuse alternatives (Himawanto, 2012; Nurherdiana et al., 2023; Yanto et al., 2019). Incorporating Styrofoam as a partial aggregate in lightweight concrete offers a dual benefit: reducing styrofoam waste and enhancing acoustic insulation, particularly for non-structural applications (Ngudi Hari Crista, 2024; Novizal et al., 2019). While such mixtures reduce concrete density to 1000–1300 kg/m³ and improve sound absorption (Cahyono et al., 2022; Ngudi et al., 2024), they also lower compressive strength significantly (Abiansyah & Rifdah, 2020; Nisumanti et al., 2024).

Although previous studies have explored ways to improve the mechanical properties of Styrofoam-based concrete—such as through fiber reinforcement (Aditama et al., 2024) and enhanced bonding techniques (Andryanto & Kushartomo, 2023)—few have comprehensively examined both mechanical and acoustic performance in a single study. Given the potential of Styrofoam to improve sound absorption while reducing density, this research addresses a critical gap by evaluating its suitability for lightweight concrete panels intended for non-structural and sound-insulating wall applications.

RESEARCH METHODOLOGY

This research adopted a quantitative laboratory-based experimental approach aimed at evaluating both the acoustic performance and mechanical strength of lightweight concrete incorporating post-consumer Styrofoam waste as a partial replacement for fine aggregates. The study was conducted in two main phases: acoustic performance testing and mechanical strength testing, each supported by thorough material characterization and strict quality control. The primary

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materials used included Type I Portland Cement, natural river sand as fine aggregate sieved through a 2.36 mm mesh to complying with SNI 03-6821-2002, cleaned and dried Styrofoam waste, and clean water. Prior to mixing, the Styrofoam waste was meticulously cleaned of any dirt, oil, or organic matter, and sieved through a 4.75 mm mesh to meet the fine aggregate gradation standard as per SNI 03-2834-2000.

The water–cement ratio (w/c) of 0.645 was selected based on preliminary workability trials intended to balance fluidity and cohesion in lightweight concrete mixtures containing styrofoam. Previous investigations on styrofoam-modified concretes have employed w/c ratios ranging from 0.6 to 1.0 to address workability challenges induced by this hydrophobic aggregate, with specific trials at 0.6, 0.8, and 1.0 demonstrating significant influences on slump and mix homogeneity (Herki, 2017). These studies underscore the necessity of fine-tuning the w/c ratio to achieve optimal consistency, thereby justifying the intermediate value of 0.645 adopted in the present work (Herki, 2017).

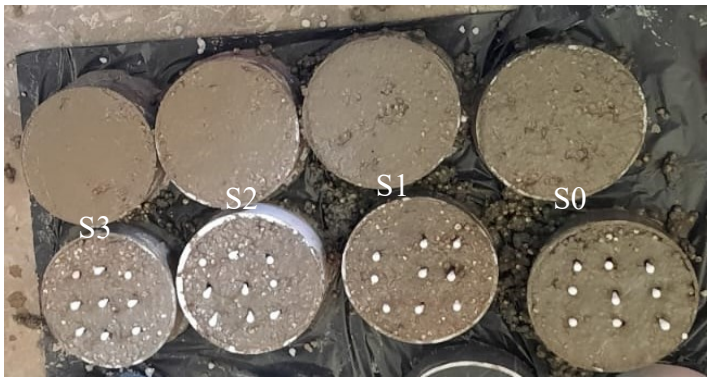


Figure 5: Mixture Variations

Four mix variations (Figure 5) were developed with the following proportions: 1PC:2Sand:3Styrofoam (S1), 1PC:1.5Sand:2.5Styrofoam (S2), and 1PC:1.25Sand:2.75Styrofoam (S3), a control mix (S0) containing no Styrofoam was also prepared for comparison. The mix composition of lightweight concrete specimens is shown in Table 4.

Table 4: Test Specimens

Sample Code	Mix Ratio (PC:Sand:Sty)	Portland Cement (kg/m^3)	Sand (kg/m^3)	Styrofoam (kg/m^3)	Water (kg/m^3)
S0	1:2:0	450	900	0	290.25
S1	1:2:3	300	600	90	193.5
S2	1:1.5:2.5	300	450	75	193.5
S3	1:1.25:2.75	300	375	82.5	193.5

Sieve analysis was conducted for both coarse and retained fine aggregates to evaluate particle size distribution. All test results, including acoustic and mechanical performance, were analyzed using statistical methods such as mean, standard deviation, and graphical trend analysis to observe variations in compressive strength and sound absorption performance. Correlation analysis was also conducted to explore the relationship between Styrofoam composition and the acoustic-mechanical performance of the concrete.

Sample Preparation for Mechanical Strength Test

Mechanical strength testing consisted of two tests: compressive strength test and flexural strength test. First, the fresh concrete was mixed using a pan mixer and cast into two types of molds: 30 × 15 cm cylindrical molds for compressive strength test and 50 × 15 × 5 cm rectangular molds for flexural strength test. Each mold was filled in three layers, with each layer compacted 25 times using a tamping rod. After 24 hours, the specimens were demolded and cured in water for 7, 14, and 28 days. Table 5 presents the mix composition of lightweight concrete used for specimens in the mechanical strength tests.

Table 5: Mechanical Strength Test Specimens

Sample Code	Mix Ratio (PC:Sand:Sty)	Portland Cement (g)	Sand (g)	Styrofoam (g)	Water (g)	Type
C-S0	1:2:0	2385.6	4771.3	0.0	1538.7	Compressive
F-S0	1:2:0	1687.5	3375.0	0.0	1088.4	Flexural
C-S1	1:2:3	1590.4	3180.9	477.1	1025.8	Compressive
F-S1	1:2:3	1125.0	2250.0	337.5	725.6	Flexural
C-S2	1:1.5:2.5	1590.4	2385.6	397.6	1025.8	Compressive
F-S2	1:1.5:2.5	1125.0	1687.5	281.3	725.6	Flexural
C-S3	1:1.25:2.75	1590.4	1988.0	437.4	1025.8	Compressive
F-S3	1:1.25:2.75	1125.0	1406.3	309.4	725.6	Flexural

Compressive strength tests were conducted using a universal testing machine in accordance with ASTM C109 (2008), while flexural strength tests followed the BS EN 1015-11 (2019) standard.

Sample Preparation for Acoustic Test

For the acoustic tests, each mix was cast into cylindrical specimens with a 10 cm diameter and two thicknesses, namely 10 cm and 15 cm. Each variation was duplicated, resulting in a total of 32 samples. Specimens were cured for 28 days under controlled conditions (temperature of 25 ± 2°C and humidity of 90%). The mix composition of lightweight concrete for the cylindrical specimens used in the acoustic test is shown in Table 6.

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Table 6: Acoustic Test Specimens

Sample Code	Mix Ratio (PC:Sand:Sty)	Portland Cement (g)	Sand (g)	Styrofoam (g)	Water (g)	Thickness (cm)
A-10-S0	1:2:0	353.4	706.9	0.0	228.0	10
A-15-S0	1:2:0	530.1	1060.3	0.0	341.9	15
A-10-S1	1:2:3	235.6	471.2	70.7	152.0	10
A-15-S1	1:2:3	353.4	706.9	106.0	228.0	15
A-10-S2	1:1.5:2.5	235.6	353.4	58.9	152.0	10
A-15-S2	1:1.5:2.5	353.4	530.1	88.4	228.0	15
A-10-S3	1:1.25:2.75	235.6	294.5	64.8	152.0	10
A-15-S3	1:1.25:2.75	353.4	441.8	97.2	228.0	15

The sound absorption coefficient tests were performed at the Acoustics Laboratory using the Impedance Tube Method, in accordance with ASTM E-1050-98 (Abdillah et al., 2019). The evaluation of sound absorption characteristics under normal incidence commonly employs the ASTM E1050-98 standard using a Brüel & Kjær impedance tube (4206 series, 30 mm diameter) with a dual-microphone setup to analyze incident and reflected sound waves from a broadband source, enabling accurate measurement of absorption coefficients across frequencies (Jena et al., 2019). Measurements were taken at eight different frequencies: 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, 9000 Hz, and 10000 Hz. Each specimen was tested three times, and the absorption coefficient was calculated as the average of the three values. The absorption coefficient represents the proportion of incident sound energy absorbed by a material, ranging from 0 (no absorption) to 1 (perfect absorption).

ANALYSIS AND DISCUSSION

Concrete Compressive Strength Test

For compressive strength test, a total of 12 specimens were produced, divided into 3 age groups with 4 specimens per age. The fresh and dry unit weights of the lightweight concrete were also measured after 28 days. The targeted compressive strength ranged from K-50 to K-175 kg/cm², determined using a modified mix design method based on the American Concrete Institute (ACI). Detailed material proportions used for the 12 cylindrical test samples are outlined in Table 7.

Table 7: Average Compressive Strength for each Age Styrofoam Concrete Samples

Sample Code	Mix Ratio	Age 7 Day kg/cm²	Age 14 Day kg/cm²	Age 28 Day kg/cm²
C-S0	1PC:2Sand:0Sty	75.81	119.37	149.36
C-S1	1PC:2Sand:3Sty	63.24	82.03	98.99
C-S2	1PC:1.5Sand:2.5Sty	51.48	62.22	78.65
C-S3	1PC:1.25Sand:2.75Sty	37.33	49.79	66.77

The compressive strength development of lightweight concrete incorporating styrofoam shows a steady upward trend over time, influenced by the mix proportions used. A mix ratio of 1PC:2Sand:3Sty demonstrated the highest strength among styrofoam-based mixes, reaching 98.99 kg/cm² at 28 days, with a cube-equivalent of 119.26 kg/cm² and an adjusted characteristic strength of 107.13 kg/cm². A second mix with 1PC:1.5Sand:2.5Sty achieved slightly lower results, culminating at 78.68 kg/cm² (cube-equivalent: 94.73 kg/cm²; characteristic strength: 84.73 kg/cm²). The third formulation, with the highest styrofoam content (1PC:1.25Sand:2.75Sty), produced the lowest values—66.75 kg/cm² at 28 days, corresponding to a cube strength of 80.41 kg/cm² and a characteristic strength of 71.93 kg/cm². These outcomes support previous findings that increased styrofoam content reduces compressive strength due to higher void ratios and weaker interfacial bonding (Rathika et al., 2023; Srividya et al., 2022).

In contrast, conventional concrete without Styrofoam exhibited significantly higher compressive strength, reaching 149.33 kg/cm² at 28 days, equivalent to a cube strength of 179.91 kg/cm² and a characteristic strength of 164.92 kg/cm² after statistical adjustments. While styrofoam-modified concrete demonstrates sufficient strength progression for non-structural applications, it remains mechanically inferior to standard concrete. This underscores the need for further optimization—such as the use of reinforcing fibers or additives—to enhance its structural viability. The comparative results of all tested mixes are illustrated in Figure 6, highlighting the trade-offs between weight reduction and strength performance.

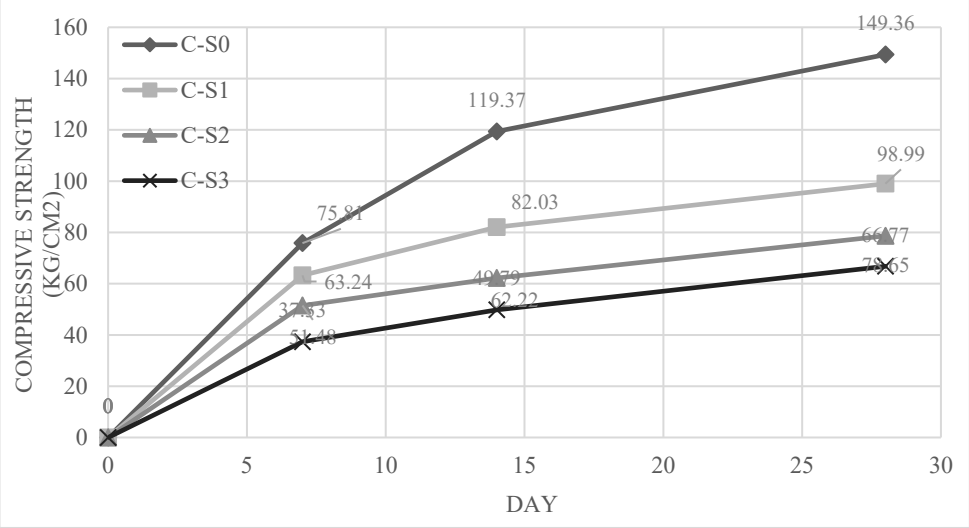


Figure 6: Compressive Strength of 28-Day Concrete Samples

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Concrete Density

An in-depth analysis of concrete mix variations incorporating Styrofoam as a lightweight aggregate substitute revealed that all tested specimens achieved fresh concrete densities well below the 1900 kg/m³ threshold. This qualifies them as lightweight concrete, in accordance with commonly accepted classifications such as those outlined in ACI 213R-14. Across all mixture types, the fresh concrete densities consistently fell within the range of approximately 1000 to 1300 kg/m³, confirming the effectiveness of Styrofoam in significantly reducing the overall weight of the concrete matrix (P. Kumar et al., 2023).

Among the evaluated combinations, the mix ratio 1PC:1.25Sand:2.75Sty produced the lightest material, with cylindrical specimens recording a fresh density of 1097.88 kg/m³. This significant reduction is directly attributed to the high proportion of Styrofoam—a material with exceptionally low specific gravity and a cellular structure that introduces numerous internal air voids into the concrete mixture (Mahmoud et al., 2023).

Other mixtures demonstrated similar trends. The 1PC:2Sand:3Sty mix yielded a fresh density of 1279.89 kg/m³, while the 1PC:1.5Sand:2.5Sty mix reached 1242.56 kg/m³. These values clearly indicate a consistent inverse relationship between Styrofoam content and fresh concrete density. As more Styrofoam is added, the volume fraction of lightweight polymer replaces a portion of the heavier sand aggregate, thereby reducing the total weight of the concrete (Rathika et al., 2023; Srividya et al., 2022).

Although the inclusion of greater amounts of Styrofoam contributes to density reduction, this must be carefully optimized. Higher Styrofoam content may compromise the mechanical integrity of hardened concrete, particularly its compressive and flexural strength. As illustrated in Figure 7, the downward trend in unit weight is evident with increasing Styrofoam content.

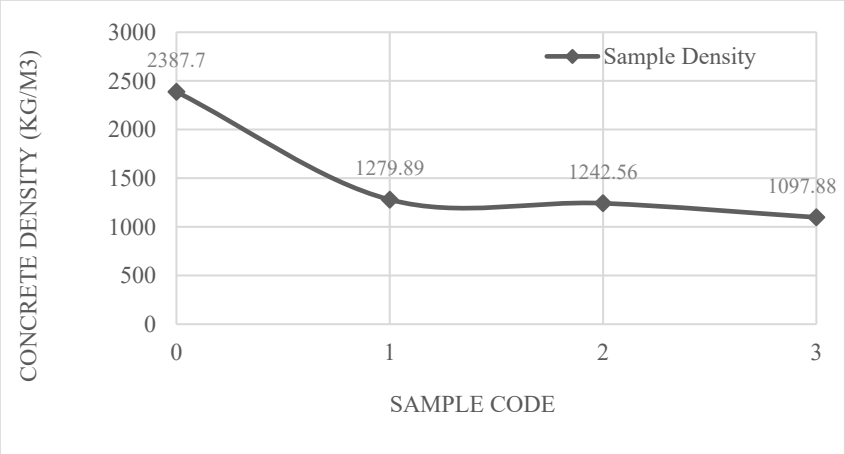


Figure 7: Density of 28-Day Concrete Samples

Concrete Flexural Strength Test

A total of 20 specimens were prepared for the flexural strength test, comprising 5 specimens for each mix ratio. The results presented in Figure 8 demonstrate the flexural strength development of various concrete mix variations after 28 days of curing. A subtle trend can be observed, in which slight increases in Styrofoam content correspond to marginal improvements in flexural strength; however, the overall values remain considerably low. This pattern suggests that while Styrofoam may moderately influence certain mechanical properties of lightweight concrete, its effect on flexural performance is minimal and, in many cases, detrimental. The integration of Styrofoam beads into the concrete mix leads to the formation of numerous air voids within the matrix, significantly lowering the material's density—a favorable characteristic for reducing dead loads in structural design (Mahmoud et al., 2023; Rathika et al., 2023).

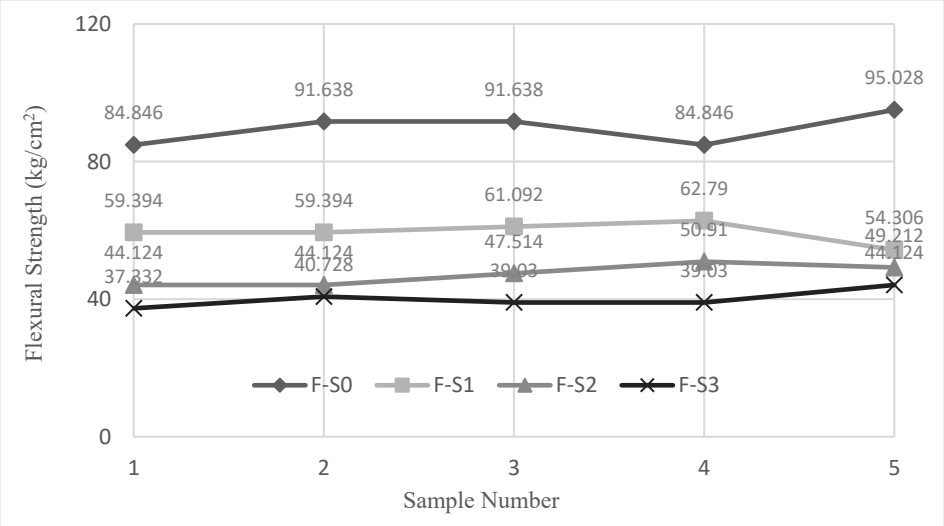


Figure 8: Tensile Strength of 28-Day Concrete Samples

However, this reduction in density comes at the cost of compromised structural integrity, particularly in terms of flexural resistance. The soft, non-rigid nature of Styrofoam, combined with the presence of internal voids, weakens the bond between the cement paste and aggregate particles, diminishing the concrete's ability to resist bending stresses (P. Kumar et al., 2023; Solikin et al., 2019). Empirical studies have shown that high Styrofoam content—especially in mixtures where it replaces 50% or more of the volume—results in markedly reduced flexural strength, thus limiting their application mainly to non-structural or insulation purposes (Srividya et al., 2022). In this study, conventional concrete exhibited superior flexural strength values ranging from 84.84 kg/cm² to 95.03

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kg/cm² at 28 days. In contrast, the mix with the highest Styrofoam content (sample F-S3 with a ratio of 1PC:1.25Sand:2.75Styrofoam) showed a significant drop in flexural strength, recorded in the range of 37.33 kg/cm² to 44.12 kg/cm². This stark contrast underscores the critical trade-off between density reduction and mechanical performance, highlighting the importance of careful optimization of Styrofoam dosage in structural concrete. Although the use of Styrofoam is advantageous for achieving lightweight properties, the negative implications on flexural strength must be addressed—potentially through refined mix design and supplementary reinforcement strategies.

Acoustic Performance Test Results 10 cm Thickness

Acoustic testing of lightweight concrete specimens incorporating varying proportions of Styrofoam was conducted in a controlled laboratory environment to evaluate their sound absorption and sound insulation capabilities. The tests focused on determining both the Sound Absorption Coefficient (SAC) and the Sound Transmission Loss (STL) of concrete panels, each measuring 10 cm in thickness. Three distinct concrete mixtures, identified as A-10-S1, A-10-S2, and A-10-S3, were formulated with increasing Styrofoam content, while a reference sample, A-10-S0, was prepared using conventional aggregate (split) with no Styrofoam. As shown in Table 8, these composition variations were designed to investigate the effect of lightweight porous fillers on acoustic performance under standardized conditions (Fediuk et al., 2021).

Table 8: Sound Absorption Coefficient of 28-Day Concrete Samples (10 cm Thickness)

Sample Code	Sample Ratio	Frequency (hz)							
		250	500	1000	2000	4000	8000	9000	10000
A-10-S0	1PC:2Sand:0Sty	0.01	0.11	0.05	0.12	0.07	0.13	0.10	0.11
A-10-S1	1PC:2Sand:3Sty	0.06	0.53	0.21	0.31	0.21	0.24	0.22	0.26
A-10-S2	1PC:1.5Sand:2.5Sty	0.05	0.16	0.28	0.16	0.25	0.15	0.20	0.24
A-10-S3	1PC:1.25Sand:2.75Sty	0.08	0.65	0.25	0.36	0.23	0.18	0.23	0.28

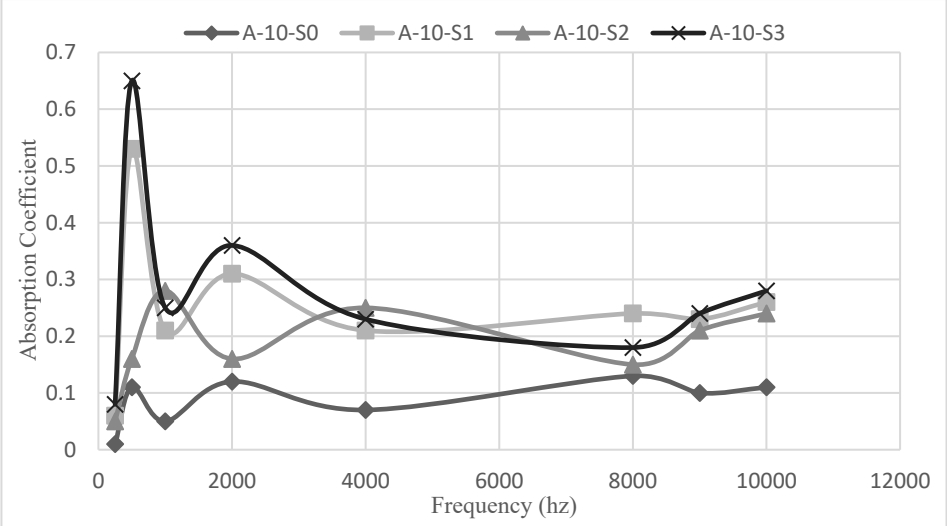


Figure 9: Sound Absorption Performance of 28-Day Concrete Samples (10 cm Thickness)

The results, presented in Figure 9, revealed a strong correlation between increased Styrofoam content and improved sound absorption performance. Among the tested samples, A-10-S3, containing the highest Styrofoam content (1PC:1.25Sand:2.75Sty), exhibited the highest absorption coefficient, peaking at 0.65 at a frequency of 500 Hz—indicating a significant acoustic response within the mid-frequency range. In contrast, the control sample A-10-S0, composed of 1PC:2Sand:3Sty, displayed minimal acoustic effectiveness due to the absence of porous or damping components like Styrofoam. Meanwhile, samples A-10-S1 and A-10-S2, with intermediate Styrofoam volumes, demonstrated moderate absorption peaks at 0.16 and 0.53 respectively at the same frequency. These results confirm that the inclusion of Styrofoam enhances sound absorption in lightweight concrete, particularly within low to mid-frequency ranges, due to the increased internal porosity and air void content introduced by the expanded polystyrene material (Fediuk et al., 2021).

Acoustic Performance Test Results 15 cm Thickness

As reflected in Table 9, the acoustic performance of 15 cm thick lightweight concrete samples reveals that increasing material thickness does not consistently result in higher sound absorption coefficients, particularly at higher frequency ranges. Although it is commonly assumed that thicker materials provide superior acoustic insulation, the results suggest otherwise—indicating that thickness alone is not the dominant factor. For instance, mixtures with higher porosity due to Styrofoam inclusion may outperform thicker but denser samples with fewer air

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voids. This implies that internal composition and material structure play a more critical role than sheer thickness in enhancing acoustic properties. The observation aligns with prior studies that emphasized the importance of pore structure and distribution in facilitating energy dissipation from incident sound waves (Cai et al., 2018).

Table 9: Sound Absorption Coefficient of 28-Day Concrete Samples (15 cm Thickness)

Sample Code	Sample Ratio	Frequency (hz)							
		250	500	1000	2000	4000	8000	9000	10000
A-15-S0	1PC:2Sand:0Sty	0.01	0.1	0.01	0.12	0.05	0.16	0.1	0.11
A-15-S1	1PC:2Sand:3Sty	0.063	0.67	0.21	0.42	0.21	0.31	0.23	0.3
A-15-S2	1PC:1.5Sand:2.5Sty	0.07	0.32	0.28	0.33	0.25	0.27	0.21	0.28
A-15-S3	1PC:1.25Sand:2.75Sty	0.085	0.73	0.25	0.46	0.23	0.35	0.24	0.31

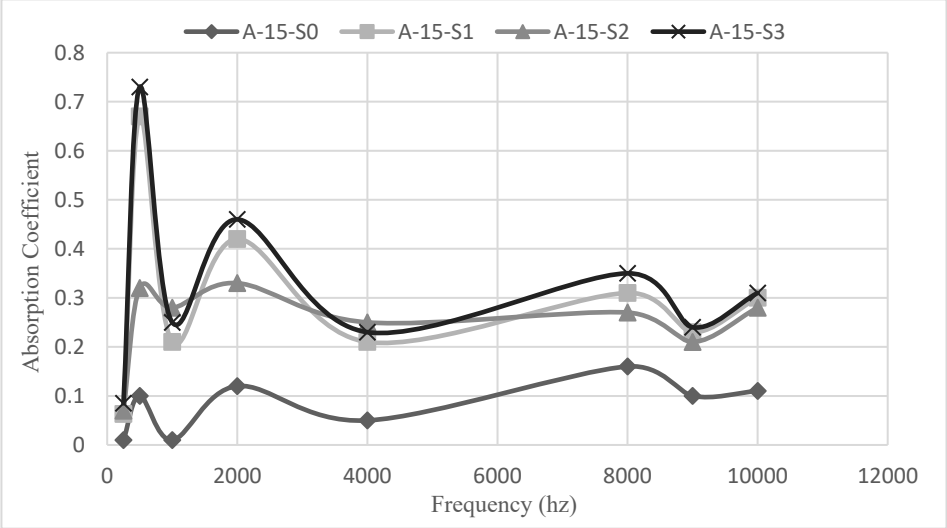


Figure 10: Sound Absorption Performance of 28-Day Concrete Samples (15 cm Thickness)

As shown in Figure 10, among the 15 cm thick samples, the mixture variation of 1PC:1.25Sand:2.75Sty (sample A-15-S3) yielded the highest sound absorption coefficient, peaking at 0.73 around 500 Hz—an important low-frequency range relevant to typical indoor environments. This improvement is attributed to the enhanced pore content from the increased styrofoam ratio, which elevates the material's ability to dampen sound through greater internal friction and scattering. Additionally, the absorption performance remained consistently strong across a broad frequency spectrum of 500 Hz to 2000 Hz, with values ranging from 0.46 to 0.73, making this mix suitable for use in residential or office interior walls. Sample A-15-S1 also showed commendable absorption (0.42–0.67), while A-15-S2 displayed moderate effectiveness (0.32–0.33) in the same

frequency range. These results reinforce the understanding that while thickness may contribute to increased acoustic mass, it is the synergy between porosity and material composition that ultimately governs sound absorption performance, particularly in low-frequency domains (Cai et al., 2018).

CONCLUSIONS

This study has demonstrated that incorporating Styrofoam into lightweight concrete mixtures significantly reduces the material's density, classifying it as lightweight concrete with fresh concrete weights ranging from 1000 to 1300 kg/m³. The densest mix was observed in the composition of 1PC:2Sand:3Sty, yielding a fresh concrete density of 1279.89 kg/m³, while the lightest mix, 1PC:1.25Sand:2.75Sty, exhibited a density of 1097.88 kg/m³ (Mahmoud et al., 2023; Rathika et al., 2023). This reduction in weight is directly attributed to the high Styrofoam content, which introduces numerous internal air voids.

The compressive strength results revealed that the mix ratio of 1PC:2Sand:3Sty achieved the highest strength (98.99 kg/cm² at 28 days), but all Styrofoam-modified mixes showed lower compressive strength compared to conventional concrete, which reached 149.33 kg/cm² (Rathika et al., 2023; Srividya et al., 2022). The mix with the highest Styrofoam content (1PC:1.25Sand:2.75Sty) displayed the lowest compressive strength at 66.75 kg/cm². These results underscore that while Styrofoam-modified concrete demonstrates promising lightweight characteristics, its compressive strength remains inferior to normal concrete, limiting its potential for structural applications.

In terms of flexural strength, the highest Styrofoam content mix (1PC:1.25Sand:2.75Sty) showed the lowest flexural strength, ranging from 37.33 to 44.12 kg/cm², which is significantly lower than conventional concrete's range of 84.84–95.03 kg/cm² at 28 days (P. Kumar et al., 2023; Solikin et al., 2019). This reduction in flexural strength is attributed to the presence of Styrofoam's internal voids, which weaken the bond between the cement paste and aggregate particles, diminishing the material's ability to resist bending stresses. Therefore, while Styrofoam-modified concrete is advantageous for reducing dead load, its mechanical performance, especially in flexural strength, limits its application to non-structural uses.

Acoustic performance tests revealed that the integration of Styrofoam into the concrete mix significantly enhanced sound absorption. For 10 cm thick samples, the sound absorption coefficient peaked between 0.53 and 0.65 at 500 Hz, while for 15 cm thick samples, the absorption coefficient reached up to 0.73, particularly in the 500-2000 Hz range (Fediuk et al., 2021). These improvements are attributed to the increased internal porosity and air voids introduced by Styrofoam, which facilitate better sound dampening. The highest absorption values were observed in the 1PC:1.25Sand:2.75Sty mix, demonstrating the

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effectiveness of higher Styrofoam content in enhancing the material's acoustic properties.

In conclusion, lightweight concrete with high Styrofoam content and a thickness of 15 cm is suitable for non-structural applications such as partition walls in residential and office buildings, due to its reduced weight, improved sound absorption, and ease of handling. However, to address its mechanical limitations, especially in terms of flexural strength, future research should explore the integration of reinforcing elements like steel fibers or alternative natural/synthetic fibers. These developments could enhance the material's strength without compromising its acoustic performance, potentially expanding the application of Styrofoam-based lightweight concrete beyond non-structural elements.

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A CONCEPTUAL FRAMEWORK PERFORMANCE OF IBS PRACTICES IN CONSTRUCTION PROJECT- A PLS-SEM APPROACH

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Abstract

In Malaysia, the Industrialized Building System, or IBS, was introduced in 1963. However, the level of acceptance and performance of IBS practices among stakeholders remains relatively low compared to developed countries, despite the government's recommendation of 70% IBS usage in government projects and 50% in private projects. This study aims to develop a PLS-SEM model and to evaluate the performance of IBS practice in construction projects to replace conventional method. A quantitative research approach was adopted, where survey data from 120 participants were collected and analysed using Smart PLS software. The environment had the highest content validity (AVE) score of 0.601, according to the model evaluation, which showed adequate convergent validity and significance. Not only that, the analysis also showed that technology, organization, and environment significantly influence by the effectiveness performance of IBS practice in construction projects. The findings of this research provide valuable insights that can contribute to improving IBS practice performance in the construction industry. The performance of IBS can reduce construction waste, minimize workers and contribute significantly among contractors.

Keywords: Relationship, Construction, IBS, Performance, PLS-SEM

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INTRODUCTION

The construction sector in Malaysia plays a crucial role in the country's journey toward becoming a developed nation. The rapid advancement of technology has transformed the industry, promoting sustainable construction practices that significantly impact social activities. Industrialised Building System (IBS) is regarded as a workable option for contemporary building projects (Irwan Hafizy Md Arif et al., 2020). However, the Malaysian construction industry faces significant challenges in meeting the demand and supply of both low-cost and affordable housing while integrating sustainable construction and green technology. Conventional construction methods appear insufficient to address the growing demand, necessitating the adoption of innovative approaches (Abd Rashid et al., 2018).

The construction industry serves as a cornerstone of economic development, and the strategic integration of advanced technologies like Industrialised Building Systems (IBS) stands as a potent catalyst for progress. The government has mandated the use of the Industrialized Building System (IBS) for government projects valued at RM100 million and above, requiring a minimum IBS score of 70%. It has also been established that modular coordination is a norm in building design (MOF, 2020).The government has actively promoted the adoption of the Industrialized Building System (IBS) among contractors through initiatives such as IBS professional training programs and levy exemptions. Despite being a well-established idea, IBS is valued for its ability to decrease dependency on foreign workers, speed up essential building projects, and be applicable in different places.

As a result of the Malaysian construction industry's necessity of moving from traditional building methods to IBS technology in accordance with the Construction 4.0 Strategic Plan 2021–2025, IBS has become one of the possible innovations and commercial ventures (Thomas Tarang et al., 2022). IBS has many benefits for stakeholders, but remains with challenges and limitations because IBS is not fully adopted in construction projects (Abdul Rahim & Latif Qureshi, 2018a). The most significant challenges that hinder the use of IBS are the lack of professionals experienced in IBS systems, high costs, complex regulations in implementing IBS and the difficulty in switching from conventional to IBS systems. Investing in training and capacity building programs to equip construction professionals with the necessary expertise to implement IBS construction practices effectively (Yusop et al., 2024).

IBS practices is defined as a method for thorough integration of system; components are manufactured in a factory and assembled on site (Syafiq Bahrin Bin Samsi1 et al., 2024). Nowadays, along with the progress of global technology, the perception of the world and the direction of development are changing. This, in turn is increasingly focused on sustainable development. This trend can be seen in every aspect of contemporary live and is linked with the shift

of demands and expectations that society puts on people (Przesmycka & Wieczorek, 2021). The building industry in Malaysia is crucial to make IBS practices work well and can change the construction field from industrial revolution 1.0 to 4.0. To improve IBS practice guidelines is key to boost sustainability and make IBS practice more effective (Riazi et al., 2020).

In Malaysia, prefabrication technology is referred to as the Industrialized Building System (IBS), which is defined as a comprehensive construction process in which most structural components are manufactured either on-site or off-site. These components are then transported to the construction site and assembled with high-precision coordinated connections, ensuring high-quality workmanship and expediting project completion. The benefits of prefabrication have made it possible for housing ministries in a number of nations, including the US, UK, Australia, Singapore, Hong Kong, and Malaysia, to satisfy the rising demand for housing (Nor et al., 2014). IBS tech helps local and global research a save cost, time, and product quality. Construction 4.0 strategic plan for 2020-2025 pushes builders to use new and clever building methods. This move shows the Malaysian government wants to tackle the IBS issue (Zuhairi Abd Hamid; et al., 2020). The practice of IBS is an alternative to overcome challenges in construction projects (Rahim et al., 2020). Conflicts often occur throughout the life cycle of a construction project. This is due to several issues such as project cost overrun, time and product quality (Khahro et al., 2015). IBS emerged as a sustainable approach in design and has been developed as a transformative approach in construction projects. Industrialized Building System is a new age construction technology that imbibes on technicalities and efficiency. Further, it is crucial to increase competitiveness to increase construction productivity in concerning quality, price, safety, and the minimization of construction waste (Al-Awag et al., 2023). In Malaysia, Construction Industry Development Board (CIDB) defines Industrialised Building System (IBS) as a construction technique in which components are manufactured in a controlled environment (either onsite or offsite), then transported, positioned and installed into a structure with less additional onsite works.

IBS contributes many benefits including labour reduction, cleaner and neater sites, easy installation, fast completion, enhancement of quality finished products and flexibility. Construction industries in countries like Singapore and Malaysia have shifted the construction methods from conventional to prefabrication (Abdul Rahim & Latif Qureshi, 2018b).

However, the IBS performance is still far from being satisfactory. Thus, the Malaysian government always supports the implementation of IBS in construction activities as a measure to replace traditional methods. IBS has a critical role in enhancing as well as in the development of the construction sector. Another disadvantage of IBS is lack of conformity to the option of dealing with

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the challenge of high demand and supply. Its adoption indirectly aids in the development of the Malaysian economy (Jing Le & Zainal, 2021). Several factors are involved in construction industry in Malaysia include planning, design, conservation and overhaul of various types of constructions developed that comprises civil works and several technologies. However, it must be understood that this still remains derivative of the conventional process. Hence the following is defined as an innovation and sustainable in developing IBS technology for IR 4.0, in cognizance of the current trend in developing IBS technology. In this regard, this paper seeks to find out the relationship between IBS practice and performance of contractors in construction projects. In order to achieve this aim, the study was conducted with the following objectives. The first objective is to evaluate the performance of IBS practices among IBS contractors in construction projects. The research process included defining problem statements, addressing research gaps, and identifying important topics in order to achieve this. As part of this process, a comprehensive literature review was conducted to refine the study's focus, including an analysis of the design and instruments used in previous studies.

The second objective of this study is to develop a Partial Least Squares Structural Equation Modeling (PLS-SEM) model performance IBS practices among IBS contractors in construction projects. Expert validation was carried out as a pre-test of the created instrument in order to accomplish this. A pilot study was conducted to evaluate the questionnaire's validity and reliability preliminary to the main survey. It serves as an initial assessment of the instrument, ensuring that it is robust and suitable for the actual study. Based on the suggested questions, the questionnaire was given to respondents in order to evaluate the study variables' dependability. Data analysis was conducted using SmartPLS version 3.3.3, which was employed to generate the hypothesized relationships. A reliable analytical method for creating and evaluating novel theoretical models is partial least squares structural equation modelling, or PLS-SEM. Additionally, the measurement model and the structural model are the two main assessments that constitute the PLS-SEM model. However, this study focuses exclusively on evaluating the measurement model.

LITERATURE REVIEW

The construction sector, based on the IBS system, is one of the innovations in construction technology today. The Construction Industry Development Board (CIDB) has organised various educational and promotional programmes to promote IBS practices for sustainable development projects and the latest technology prefabrication. This initiative aims to support to support the performance of IBS practices to replace conventional practices. With IBS practices, contractors can execute projects quickly and eco-friendly construction environment. The construction sector plays a key role in the country's growth. So,

it is crucial that it delivers work that meets customer needs in quality and how sites are run. This means sticking to what's laid out in the specs (Jaffar & Lee, 2020).

The IBS research trend is to measure the performance of IBS practices against the demand and supply of IBS components in construction projects. Global technology and standardisation are changing conventional construction industry practices to IBS systems. This has influenced the environment, land conditions, and skills to meet the demands of various building construction categories towards sustainable technology (Ismail et al., 2018). The transition from conventional building methods to hybrid Industrialised Building Systems (IBS) involves multiple stages. The government's IBS strategy, introduced in 1960, initially gained little traction within the industry. However, significant changes occurred in 2008 when the government mandated the use of IBS in public construction projects. According to statistical analysis from IBS surveys conducted in 2003 and 2008, steel frame systems have become widely used in the construction industry. Malaysia may advance in the transformation of the IBS construction industry by investing more resources in automation and robotics technologies, when the government assumes accountability for this issue. By departing from the size into multiple parts and having strong capabilities in IBS component development, IBS manufacturing is able to transport IBS components more economically (Riazi et al., 2020). The rapid pace of technological modernization today has changed the world's industrial landscape. Industrial Building System (IBS) can be utilized as a pilot project for industrial construction by applying the use of robotic technology in the production of components first, as a move toward the Fourth Industrial Revolution in the construction industry (Irwan Hafizy Md Arif et al., 2020).

The performance of IBS use practices to a system applicable today’s demand and supply of IBS. These factors are critical to labor in the production of components, robotics and automation, transportation to enable accomplishment of the work process and the construction of the building needs to be fast. The CIDB Construction Industry 4.0 strategic plan 2020-2025 of the Construction Industry Industrial Development Board, CIDB thus highlighted that construction players should embrace an innovative and creative construction method. Thus, it demonstrates that the Malaysian government has a positive attitude towards solving the More information regarding IBS problem. Problems in practice of construction managerial practices like delays, poor productivity and lack of good practice performance are indicative that IBS projects should seek other management strategies for improving IBS project performance (Rahim et al., 2020). The IBS system is prominent and is considered a contemporary construction technique that emphasizes efficiency and technicality. As part of this it also focuses on the degree of competition to enhance the performance of construction in terms of quality cost and safety as well as the wastage of resources

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in the construction sector (Al-Awag et al., 2023). It is because, the Malaysian government often suggest that IBS should be used instead of conventional method in conducting construction activities. Hence, IBS has great value in supporting the development of the construction industry.

Organizational characteristics encompass various aspects of organizations that operate under different circumstances, including work scope, company size, and management approaches in IBS project practices. This perspective emphasizes how important organizational elements serve the purpose of fostering innovation in IBS initiatives, especially in light of Industry 4.0's continuous change (Irwan Hafizy Md Arif et al., 2020). Productivity in an organization is a system of interrelated components that includes continuous process improvement, overall quality management, and the project life cycle. These elements collectively support the industry's ability to enhance innovation productivity and meet the evolving market demands in line with current trends (Qin et al., 2020). As a result, this study highlights three organizational elements that are crucial to the success of IBS projects which are internal stakeholders, organizational resources, and organizational creativity.

The environment is defined as an attribute that enhances IBS performance practices in the construction industry. IBS systems have many benefits in the environment such as the generation of construction waste, the use of recycled or renewable materials (Yunus et al., 2019). In this context, "environmental" refers to external factors that affect a business's capacity to apply sustainable innovation in building projects. It shows how organizations react to opinions about procedures, difficulties, and business concerns, leading to logical conclusions based on past performance and societal justification. This study is classified into three parts: government policy, IBS popularity in the construction industry, and competition from other companies. The construction industry's embrace of information technology is significantly supported by government policies. The Construction Industry Development Board (CIDB) has established policies mandating the government’s role in ensuring IBS project performance. For instance, the government requires that commercial projects accomplish at least 50% IBS implementation, while all public projects must reach at least 70% (Yusof et al., 2024). The government’s role is also essential in enforcing regulations that drive industry stakeholders to take proactive and innovative measures for sustainable project delivery. These efforts serve as a source of productivity which aligning with the goals of Industry 4.0 transformation (Roslan, 2022).

The government has put in place a policy where each project is required to achieve a minimum level of 70% IBS use and 50% IBS use in private projects (Yusof et al., 2024). The role of the government is very important to see the extent to which regulations are required to ensure that each party involved in the IBS project takes active and innovative steps towards sustainable delivery and

productivity drivers towards industrial revolution 4.0. (Roslan, 2022). The conceptual model demonstrates the direction of the research investigation by demonstrating the direct and direct relationship between the research variables. The research model depicted in figure 1 embodies technology, organizations that have IBS practice performance in construction projects. The model also includes three projected hypotheses with arrows indicating the hypothesized relationships.

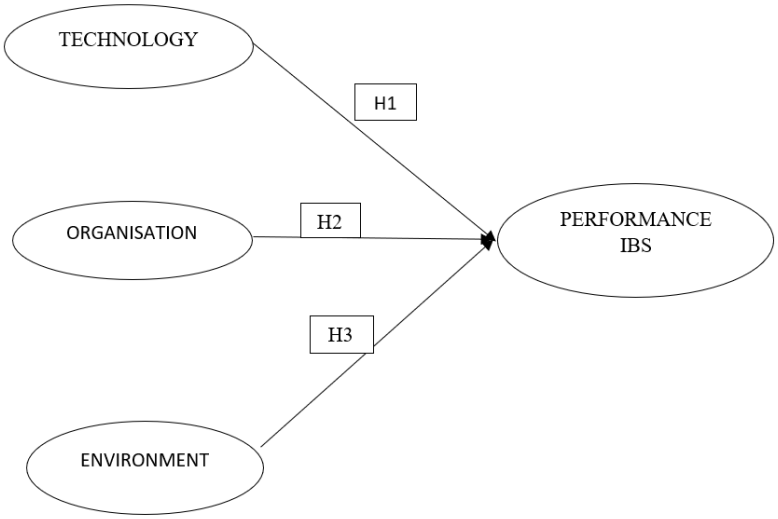


Figure 1: Conceptual Framework

H1: There is a significant relationship between technology utilisation and the construction period on-site, as high costs are required for ordering formwork, machinery, and transportation for the installation of IBS components. Not only that, many contractors also find it difficult to switch from traditional methods to IBS, which is a significant issue in IBS practice.

H2: There is a significant relationship between an organisation's utilisation of resources such as knowledge and skills in IBS to enhance productivity, compete with developed countries, and gain internal support through social factors.

H3: There is a significant relationship between the environment, government policies, popularity, and competition from various conditions. The environment, governmental regulations, public opinion, and competition from different circumstances are all significantly correlated. One of the major environmental advantages of IBS methods is reducing construction waste. Additionally, government regulations also play a role to the development of information technology in the building sector.

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RESEARCH METHODOLOGY

This study uses a quantitative approach through a questionnaire survey. The instrument used in the study is a questionnaire. The instruments used must meet the criteria of reliability and validity (Sanchez-Franco & Roldán, 2010). An expert panel was interviewed to validate the developed instrument, providing evidence of its reliability and content validity. The insights and contributions of these experts played a crucial role in refining the instrument before distributing the questionnaire to respondents. The validity of the instrument was further strengthened by conducting a pilot test to find any potential flaws and improve reliability. The expert panel comprised individuals with extensive experience in Industrialized Building Systems (IBS), ensuring the credibility of the validation process. A total of nine (9) expert panels were identified for instrument content validation. The panel of experts identified are experts in the field of civil engineering from various organisations, namely two (2) from the Public Works Department (JKR), three (3) from CIDB, and four (4) from private companies. The validation of the questionnaire, the number of responded regarded as sufficient for the pilot test is between 20 and 40. Hence 30 people responded to the questionnaire out of which 10 people had more than ten (10) years of experience in the field of IBS.

The data that was gathered was then examined through a reliability analysis test. This test supports that one has construct validity of the used instrument as well as the range within which Cronbach's alpha value should be more than 0.6 (Hair et al., 2019). As a result of the findings obtained in this study, all the reliability of the pilot test exceeded 0.600 as shown in table 1. This is evident in the instrument being the survey administered real with more confident respondents. This study employed a survey method, with five-point Likert scale as a tool. The major aim of the survey was to identify the participant of the respondents whereas the second part was intended to identify the performances of IBS for government construction projects.

Table 1: Reliability test for pilot test

Construct	Item	Alpha Cronbach
Time	3	0.642
Cost	4	0.810
Challenge	10	0.778
Resources	5	0.839
Productivity	6	0.889
Social cultural factors	8	0.918
Government Policy	6	0.935
Popularity	3	0.942
Clean environment	5	0.952

The survey was distributed to IBS contractors utilizing precast concrete in government construction projects. Selangor was chosen as the primary focus area because, compared to other states, it has the highest number of CIDB-registered contractors. According to CIDB statistics as of 2022, the state of Selangor registered a diverse range of IBS contractors across multiple system categories, including 602 contractors specializing in precast concrete systems, 2,218 in steel frame systems, 96 in formwork systems, and 42 in timber frame systems. Therefore, this study specifically focuses on the implementation of precast concrete systems within the state of Selangor. Moreover, personnel from the Construction Industry Development Board (CIDB) were also interviewed to provide a more comprehensive understanding and in-depth analysis of IBS performance among contractors using precast concrete in government construction projects.

120 survey questionnaires were distributed to contractors engaged in IBS projects via an email attachment or Google Forms (online self-administered web-based questionnaires). The completed questionnaires or forms were returned to us via the same method or submit to an email. The respondents involved in this research are the respondents are experienced contractors in IBS projects in Malaysia. This study focuses on contractors involving precast concrete in IBS projects in Selangor. From 120 questionnaires distributed, only 114 responses were received. Next, Structural Equation Modelling (SEM) used for analysis. Structured equation modelling (SEM) is a second-generation statistical analytic technique for investigating the interrelationships among various variables in a model (Zhang et al., 2020). The PLS-SEM technique is widely used in model development by researchers in various fields approach to investigate the factors influencing social network acceptance. In this research, the analysis used a single approach suggested (Hair et al., 2014) which focus on the assessment of measurement model only. Generally, the objective for evaluating the research model is to examine whether both measurement and structural meet the underlying quality criteria for empirical work (Hair et al., 2014).

RESULTS AND DISCUSSION

With the help of the questionnaire, 114 questionnaire forms were collected which were used for statistical analysis. The respondents participating in the survey had several level of academics background and experience level as summarized in Table 2.

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Table 2: Characteristics of the respondents

		Frequency	Percent	Cumulative Percentage
Company Grade	G1	5	4.3%	4.3%
	G2	5	4.3%	8.6%
	G3	8	7.0%	15.6%
	G4	2	1.7%	17.3%
	G5	8	7.0%	24.3%
	G6	10	8.7%	33.0%
	G7	76	67%	100%
Total	114	114	100%	
Experience	1-5 years	51	44.7%	44.7%
	6-10 years	26	23.0%	67.7%
	11-15 years	15	13.1%	80.8%
	>15 years	22	19.2%	100%
Total	114	114	100%	

PLS-SEM model analysis is a popular among researchers to evaluate measurement model for validating the relationships between reliability refers to degree to which a scale delivers consistent and stable (Hair et al., 2014). The analysis of the reliability and validity of the model measure was carried out through partial least squares-structural equation modelling (PLS-SEM) analysis by using Smart-PLS software application (Fatimah Hashim et al., 2023). This evaluation is crucial to ensure the validity of the measurement model before proceeding with any model checking or hypothesis testing. Thus, for this study, one of the expressed aims has to be the proof of construct validity which has to be confirmed by checking whether the measurement constructs exhibit a consistent pattern or not. Information about the construct validity can be derived from – Convergent – "Cronbach Alpha" and factor loadings Discriminant validity – AVE and last but not least measurement reliability.

PLS SEM Model Analysis: Internal Consistency Reliability and convergent validity

Cronbach's alpha, rho_A and composite reliability are secondary indicators of reliability. Mainly, the independent variables used in earlier research include most of the time CA, rho_A, and CR. CA is most often used when applying measurements to examine the internal consistency of the data collected. It gives a measure of reliability from the observed measures or items of an instrument or an assessment test. Though, theoretically, it is believed that CR provides a better measurement in internal consistency since when PLS algorithm is employed, a different standardisation is used of its items; however, CA is most often utilised for defining internal consistency reliability. A satisfactory value of Cronbach's alpha, CR, and rho_A is above 0.70. Nevertheless, a value of 0.60 and above is accepted because the value is close to 0.70 (Hair et al., 2019).

Table 3: Internal consistency reliability

Criteria	Alfa Cronbach	Rho_A	Composit Reliability
Organization	0.663	0.696	0.795
Environment	0.780	0.801	0.857
Performance IBS	0.611	0.621	0.776
Technology	0.710	0.723	0.811

Convergent Validity

The level of construct convergence was evaluated using 'Average Variance Extracted (AVE)' to examine the convergent validity of the measurement model. AVE is the arithmetic mean of all the individual indicator variances shown as a proportion of the overall variability in the construct (Salhi & Messaoudi, 2021). Convergent validity then refers to the closeness of each item that a construct has with the items that is measuring another construct. Regarding the method of analysing the convergent validity, according to (Sarstedt et al., 2022), it is to be averaged on the measure that is the value the variance extracted which a higher substantive aspect of the latent construct implies the greater degree of the explained variances of items. Therefore, it must explain in excess of 50% the AVE, (AVE $\geq$ 0. 500) in order to obtain a reasonable level of convergent validity, the defined item. During the research, the first enjoy of the PLS-Algorithm has indicated that all the construct's achieved an AVE value more than 0. 50, as is evident in Table 4, emphasizing that the value of each research construct's AVE is between 0. 465 and 0. 601 is higher than the standard value that is prescribed, according to which external loading should be at least 0. 600 and the better if it equals 0. 70. Other literature suggests that items with an external load between 0.400 and 0.700 can be maintained (accepted) if the CR and AVE values are higher than the threshold (0.70 for CR and 0.5 for AVE) (Hair et al., 2019) .The developed model is depicted graphically in Figure 2.

Table 4: Convergent Validity

Criteria	AVE
Organization	0.498
Environment	0.601
Performance IBS	0.467
Technology	0.465

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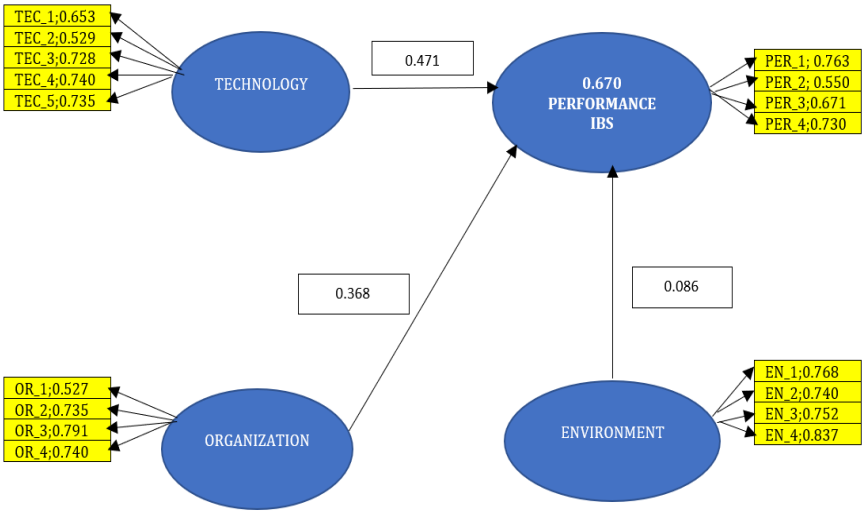


Figure 2: Results of Measurement Model

PLS SEM Model Analysis: Discriminant validity

Discriminant Validity

Discriminant validity on the other hand refers to the level of separation between the various dimensions of a research concept. It indicates the level of dissimilarity between one construct and the others within any given model. In Smart PLS 3.0, discriminant validity can be assessed using three main criteria: the Cross Loading Criterion, Fornell-Larcker Criterion, and the Heterotrait-Monotrait Ratio (HTMT). The cross-loading criterion for discriminant validity is met if the items loading is higher within their own constructs than on any other construct. Table 5 demonstrates that all indicators are appropriately loaded onto their respective constructs, confirming discriminant validity among all constructs. The results showed no significant issues with high cross-loadings between items.

Table 5: Cross Loading Result

Construct	Technology	Organization	Environment	Performance IBS
PER 1	0.474	0.361	**0.763**	0.613
PER 2	0.323	0.432	**0.550**	0.558
PER 3	0.556	0.412	**0.671**	0.396
PER 4	0.581	0.531	**0.730**	0.474
EN 1	0.379	**0.768**	0.454	0.528
EN 2	0.508	**0.740**	0.474	0.478
EN 3	0.527	**0.752**	0.386	0.430
EN 4	0.644	**0.837**	0.611	0.537
OR 1	**0.527**	0.264	0.329	0.236

Construct	Technology	Organization	Environment	Performance IBS
OR 2	**0.375**	0.518	0.447	0.436
OR 3	**0.791**	0.547	0.613	0.506
OR 4	**0.740**	0.517	0.562	0.480
TEC 1	0.437	0.449	0.569	**0.653**
TEC 2	0.370	0.417	0.343	**0.529**
TEC 3	0.391	0.428	0.486	**0.728**
TEC 4	0.313	0.439	0.510	**0.740**
TEC 5	0.539	0.454	0.594	**0.735**

Fornell-Larcker criterion. This criterion states that if need to demonstrate sufficient discriminant validity, the square root of the AVE for a particular construct must be higher than its correlation with any other construct (Hair et al., 2014). The results presented in Table 6 indicate that all constructs meet this requirement, demonstrating sufficient discriminant validity. This finding demonstrates the sufficient validity of the main constructs associated with IBS practice performance, such as technology, organization, and environment.

Table 6: Fornell-Larcker Criterion

	Organization	Environment	Performance IBS	Technology
Organization	**0.706**			
Environment	0.673	**0.775**		
Performance IBS	0.712	0.635	**0.683**	
Technology	0.608	0.640	0.750	**0.682**

The Heterotrait-Monotrait (HTMT) ratio is used to assess the correlation between constructs to determine discriminant validity. According to Hair et al. (2014), the value of HTMT value shows less than 1 which means the ration of correlations within the constructs to correlation between the construct is acceptable.

Table 7: HTMT Result

	Organization	Environment	Performance IBS	Technology
Organization				
Environment	0.894			
Performance IBS	1.086	0.904		
Technology	0.850	0.861	1.118	

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The HTMT value of the environmental construct to the organizational construct is 0.894. The HTMT value of the IBS performance construct against the organizational construct is 1.086, while the HTMT value of the IBS performance construct of the environment construct is 0.904. The HTMT value of the technology construct to the organization is 0.850. Next, the HTMT value of the technology construct to the environment construct is 0.861 and the HTMT value of technology to the IBS performance construct is 1.118. Therefore, it can be concluded that the construct measured is acceptable excepted HTMT value of the IBS performance construct against the organizational and HTMT value of technology to the IBS performance.

CONCLUSION

This paper reports on various factors that influence the effectiveness of IBS practices in construction projects to replace conventional practices. This study was conducted by developing the relationship between factors influencing the practices of IBS contractors. Data collection was carried out through questionnaire survey where 114 data samples were collection and analyzed with SmartPLS software. The evaluation model developed to study the effectiveness of IBS practices among contractors in construction projects revealed that technological factors such as time, cost and challenges while organizational factors such as resources, productivity, social and environmental factors such as government policy, popularity and orderliness. This study will help contractors understand effective practices in IBS construction projects to replace conventional practices.

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ETHICAL STATEMENT

This study obtained informed consent from all participants and was conducted in strict confidence. The authors declare that there are no conflicts of interest and confirm that the study is original, unpublished and not under consideration elsewhere.

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EVALUATING THE OCCUPATIONAL SAFETY AND HEALTH INSTRUMENTS FOR PREVENTION THROUGH DESIGN IMPLEMENTATION IN MALAYSIAN CONSTRUCTION

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Abstract

Prevention through Design (PtD) is a proactive approach widely practiced in developed countries to reduce construction-related accidents. In Malaysia, however, its implementation remains limited due to low awareness and understanding among practitioners. This study aims to explore and classify existing Occupational Safety and Health (OSH) instruments published by the Department of Occupational Safety and Health (DOSH) and the Construction Industry Development Board (CIDB), and to determine their alignment with PtD principles. A qualitative content analysis was conducted on official documents, and the instruments were grouped into three categories: technical documents, assessment tools, and digital tools. The findings shows that PtD elements are present in instruments such as the HIRARC framework and Building Information Modelling (BIM), though the level of integration remains inconsistent. By mapping this alignment, the study highlights the current readiness of these instruments to support PtD practices and provides a foundation for enhancing safety planning in the design phase, in line with the OSHCIM 2017 guideline.

Keywords: OSHCIM, Prevention through Design (PtD), OSH Instrument, construction, safety

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INTRODUCTION

Occupational safety and health (OSH) in the Malaysian construction industry continues to face significant challenges, particularly in managing risks during the early stages of project development. The persistently high accident rates on construction sites pose serious threats to worker safety, human resource sustainability, and overall project value due to the inherent hazards of site conditions (Jaafar et al., 2018). Despite the existence of safety procedures, policies, and regulations, the effectiveness of these measures remains questionable, as accident rates continue to rise prompting increasing concern from the Malaysian government (Nawi et al., 2016). In response, regulatory bodies such as the Department of Occupational Safety and Health (DOSH) and the Construction Industry Development Board (CIDB) have introduced several OSH instruments aimed at enhancing safety performance within the construction sector (Musarat et al., 2023). However, many of these instruments are still implemented reactively during the construction phase, rather than proactively integrated at the design stage where risks can be more effectively anticipated and mitigated.

To address this gap, DOSH has introduced the Occupational Safety and Health in Construction Industry (Management) Guidelines 2017, known as OSHCIM which represent a significant advancement by formally introducing the concept of Prevention through Design (PtD). PtD promotes the integration of hazard identification and elimination during the design phase, well before construction begins, offering a more proactive and effective approach to safety management. However, the adoption and operationalization of PtD within current Malaysian practice remain limited, with implementation still skewed toward the later stages of construction.

The present study aims to explore the common OSH instruments in Malaysia, specifically those published by the Department of Occupational Safety and Health (DOSH) and the Construction Industry Development Board (CIDB). It focuses on determining the alignment of each identified instrument with the PtD principles as outlined in the OSHCIM 2017 guideline. Based on this alignment, the instruments are then categorised to provide a clearer understanding of their role in supporting design-stage safety planning. This study contributes to the body of knowledge by mapping the presence of PtD elements across existing OSH instruments and offering insights into their current position within Malaysia's construction safety framework.

LITERATURE REVIEW

The Prevention through Design (PtD) principles as emphasized in the OSHCIM 2017, promotes the integration of hazard analysis and risk assessment at the early

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design stages of construction projects to reduce risks to an acceptable level (Sinha et al., 2021). The implementation of PtD has been widely adopted in several countries where it is mandated by law. For example, Singapore enforced the Workplace Safety and Health (Design for Safety) Regulations in 2016, while the European Union, Australia, the United Kingdom, and South Africa have also institutionalized similar requirements. In contrast, the adoption of PtD in the United States remains voluntary and varies depending on project or client requirements (Aires et al., 2016). In Malaysia, the implementation of OSHCIM began on a voluntary basis but DOSH has announced plans to mandate the integration of PtD principles, reinforcing its commitment to strengthening OSH standards across the construction industry.

By addressing hazards during the design phase, PtD helps to reduce accidents and injuries on construction sites (Gambatese et al., 2005). Study in Hong Kong also confirmed PtD's positive impact on safety performance, productivity, and project outcomes (Lam et al., 2006), while others have linked it to cost savings and improved quality (Howe, 2008). Early hazard identification not only improves safety outcomes but also lowers costs related to injuries and claims (Anderson & Galecka, 2013). In addition, PtD contributes to better constructability, worker morale, cost-efficiency, quality, and adherence to schedules (Karakhan, 2016). These research findings consistently highlight the vital role of PtD in raising safety standards and construction performance. Over time, PtD has proven to be a practical strategy for reducing work-related injuries and illnesses in the construction industry (Che Ibrahim et al., 2022).

It is notable that achieving a safe construction environment is complex and evolving goal that demands the concerted efforts of all project stakeholders. Active stakeholder participation has been widely recognized as a key factor in this process (Ismail et al., 2022). Additionally, effective hazard identification and risk assessment during the design stage are essential to support the successful implementation of OSH practices (Elkaseh et al., 2024). However, previous studies have shown that the use of formal risk assessment techniques in the Malaysian construction industry remains limited (Zaini et al., 2011). Furthermore, lack of regulatory enforcement and poor implementation practices continue to contribute to the risk of workplace accidents (Ayob et al., 2018). Addressing these challenges require a shift towards structured and proactive risk management approaches that begin at the earliest stages of design. In this context, the application of PtD during the planning stage of construction not only involves design-based strategies but also the integration of PtD into legislation, including relevant laws, regulations and guidelines (Samsudin et al., 2023).

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RESEARCH METHODOLOGY

This study adopted a qualitative research approach, which allowed for an in-depth exploration of OSH instruments adopted in the Malaysian construction sector particularly in relation to their alignment with PtD principles. The research process was guided by well-defined objectives and research questions aimed at understanding the extent to which current OSH instruments promote proactive design-stage safety planning.

To facilitate a comprehensive content analysis, data were sourced from both academic databases and official institutional websites. Specifically, Scopus, Web of Science and Google Scholar were utilized to retrieve peer-reviewed journal articles relevant to PtD frameworks, safety by design strategies, and international OSH practices. These databases were selected due to their broad coverage of reputable, indexed literature, and their advanced filtering capabilities. In parallel, a document search was conducted through the official institutional websites of the Department of Occupational Safety and Health (DOSH) (www.dosh.gov.my) and the Construction Industry Development Board (CIDB) (www.cidb.gov.my). These agencies were selected due to their credibility, regulatory authority, and established roles in OSH enforcement and promoting safety standards in Malaysia's construction sector. The search was conducted between January and April 2024, covering all publicly accessible guidelines, technical standards, management tools, and regulations relevant to construction safety.

A keyword-based search strategy was applied to identify relevant instruments. Keywords included: "OSH tools," "risk assessment tools," "safety guidelines," "construction safety," "OSH management," "design safety," and "Prevention through Design". Other search keywords were focused on the "Guidelines", "Publications," "OSH Management Systems," "Legislation,". The inclusion criteria required that materials be directly related to OSH practices in the construction sector and provide actionable insights for hazard prevention, risk minimization, or regulatory compliance. All identified documents were compiled into a structured database. For each item, metadata were recorded, including the document title, issuing agency, publication year, purpose and scope, target users, and relevance to PtD or other design-stage interventions. The instruments were then categorized and analyzed to evaluate their applicability to safety management in construction projects.

The next phase involved a focused content analysis to determine the presence, relevance, and level of integration of PtD concepts across the documents. This included evaluating whether the instruments explicitly or implicitly aligned with the PtD framework introduced in OSHCIM 2017. To aid interpretation, findings were tabulated into a PtD-OSH integration heatmap.

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To ensure the credibility of the findings, a validation phase was carried out through expert consultation. This involved a semi-structured review session with one senior officer from DOSH who possessed extensive experience in policy enforcement and two construction safety professionals with over 10 years of field experience in implementing OSH tools in safety design and site management. The experts reviewed the PtD–OSH integration heatmap and thematic summaries and were asked to assess the accuracy of categorization, the relevance of PtD elements, and to identify any missing or unclear items. Their feedback helped improve to refine the classification of instruments and confirm the overall interpretation of PtD integration in the reviewed documents.

ANALYSIS AND DISCUSSION

Prevention through Design Principles and Elements

To evaluate the extent to which Malaysian OSH instruments align with Prevention through Design (PtD) principles, seven (7) core PtD elements were identified from recent scholarly literature as shown in Table 1. These elements serve as the conceptual basis for integrating safety considerations during the design stage of construction project.

Table 1: Element of PtD

ID	PtD Element	Description	Author
PtD1	Hazard Identification at Design Stage	Early detection of potential hazards during conceptual and detailed design to allow proactive risk planning.	Hossain et al. (2023)
PtD2	Risk Elimination or Reduction	Eliminating or reducing risks through safer design choices, materials, and construction methods.	Zhou et al. (2023)
PtD3	Design for Safe Maintenance and Use	Ensuring long-term safety in access, maintenance, and eventual demolition of the structure.	Samsudin et al.(2022)
PtD4	Stakeholder Collaboration	Integrating input from clients, designers, engineers, and contractors to ensure coordinated safety decisions.	Che Ibrahim et al.,(2021)
PtD5	Lifecycle Safety Consideration	Addressing OSH risks across all stages from construction to use and eventual decommissioning.	Jin et al. (2023)
PtD6	Compliance with Legal and Industry Standards	Aligning designs with applicable OSH legislation such as OSHCIM, OSHA 1994, or CDM regulations.	(Him et al., 2023)
PtD7	Documentation and Communication of Safety Risks	Recording safety measures and residual risks in project documentation for contractor awareness.	(DOSH, 2017)

OSH Instruments regulated by the DOSH

Table 2 shows the eleven (11) OSH instruments in the form of documents which has been published and regulated by DOSH. Those documents categorized under Building Construction and Engineering Work, include eight (8) guidelines (D1, D2, D3, D4, D6, D7, D8, D10) and three (3) supplementary resources (D5, D9, D11) such as best practice manuals and spreadsheet-based calculation tools. All documents were in English, except for D10, which was published in Malay. These instruments were developed in alignment with the Occupational Safety and Health Act (OSHA) 1994 which aim to enhance safety compliance, reduce accident rates, and instil a culture of proactive risk management in the Malaysian construction industry. For example, the Guidelines for the Prevention of Falls at Workplaces (2007)-D3, were published in response to alarming fatality rates involving falls from height, which accounted for 51.97% of 229 fatal cases between 1996 and 2005 (Murty et al., 2006). This document guides employers, particularly contractors, on designing and implementing fall prevention strategies at the design stage. Nevertheless, despite the availability of such resources, fatal injuries particularly among foreign workers remain frequent, with primary causes linked to falls, being struck by objects, and unsafe worker actions (Rafindadi et al., 2022). These findings suggest a gap between guideline availability and effective on-site implementation, often influenced by factors such as cost constraints, job complexity, lack of protective measures, and pressure to meet deadlines (Hamid et al., 2019).

Table 2: Documents published by DOSH

ID	Name of Documents	Year	Summary of Content
D1	Guidelines on Occupational Safety and Health in Tunnel Construction	1998	Outlines safety procedures in tunnel construction, focusing on ventilation, emergency preparedness, and confined space safety.
D2	Guidelines on Trenching for Construction Safety	2000	Details trenching hazards and control measures such as shoring and soil stability assessment to prevent collapses.
D3	Guidelines for the Prevention of Falls at Workplaces	2007	Presents fall prevention strategies, including PPE use, safe access routes, and risk management for work at height.
D4	Guidelines for Public Safety and Health at Construction Sites	2007	Covers site control measures for public protection, including barriers, signage, and hazard communication.
D5	Calculation Loading of Scaffolding	2016	Provides methods for calculating scaffold loading to ensure structural safety during construction.
D6	Guidelines for Approval of Design Scaffolding	2016	Specifies submission and approval procedures for safe scaffold design in line with regulatory requirements.

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ID	Name of Documents	Year	Summary of Content
D7	Guidelines of Occupational Safety and Health in Construction Industry (Management)	2017	Introduces PtD principles and stakeholder responsibilities for safety planning and OSH management.
D8	Guidelines of Occupational Safety and Health in Construction Industry (Excavation Work)	2017	Focuses on excavation safety, including hazard identification, control strategies, and protective systems.
D9	Best Practices on Occupational Safety and Health in Construction Industry	2019	Compiles effective OSH practices in construction, emphasizing continuous improvement and leadership commitment.
D10	*Garis Panduan Keselamatan dan Kesihatan Pekerjaan Industri Pembinaan (Pengurusan*)	2020	Malay-language OSH management guideline mirroring OSHCIM principles for local implementation.
D11	Guidance on Safe Use of Mobile Access Tower	2023	Details safe use procedures for mobile access towers, focusing on stability, assembly, and fall protection.

Source: (DOSH, 2024)

Additionally, the Hazard Identification, Risk Assessment and Risk Control (HIRARC) model is one of key framework published by DOSH. HIRARC enables the systematic identification and evaluation of workplace hazards based on their likelihood and severity. It supports risk mitigation strategies consistent with PtD principles and fulfils the legal obligation under OSHA 1994, which mandates employers to provide a safe working environment. The application of HIRARC encourages structured planning, early hazard recognition, and the prioritization of controlling key components of effective design-stage safety integration. The HIRARC model is a general guideline that been referred and adopted by all sectors including construction.

OSH Instruments based on CIDB

Out of thirty (30) Construction Industry Standards (CIS) published by the Construction Industry Development Board (CIDB) which covering diverse construction aspects and processes, a total of fifteen (15) CIS covered on the design, safety and health aspects as shown in Table 3. Mainly, these standards were published in English languages to ensure uniformity in construction practices and establish measurable benchmarks across the industry.

Table 3: CIS in relation to improve OSH practices

CIS	Title	Year	Summary of Content
CIS 8	Design Guide on Precast Concrete Hollow Core Slab	2007	Guidelines for the design and application of hollow core precast concrete slabs in building construction.
CIS 9	Guidelines On Handling, Transportation, Stacking and Installation of Precast Concrete Components	2023	Standards for safe handling, stacking, and installation of precast elements to avoid structural damage and ensure safety.
CIS 10	Safety And Health Assessment System in Construction (SHASSIC)	2020	A tool to assess contractors' safety and health performance through documentation, site inspection, and interviews.
CIS 11	Design Guide on Precast Concrete Frame with Moment Connection	2008	Design procedures for structural precast concrete frames with moment-resisting connections.
CIS 13	Guidelines On Handling, Transportation, Stacking and Installation of Structural Steel	2023	Procedures for handling and installing structural steel to ensure safe assembly and site practices.
CIS 14	Guidelines On Construction Works at Night	2019	Safety measures for night construction, including lighting, noise management, and worker visibility.
CIS 15	Guidelines On Prevention of Fall at Construction Site	2019	Prescribes fall protection systems, work-at-height protocols, and hazard control strategies.
CIS 16	Guidelines For Works at Confined Space in Construction Site	2019	Instructions for confined space entry, including air monitoring, permits, and emergency procedures.
CIS 17	Guidelines For Working at Noisy and Dusty Areas in Construction Site	2010	Health protection measures against excessive noise and dust, with emphasis on PPE and control systems.
CIS 22	Product Conformity for Used Scaffolding in Construction	2023	Criteria for evaluating and certifying the safety compliance of reused scaffolding equipment.
CIS 23	Product Conformity for Falsework in Construction	2023	Standards for the design, material, and reuse of falsework systems in construction.
CIS 24	Industrialised Building System (IBS) Assessment & Certification	2023	Provides assessment metrics for IBS adoption, supporting industrialised construction practices.
CIS 25	Construction Activities Risk Assessment (CARA) Hazard Identification, Risk Analysis and Risk Control (HIRARC)	2018	Framework for hazard identification, risk assessment, and risk control in construction activities.
CIS 27	Occupational Safety and Health – Specification &Bill of Quantities (BQ) for Construction Works	2019	Guidance on including OSH specifications in tender documents and bills of quantities.
CIS 28	Public & Road User Safety – Construction Works Adjacent to and Above Roadways	2021	Guidelines for protecting public and road users during nearby or overhead construction works.

Source: (CIDB, 2023)

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Additionally, CIDB advocates the adoption of Building Information Modelling (BIM), an innovative digital tool that enhances collaboration and hazard identification during the design phase. BIM supports key safety functionalities such as visualization, simulation, and clash detection, enabling designers to integrate safety solutions into the project lifecycle. BIM's role in improving safety planning, inspections, and communication is well documented (Yap et al., 2023), with evidence suggesting it can significantly reduce workplace incidents and fatalities.

Integrating PtD Elements in the OSH Instruments

An extended content analysis was conducted to evaluate the existent of Prevention through Design (PtD) principles which are embedded and aligned with the OSH instruments identified in this study. The analysis focused on four (4) main instruments: DOSH-published guidelines, CIDB-published Construction Industry Standards (CIS), the HIRARC framework, and Building Information Modelling (BIM).

The DOSH-published guidelines targeted safety measures and procedures that align with PtD principles. These documents guide practitioners in conducting risk assessments, planning safe work environments, and documenting safety procedures. Although CIDB-published CIS do not explicitly mention the PtD principles, the detailed work methods and preventive measures encourage practitioners to incorporate safety considerations into the planning and execution phases. Overall, the DOSH-published guidelines emphasize continuous improvement in safety practices, reflecting the foundational principles of PtD. Similar to the CIDB-published CIS documents which complement the OSHCIM guideline by offering technical specifications for safe construction practices, thus reinforcing the importance of early-stage safety planning. Together, the DOSH-published guideline or CIDB-published CIS and OSHCIM may form a comprehensive structure that promotes PtD-aligned practices across various project stages.

Meanwhile, the HIRARC framework shows its strong alignment with PtD principles by emphasizing hazard identification and risk control during the early stages of project planning. The framework recommends hazard reviews during three key stages: concept design, detailed design and maintenance, and pre-construction planning. These stages mirror the PtD model that required in the OSHCIM guidelines which promotes hazard elimination through thoughtful design solutions.

Among the reviewed OSH instruments, BIM demonstrates the highest potential for operationalizing PtD in the construction industry. BIM facilitates hazard identification and communication, safety planning, and design simulation

through 3D modelling and digital collaboration tools. These features enable stakeholders to embed safety information throughout the design and construction lifecycle and site inspections (Yap et al., 2023). In addition, Zulkifli et al. (2021) and Rodrigues et al. (2018) confirm BIM's usefulness as a Design for Safety (DfS) tool aligned with PtD principles. Despite its potential, the widespread use of BIM in Malaysia faces several challenges, including high implementation costs, limited awareness, lack of standardized training, and weak regulatory support (Taat et al., 2022). The adoption of BIM technology for site safety management in the construction industry also remains relatively low (Li Ting & Yahaya, 2024).

Overall, the combination of technical guidelines, assessment tools, and digital innovations provides a strong foundation for integrating PtD into Malaysian construction practices. In addition, management commitment plays a crucial role in shaping a positive safety culture among industry stakeholders (Him et al., 2023). To enhance pattern recognition, a heatmap was generated to visualize the extent of alignment between PtD elements and each OSH instrument as shown in Figure 1. This allowed for the identification of instruments with the strongest coverage of PtD principles, particularly within DOSH-published guidelines and CIDB-published Construction Industry Standards (CIS).

Instrument		Prevention through Design Elements						
		PtD 1	PtD 2	PtD 3	PtD 4	PtD 5	PtD 6	PtD 7
DOSH	D1	1	0	0	1	0	0	1
	D2	1	1	0	1	1	0	0
	D3	1	0	1	1	0	0	1
	D4	1	0	1	1	1	0	1
	D5	1	1	0	1	0	0	1
	D6	0	1	0	1	1	1	1
	D7	1	1	1	0	1	1	1
	D8	1	0	1	1	1	1	0
	D9	0	1	0	0	1	1	0
	D10	1	1	1	1	0	0	0
	D11	1	1	0	1	0	0	1
	HIRARC	1	0	0	0	1	0	1
CIDB	CIS 8	1	0	1	1	0	1	0
	CIS 9	1	0	1	1	1	1	0
	CIS 10	0	1	1	0	0	0	1
	CIS 11	1	1	0	1	1	0	1
	CIS 13	0	0	1	0	0	0	1
	CIS 14	0	1	0	1	0	1	0
	CIS 15	1	0	1	1	0	1	0
	CIS 16	1	0	1	0	0	0	1

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Instrument	Prevention through Design Elements						
	PtD 1	PtD 2	PtD 3	PtD 4	PtD 5	PtD 6	PtD 7
CIS 17	0	1	1	0	1	1	1
CIS 22	1	1	0	1	1	0	1
CIS 23	1	0	0	0	1	1	1
CIS 24	1	0	1	0	0	1	0
CIS 25	0	1	1	1	1	0	0
CIS 27	1	1	1	0	1	0	1
CIS 28	1	0	0	1	0	1	1
BIM	1	1	1	1	1	0	1

Figure 1: Integration of PtD elements and OSH instruments
Color intensity reflects the degree of alignment with PtD elements
(0 = none, 1 = partial - strong)

Additionally, based on the analysis, four (4) CISs have been identified as tools for monitoring safety aspects and performance assessment namely CIS10, CIS22, CIS23 and CIS24. For example, CIS10, known as the Safety and Health Assessment System in Construction (SHASSIC), primarily evaluates contractor performance during the construction phase. While it does not fully align with the design-focused principles of PtD, SHASSIC contributes to an overarching safety framework by promoting continuous safety monitoring and performance evaluation throughout project implementation. Furthermore, Abas et al. (2020) emphasize that although SHASSIC offers limited integration at the design stage, it remains a valuable tool for reinforcing organizational safety practices. In contrast, CIS22 and C23 focuses on the safety compliance and conformity of reused scaffolding equipment and falsework, ensuring its integrity and safe application on-site. Meanwhile, CIS24 provides a structured assessment framework for evaluating the adoption and implementation of the Industrialised Building System (IBS) in construction projects, which indirectly supports risk minimization through prefabrication and off-site construction practices.

Category of OSH Instruments

The OSH instruments identified from DOSH and CIDB are grouped into three main categories based on their purpose and format: technical documents, assessment tools, and digital tools. Technical documents such as guidelines, regulations, and procedures which serve as key references to ensure compliance and manage risks during both the planning and execution stages of construction. This category includes most of DOSH-published guidelines and CIDB-published Construction Industry Standards. Assessment tools, like the HIRARC framework, help identify and control risks in a structured way to improve safety performance. CIDB has also developed tools such as SHASSIC to enhance site safety practices. Digital tools, particularly Building Information Modelling

(BIM), support safety planning, hazard visualization, and collaboration during the design stage, aligning well with PtD principles. Overall, DOSH focuses mainly on technical and assessment tools, while CIDB contributes through both conventional standards and digital innovations. This categorization provides a clear view of how these instruments can be integrated to support effective safety management from design to construction.

CONCLUSIONS

This study has explored and categories the Occupational Safety and Health (OSH) instruments developed by the Department of Occupational Safety and Health (DOSH) and the Construction Industry Development Board (CIDB), with a particular focus on their alignment with Prevention through Design (PtD) principles as outlined in the OSHCIM 2017 guideline. Malaysia's construction sector is supported by a range of instruments, including technical guidelines, risk assessment frameworks, and digital tools such as Building Information Modelling (BIM). While the explicit integration of PtD within these instruments remains limited and inconsistent, core PtD elements were identified in several key tools namely the Construction Industry Standards (CIS), the HIRARC framework, and BIM. These instruments demonstrate a foundational alignment with PtD principles, particularly in relation to early hazard identification and proactive risk planning.

The study's findings indicate that although current instruments are not formally structured around PtD, they exhibit the potential to support its adoption. For example, BIM is increasingly recognised as a digital tool that facilitates early hazard detection through 3D visualization, enabling design teams to foresee and mitigate safety risks during the planning stage. Similarly, HIRARC provides a structured and systematic approach to hazard recognition and risk control which aligns well with the proactive ethos of PtD by promoting risk elimination before construction activities begin. By mapping this alignment, the study contributes to a clearer understanding of how existing OSH instruments may serve as a basis for strengthening design-stage safety practices. Further efforts such as formal guidance, regulatory reinforcement, and enhanced collaboration between DOSH and CIDB can help advance the integration of PtD and support the development of a more preventive safety culture in Malaysia's construction industry.

ADDITIONAL INFORMATION

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INTEGRATING MAQASID SHARIA INTO THE PLANNING STAGE OF PUBLIC-PRIVATE PARTNERSHIP (PPP) SHARIA FOR INFRASTRUCTURE DEVELOPMENT IN INDONESIA

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Abstract

Public-Private Partnerships (PPPs) play a critical role in addressing Indonesia's infrastructure needs, yet the integration of Sharia values into the planning stage has received limited scholarly attention. This study seeks to address this gap by incorporating Maqasid Sharia into PPP planning to support the development of a Sharia-compliant framework. A qualitative approach was employed, drawing on semi-structured interviews with 25 participants representing academia, government institutions, professional associations, and the business sector. The data were analyzed using thematic analysis, which facilitated the systematic categorization of responses and the identification of themes. The findings demonstrate that embedding Sharia principles into PPP planning enhances compliance with Sharia values while ensuring economic feasibility, with social welfare, justice, and sustainability emerging as central considerations in the preparation of planning documents. The study contributes conceptually by advancing the development of a Sharia-compliant PPP blueprint for Indonesia and provides practical insights for policymakers. Beyond Indonesia, the findings also serve as a reference for other Muslim-majority countries seeking to align infrastructure development with Sharia principles. This study is among the first to explicitly examine the integration of Maqasid Sharia into PPP planning, thereby advancing the literature on Sharia-compliant infrastructure and providing a foundation for future research in this emerging field.

***Keywords*:** Infrastructure; Maqasid Sharia; Planning; PPP; Semi-structured Interview

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INTRODUCTION

Indonesia's infrastructure investment needs under the Public-Private Partnership (PPP) scheme are projected to reach 42 percent of the total requirement, amounting to approximately USD 190 billion (Presidential Regulation No. 18, 2020; Sunandar and Indiyati, 2023). In practice, several ministries, including the Ministry of Public Works and the Ministry of Transportation, as well as regional governments in Aceh, West Sumatra, Gorontalo, and West Nusa Tenggara, have expressed the need for a Sharia-compliant PPP scheme (Ministry of National Development Planning, 2023a). This scheme is also expected to attract investors who prioritize infrastructure projects aligned with Sharia principles, particularly those from the Middle East and member states of the Organization of Islamic Cooperation (KNKS and PT PII, 2020).

Globally, extensive research has examined infrastructure PPPs across diverse sectors, including toll roads (Rohman, 2022), water and wastewater (Amiri et al., 2022), solid waste management (Dolla and Laishram, 2022), electricity infrastructure (Kukah et al., 2023), bridges (Oliveros-Romero and Paton-Cole, 2023), hospitals (McGuire et al., 2024), transportation (Li and Love, 2022), and smart cities (Zhao et al., 2023). However, studies specifically addressing PPP Sharia remain limited, and the planning stage has received little systematic attention. The existing literature on Islamic finance in infrastructure has primarily emphasized financing mechanisms or contractual structures, while the integration of Maqasid Sharia, the higher objectives of Sharia, into PPP planning documents and processes has been largely overlooked (Hamid et al., 2019; Rakhmadi et al., 2022). This gap is particularly significant, as the planning stage constitutes the foundation of Indonesia's PPP framework and shapes the long-term feasibility, regulatory compliance, and societal impact of PPP projects (Ministry of National Development Planning, 2023b).

Recent studies on conceptual frameworks for Sharia-compliant PPPs have recognized the importance of Maqasid Sharia but have not explored it in sufficient depth (Sunandar et al., 2025a). The lack of clear guidance on how Maqasid Sharia can be operationalized at the planning stage therefore presents both theoretical and practical challenges. Theoretically, conceptual clarity remains limited regarding how Sharia objectives such as social welfare, justice, and sustainability can be integrated into PPP planning practices. Practically, the absence of Sharia-oriented planning instruments may hinder Indonesia's ability to attract Sharia-sensitive investors and to meet the expectations of domestic stakeholders who demand Sharia compliance in public infrastructure.

This study seeks to address these gaps by focusing on government-initiated (solicited) PPPs in Indonesia and examining how Maqasid Sharia can be integrated into PPP planning processes, as well as what thematic elements from stakeholder perspectives can inform the development of a Sharia-compliant PPP

framework. By engaging with these questions, the study contributes both conceptually and practically to the discourse on Sharia-based infrastructure investment, offering insights relevant not only to Indonesia but also to other Muslim-majority countries confronting similar demands for Sharia-compliant development models. This study is among the first to explicitly examine the integration of Maqasid Sharia into PPP planning, thereby advancing the literature on Sharia-compliant infrastructure and providing a foundation for future research in this emerging field.

LITERATURE REVIEW

Public-Private Partnership (PPP)

The development of public infrastructure requires substantial funding and is typically characterized by long-term investment. In this context, governments often face constraints related to both financial resources and service innovation (Qingbiao et al., 2024). The participation of private entities or investors therefore becomes essential in supporting infrastructure provision, commonly achieved through formal agreements between the government and the private sector (Mat Aron et al., 2024). Such agreements stipulate requirements related to service quality and reliability within the framework of the PPP scheme (Yescombe & Farquharson, 2018).

A PPP project initiated by the government, represented by a Government Contracting Agency (GCA), is categorized as a solicited project, whereas one proposed by the private sector is categorized as unsolicited. In Indonesia, GCAs authorized to plan solicited PPP projects include ministers, heads of agencies, governors, mayors, regents, and chief executive officers of state-owned enterprises, in accordance with their respective statutory mandates (Sunandar et al., 2024; Sunandar and Indiyati, 2023).

Solicited PPP Indonesia Planning Stage

The mechanism for solicited PPPs in Indonesia at the planning stage is is governed by:

1. Presidential Regulation No. 38/2015 on Public-Private Partnership in Infrastructure Provision.
2. Regulation of the Minister of National Development Planning No. 7/2023 on the Implementation of Public-Private Partnerships in Infrastructure Provision.

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According to these regulations, the planning stage of the solicited PPP mechanism in Indonesia consists of the following elements:

a. Identification of PPP
b. Establishment of Funding Scheme
c. Preparation of Budget Plan
d. Public Consultation
e. Proposal to the PPP Plan List
f. Preparation of PPP Plan List

Maqasid Sharia

Al-Imam al-Ghazali emphasized that the concept of Maqasid Sharia is central to preserving the fundamental objectives of the Sharia system, serving as the primary framework for guiding human life. It aims to safeguard society from threats to its stability while simultaneously promoting overall well-being. Allah, the Almighty, has established Sharia to enhance human life in both this world and the hereafter, thereby ensuring prosperity in both realms through the preservation of five essential dimensions: religion, life, intellect, lineage, and wealth (Hamid et al., 2019; Hidayah et al., 2022).

Fulfilling Maqasid Sharia, as the fundamental objectives of Sharia, is a core requirement for ensuring Sharia compliance. It secures the realization of benefits while mitigating potential harms in human activities and transactions. The overarching objective of Maqasid Sharia is to protect the essential necessities of human life, which encompass the following (Hamid et al., 2019; Hidayah et al., 2022; Rakhmadi et al., 2022; Ribadu et al., 2020):

a. Hifdz Ad-Din (preservation of religion)
b. Hifdz An- Nafs (preservation of life)
c. Hifdz Al-Aql (preservation of intellect)
d. Hifdz An-Nasb (preservation of progeny)
e. Hifdz Al-Maal (preservation of wealth)

RESEARCH METHODOLOGY

This study adopted a qualitative research design, employing semi-structured interviews as the primary method of data collection (Dai et al., 2023). Expert participants were recruited through purposive sampling and the snowball technique (Kukah et al., 2023). The inclusion criteria required participants to possess professional or academic expertise in infrastructure development, PPPs, or Sharia compliance, with a minimum of five years of relevant experience. Individuals without direct involvement in PPP-related policy, practice, or research were excluded. Data saturation was achieved with 25 respondents, as no

new insights emerged beyond that point. A summary of the respondents is presented in Table 1 and Figure 1.

The interviews were conducted online, scheduled according to participant availability, and held without a predetermined sequence. Each session lasted between 45 and 90 minutes, with an average duration of 49 minutes and 28 seconds. Participation was voluntary, and informed consent was obtained before each interview.

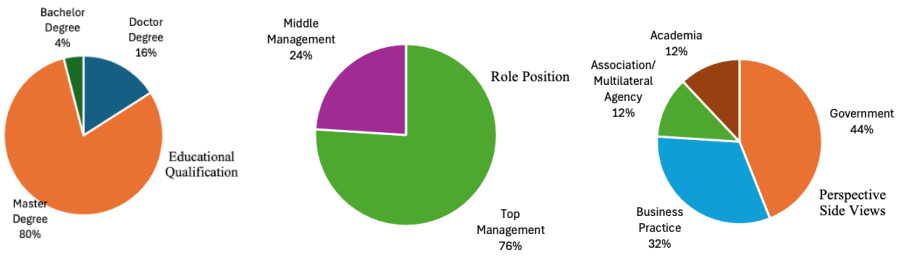


Figure 1: Interviewees Background (Educational Qualification, Role Position, and Perspective Side View)
Source: Author's Own Creation (2025)

Table 1: Interview Respondents

Code	Position	Organization	Code	Position	Organization
A1	Director	Ministry of Public Works	A14	Director	PT Jasa Marga
A2	Director	Ministry of Investment	A15	Partner	PwC
A3	Director	Nusantara Capital City Authority	A16	SVP	PT PP
A4	Deputy Director	National Committee for Islamic Economy and Finance	A17	Manager	PT PP
A5	Deputy Director	Ministry of National Development Planning	A18	Manager	Bank Syariah Indonesia
A6	Deputy Director	Ministry of Finance	A19	Manager	Bank Syariah Indonesia
A7	Deputy Director	Ministry of Public Works	A20	National Sharia Council	Majelis Ulama Indonesia
A8	Deputy Director	Ministry of Transportation	A21	VP	Asian Infrastructure Investment Bank
A9	Deputy Director	Ministry of Transportation	A22	Founder	Association of PPP Indonesia Expert

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Code	Position	Organization	Code	Position	Organization
A10	Deputy Director	National Public Procurement Agency	A23	Lecturer & Researcher	State Polytechnic of Banjarmasin
A11	Deputy Director	National Public Procurement Agency	A24	Lecturer & Researcher	Universitas UPN Jawa Timur
A12	Commissioner Independent	Bank Syariah Indonesia	A25	Lecturer & Researcher	Universitas Mercu Buana
A13	Director	PT. SMI			

Source: Author's Own Creation (2025)

All interviews were audio recorded with participant consent and transcribed verbatim. The transcripts were subsequently returned to participants for verification, allowing them to review and amend the content if necessary. Finalized transcripts were uploaded into qualitative analysis software and analyzed using thematic analysis, following the procedures outlined by Saldana (2021). The process involved iterative coding, categorization, and the identification of overarching themes concerning the integration of Maqasid Sharia into PPP planning.

To ensure rigor and reliability, coding was carried out independently by two researchers and cross-checked to resolve discrepancies. Intercoder reliability was strengthened through regular discussions, while participant validation confirmed the accuracy of the interpretations. A potential limitation of the sampling strategy was the reliance on purposive and snowball techniques, which may introduce selection bias. This was mitigated by recruiting participants across diverse stakeholder categories and aligning the selection with Indonesia's PPP institutional framework. Although the online interview format limited the observation of non-verbal cues, it improved accessibility and enabled participation from geographically dispersed respondents. These limitations should be considered when interpreting the findings.

ANALYSIS AND DISCUSSION

Maqasid Sharia, which represents the fundamental objectives of Sharia, is a vital prerequisite for ensuring Sharia compliance. Its primary purpose is to safeguard the essential necessities of human life, which include:

a. Hifdz Ad-Din (preservation of religion)
b. Hifdz An- Nafs (preservation of life)
c. Hifdz Al-Aql (preservation of intellect)
d. Hifdz An-Nasb (preservation of progeny)
e. Hifdz Al-Maal (preservation of wealth)

Based on the insights of 25 experts, the collective view suggests that Maqasid Sharia can be systematically integrated into all components of the planning stage within the solicited PPP mechanism. These components include the identification of PPP projects, the establishment of funding schemes, the preparation of budget plans, public consultation, proposals for inclusion in the PPP plan list, and the final preparation of the PPP plan list. Table 2 summarizes the expert responses from four group perspectives regarding the integration of Maqasid Sharia across the elements of the planning stage.

Table 2: Summary Responses on the Adoption of Maqasid Sharia in the Planning Stage

Code	Represent	Response
A2	Government	"Sharia, as taught by the Prophet Muhammad, is fundamentally grounded in honesty. In my view, this ensures overall alignment. Therefore, I believe that all stages, including the funding scheme, budget planning, public consultations, and the preparation of the plan list, can be integrated. This is certainly feasible."
A4	Government	"… The five? Do you mean whether all five can be applied to all elements? Yes, they can."
A16	Business Practices	"In my opinion, the implementation of Maqasid Sharia in PPPs is quite strong, both in the process and in execution. For example, we can observe a tangible relationship in the form of infrastructure. Indeed, in the daily operation of PPP elements, there may be a generation of connections that link religion, life, intellect, and wealth."
A17	Business Practices	"… The principles of Maqasid Sharia provide a holistic ethical and practical framework that aligns closely with the Planning Stage of the solicited PPP mechanism. By integrating these principles, planners can ensure that PPP projects meet not only economic and technical objectives but also uphold Sharia values, thereby fostering public trust, sustainability, and societal well-being."
A21	Association	"… If we are discussing Sharia compliance and the principles to be applied, I am confident that they can be adopted. However, the quality of implementation may vary."
A24	Academia	"In my opinion, Maqasid Sharia can be applied in PPPs, particularly in the aspects of preserving life and wealth, Hifdz Al-Maal, and Hifdz Al-Aql. With regard to Hifdz An-Nafs, this pertains to human life, which is closely linked to the future impact of the project, especially on community well-being."

Source: Author's Own Creation (2025)

The PPP Sharia Planning Stage constitutes a fundamental component in the implementation of projects that comply with Sharia principles. This stage emphasizes six interconnected sub-themes, each of which is classified within the conceptual framework of Maqasid Sharia to ensure alignment with its overarching objectives of Sharia compliance. These sub-themes correspond to the five dimensions of Maqasid Sharia. The integration of Maqasid Sharia into each stage of the PPP planning process ensures that initiatives not only fulfill technical

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and financial requirements but also align with Sharia objectives. Such integration promotes ethical, sustainable, and equitable development.

Sub-Theme 1: Identification of PPP

The identification stage involves determining potential projects that are suitable for PPP implementation while ensuring their compliance with Sharia principles. This stage establishes a fundamental framework for evaluating how proposed projects contribute to public welfare and align with Sharia guidelines.
Category: Maqasid Sharia

Sub-Category:

a. Hifdz Ad-Din (preservation of religion): Ensuring that project identification is consistent with the ethical standards prescribed by Sharia.
b. Hifdz An-Nafs (preservation of life): Assessing potential projects based on their impact on societal well-being and public safety.
c. Hifdz Al-Aql (preservation of intellect): Promoting intellectual development and awareness through a well-informed selection process.
d. Hifdz An-Nasb (preservation of progeny): Evaluating long-term societal benefits to foster justice and community stability.
e. Hifdz Al-Maal (preservation of wealth): Promoting economic sustainability and ensuring the equitable distribution of resources.

Sub-Theme 2: Establishment of Funding Scheme

This stage focuses on developing Sharia-compliant financial mechanisms to support the implementation of the PPP initiative. The primary objective is to ensure the exclusion of prohibited elements such as riba (usury) and gharar (excessive uncertainty) while promoting ethical and transparent financial practices.

Category: Maqasid Sharia
Sub-Category:

a. Hifdz Ad-Din (preservation of religion): Ensuring strict adherence to Sharia principles in financial structuring.
b. Hifdz An-Nafs (preservation of life): Facilitating equitable access to financing to strengthen societal well-being.
c. Hifdz Al-Aql (preservation of intellect): Encouraging ethical financial innovation within the framework of Sharia compliance.
d. Hifdz An-Nasb (preservation of progeny): Establishing stable and sustainable funding mechanisms to safeguard intergenerational equity.
e. Hifdz Al-Maal (preservation of wealth): Maintaining financial integrity through transparent, accountable, and responsible funding practices.

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Sub-Theme 3: Preparation of Budget Plan

The budget preparation phase involves comprehensive financial planning to ensure the effective allocation of resources in alignment with Sharia principles. This process emphasizes ethical financial management and supports sustainable development outcomes.

Category: Maqasid Sharia
Sub-Category:

a. Hifdz Ad-Din (preservation of religion): Embedding ethical considerations into budgetary decisions.
b. Hifdz An-Nafs (preservation of life): Prioritizing expenditures that directly enhance societal well-being.
c. Hifdz Al-Aql (preservation of intellect): Applying rigorous financial analysis to strengthen project sustainability.
d. Hifdz An-Nasb (preservation of progeny): Promoting equitable resource distribution to ensure long-term societal stability.
e. Hifdz Al-Maal (preservation of wealth): Maximizing resource efficiency to avoid waste and reinforce financial accountability.

Sub-Theme 4: Public Consultation

The public consultation process facilitates meaningful community engagement, ensuring that project objectives are aligned with the needs and aspirations of stakeholders. This stage enhances transparency, fosters mutual trust, and promotes inclusive decision-making.

Category: Maqasid Sharia
Sub-Category:

a. Hifdz Ad-Din (preservation of religion): Ensuring ethical participation and collective decision-making in project development.
b. Hifdz An-Nafs (preservation of life): Addressing community concerns to strengthen social cohesion and safeguard public welfare.
c. Hifdz Al-Aql (preservation of intellect): Facilitating informed dialogue to improve project effectiveness.
d. Hifdz An-Nasb (preservation of progeny): Reinforcing social bonds through inclusive stakeholder engagement.
e. Hifdz Al-Maal (preservation of wealth): Advancing transparency to cultivate confidence in financial governance.

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Sub-Theme 5: Proposal to the PPP Plan List

The submission of projects for inclusion in the PPP Plan List formalizes their consideration, ensuring that they meet eligibility criteria while adhering to Sharia-compliant principles.

Category: Maqasid Sharia
Sub-Category:

a. Hifdz Ad-Din (preservation of religion): Ensuring compliance with Sharia ethical and legal standards.
b. Hifdz An-Nafs (preservation of life): Selecting projects that enhance societal well-being and safeguard public interests.
c. Hifdz Al-Aql (preservation of intellect): Employing evidence-based assessments to support project inclusion.
d. Hifdz An-Nasb (preservation of progeny): Prioritizing projects that deliver long-term benefits to society.
e. Hifdz Al-Maal (preservation of wealth): Emphasizing projects with sustainable financial viability and accountability.

Sub-Theme 6: Preparation of PPP Plan List

The preparation of the PPP Plan List involves consolidating selected projects to ensure alignment with both national development priorities and Sharia principles.

Category: Maqasid Sharia
Sub-Category:

a. Hifdz Ad-Din (preservation of religion): Upholding Sharia values in the prioritization of projects.
b. Hifdz An-Nafs (preservation of life): Compiling projects that effectively address fundamental societal needs.
c. Hifdz Al-Aql (preservation of intellect): Applying a rational and evidence-based approach to project selection.
d. Hifdz An-Nasb (preservation of progeny): Emphasizing long-term societal and generational stability.
e. Hifdz Al-Maal (preservation of wealth): Ensuring financial prudence and the strategic allocation of resources.

Discussion and Conceptual Framework

The integration of Maqasid Sharia into the PPP planning stage provides a solid conceptual foundation for aligning infrastructure development with Sharia objectives. Nevertheless, its practical implementation presents notable challenges. Project identification and prioritization, for example, often involve competing interests related to economic efficiency, political agendas, and ethical

considerations. This tension raises the risk that Sharia compliance may be subordinated to short-term financial or political objectives. The establishment of Sharia-compliant funding schemes also introduces significant operational complexities. Although the framework emphasizes the exclusion of riba and gharar, such financing structures remain limited in practice and may not always meet investor expectations in global financial markets. Expanding the availability and understanding of Sharia-compliant instruments therefore requires regulatory support, financial innovation, and capacity building among stakeholders.

Public consultation, another essential element of the framework, faces implementation barriers as well. While designed to enhance inclusivity and transparency, consultations in PPP projects are often reduced to procedural formalities, thereby limiting genuine community participation. Embedding Maqasid Sharia principles in this process would require stronger institutional commitment and governance reforms to ensure meaningful engagement. Moreover, the preparation of budget plans and the consolidation of PPP project lists must reconcile the dual objectives of technical feasibility and Sharia alignment. Although the framework advocates ethical budgeting and intergenerational equity, resource constraints and political pressures may limit adherence to these principles. In the absence of clear monitoring and accountability mechanisms, the integration of Maqasid Sharia risks remaining aspirational rather than transformative.

Taken together, these challenges suggest that while the conceptual framework provides a strong normative direction, its success ultimately depends on the institutional capacity, political commitment, and financial innovation available within Indonesia's PPP ecosystem. Furthermore, the conceptual framework for the adoption of Maqasid Sharia in the PPP Planning Stage is formulated around its overarching theme, supported by sub-themes, categories, and subcategories, as illustrated in Figure 2.

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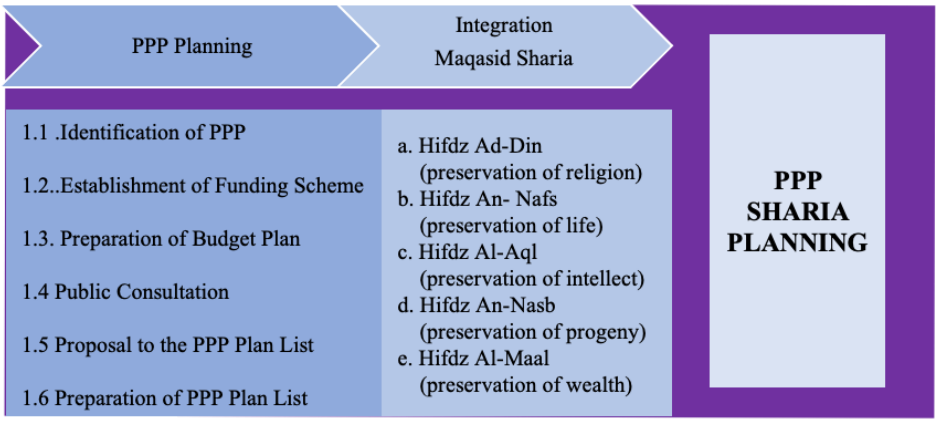


Figure 2: The Conceptual Framework for Adoption of Maqasid Sharia in the PPP Planning Stage
Source: Author's Own Creation (2025)

CONCLUSION

This study demonstrates that the systematic integration of Maqasid Sharia into the planning stage of PPPs provides both a normative framework and practical direction for ensuring Sharia compliance in infrastructure development. Unlike earlier studies on Sharia-compliant PPPs that primarily emphasize financing instruments, this research advances the discourse by embedding Maqasid Sharia principles across all planning components, including project identification, funding schemes, budget preparation, public consultation, and project selection. This comprehensive approach constitutes the study's main contribution, as it illustrates how Sharia objectives can be operationalized throughout the entire planning process rather than being restricted to financial structuring.

The findings carry significant implications for policy and practice. The framework suggests that government institutions such as the Ministry of Finance and the National Development Planning Agency should incorporate explicit Sharia-compliance indicators into project appraisal and budget allocation criteria. In addition, PPP regulatory guidelines could be revised to include Maqasid Sharia as a formal assessment dimension, ensuring that project selection balances technical feasibility, financial sustainability, and ethical considerations. Mechanisms such as Sharia advisory boards within PPP units and structured platforms for public consultation are also recommended to enhance transparency, inclusivity, and accountability.

Beyond Indonesia, the framework provides valuable insights for Muslim-majority countries seeking to integrate Sharia principles into infrastructure development. Although regulatory and institutional contexts may vary, the underlying approach of embedding Maqasid Sharia into planning stages

offers a replicable model. This is particularly relevant where conventional PPP frameworks have faced difficulties in addressing ethical concerns, building public trust, and ensuring intergenerational equity.

Overall, this study contributes to both academic knowledge and policy practice by demonstrating that Maqasid Sharia can serve not only as a theological foundation but also as a practical governance tool. By linking ethical objectives with operational guidelines, the framework presents a pathway toward ethical, sustainable, and socially responsible infrastructure development. Future research should build on these findings by testing and institutionalizing the framework in different PPP contexts, including unsolicited projects and stages beyond planning.

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DISCLOSURE

The authors declare that there is no conflict of interest associated with this research.

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PARK FACILITIES IN INFLUENCING VISITATION AND STRESS LEVEL OF LOW-INCOME URBANITES

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Abstract

Mental health problems among low-income urbanites have gradually fluctuated with the current inflation. Understandably, participation in green areas can reduce the symptoms of mental health problems. Due to the limited green spaces in low-income neighbourhoods, the time constraints, distance and awareness of the importance of spending time in green space areas are not taken seriously. The fact of design preference, park facilities, and existing spaces did not attract this group to see the benefits from it. This study examines the visitation and stress levels of low-income urbanites in Kuala Lumpur through the influence of park facilities. Self-reported stress level scale and survey questionnaires as the main methodology were distributed to the residents from Program Perumahan Rakyat (PPR) to identify stress levels, the frequency of park visits and the park facilities at Rimba Bukit Kerinchi Park. The findings show that the park's safety is significantly associated with residents under antidepressants. The residents identify that good natural lighting, clear information about user safety, and feeling safe in the park are the most satisfying elements when visiting the park. Therefore, proper planning guidelines on PPR's housing to utilise the benefits of green spaces among low-income urbanites for better lifestyles are needed.

Keywords: Urban park, low-income community, mental health, preliminary study

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INTRODUCTION

The poverty pattern has recently changed in Malaysia, where the poverty group increased from 5.6% in 2019 to 8.4% in 2020 (Department of Statistics Malaysia, 2020). According to the Department of Statistics Malaysia (DOSM) Household Income & Basic Amenities Report 2019, the National Mean Poverty Income Line (PLI) has amended the mean value less than RM2, 500 to consider a household in poverty or known as Below 40 (B40) in B1 household group. The situation worsened when the world was announced with a deadly COVID-19 virus in 2019. People lost their jobs and sources of income, affecting the sanity of their minds (De Miquel *et al.,* 2022). Living in persistent poverty tends to have higher percentages of mental issues, as mentioned by Marchi *et al.* (2024). They added that the child's condition of living in a low-income family, especially poverty, imposes stress on parents, making the parenting process harsher and unable to meet the child's needs, contributing to the psychiatric problem. In a study done by Chang *et al.* (2020), there is no statistically significant difference between poverty and mental health. However, the study also identifies that the result of adverse life events and social support has a relationship with mental health issues. Globally, poverty has decreased in China, Kyrgyz Republic, Moldova, Vietnam, India, East Asia and Pacific, and Europe and Central Asia over the year with the initiative from the government and non-profitable organisations (Aguilar *et al*., 2023). However, poverty is still difficult to overcome and cannot be solved daily.

Poverty-related mental issues make it difficult for people to engage in basic activities, including recreational physical activity. Poverty impacts physical and cognitive performance through poor nutrition, inadequate education, and unfavourable health circumstances, which affect productivity (Dalton *et al.,* 2017). Stressful situations such as financial difficulties, mourning, relationship problems, and the death of a loved one also contribute. Hedblom *et al.* (2019) studied the impact of natural elements in parks on stress levels. They found that bird songs and natural smells in green areas can lower stress levels. Additionally, abundant vegetation reduces psychological stress for both genders (Mennis *et al*., 2018). Hussein *et al.* (2021) reported that local parks do not meet the quality expected by residents with moderate stress levels. Preferred parks can improve mental and physical health by increasing the number of visits. Ishak *et al.* (2022) identified design, accessibility, landscape features, and safety as crucial for treating stress.

Therefore, this study aims to determine park facilities that influence visitation and stress levels of low-income urbanites in Kuala Lumpur. The objectives are to describe stress levels of low-income urbanites and identify preferred park facilities influencing visitation. These purposely to inform urban planning and public health strategies that support mental well-being and equitable access to green spaces. Urban living can be suffocating, especially for disadvantaged communities. Rapid development has reduced green spaces due to

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inadequate planning and regulatory control (Muhamad Nor *et al.,* 2021). Green spaces in cities are managed by local authorities. Urban growth brings disadvantages, including long-lasting mental health issues (stress) and poverty. High air and noise pollution in urban areas increase perceived stress, which can be reduced by green spaces (Liu *et al.,* 2024). Natural environments can alleviate stress. Access to green spaces for low-income communities is limited, especially in urban areas. Rigolon and Németh (2020) identified access issues for low socio-economic and minority groups. High housing prices in green space areas make it difficult for low-income urbanites to afford (Wolch *et al.,* 2014). Despite job opportunities and services, the high cost of living affects people's mental and physical health. Having well-maintained green spaces not only enhance the visual appeal of communities but also have a positive impact on residents' mental well-being (Ibrahim *et al.,* 2024). Some green spaces charge admission for improved nature and recreation. In Bochum, Germany, societal, physical, and sociodemographic factors discourage the community from using public green spaces. (Romelli *et al.,* 2025). Park quality, use patterns, and residents' satisfaction with parks are linked to motivation to visit nearby green spaces (Malek *et al.,* 2015). Residents demand appropriate facilities for recreational and sports activities at parks (Anuar & Muhamadan, 2018).

Hussein *et al.* (2021) suggested that quality parks meeting residents' expectations should undergo annual evaluations to identify problems and improve visitation, reducing stress levels. Better facilities and services, such as toilets, car parks, bicycle racks, trees for shelter, and safety information, can help residents relax and reduce stress. Cleanliness, water features, various activities, and good lighting also contribute to reducing stress (Ishak *et al.,* 2018). Natural elements like clean air and green settings make park users feel calmer (Moulay & Ujang, 2016; Ujang *et al.,* 2015). Moreira and Duarte (2023) supported the importance of landscape elements such as water features, outdoor play areas, and scented plants, along with proper design, to reduce residents' stress.

METHODS

To achieve the study's aim, it's essential to select an urban park near low-income residential areas. Rimba Bukit Kerinchi Park in Kuala Lumpur is chosen as the case study. This park is surrounded by high-density residential areas within walking distance and is within 500 meters of schools and commercial areas. It covers 66.15 hectares and is maintained by the Kuala Lumpur City Council. The park includes both hardscape and softscape for recreation and is part of Bukit Gasing, formerly a rubber plantation now requested to be a reserved forest. Rimba Bukit Kerinchi Park is centrally located for low-income urbanites from the Program Perumahan Rakyat (PPR) or the People's Housing Project. It is within a 3 km radius of nearby low-income housing, making it suitable for the study. Visitors can explore the park's natural stream, canopy walk, lush vegetation,

children's playground, and open areas like a camping site. The park also offers hiking trails with varying difficulty levels, from easy to quite challenging. Figure 1 shows amenities at Rimba Bukit Kerinchi Park for the public.



a) Natural stream at park



b) Camping site



c) Hiking trails for beginners



d) Platform stairs at the second entrance

Figure 1: Attractive places at Rimba Bukit Kerinchi Park
Source: Petitgo website, retrieved on 17th August 2023

The park's suitability for the case study and the identification of respondents in this study took two weeks of examination with the help of the local authority. Targeted respondents from the nearby high-density, low-income residents familiar with Rimba Bukit Kerinchi Park either have visited the park or at least know the park's location. Figure 2 shows the space segregation for each recreational activity at the park provided by the Landscape and Recreational Department from Kuala Lumpur City Council.

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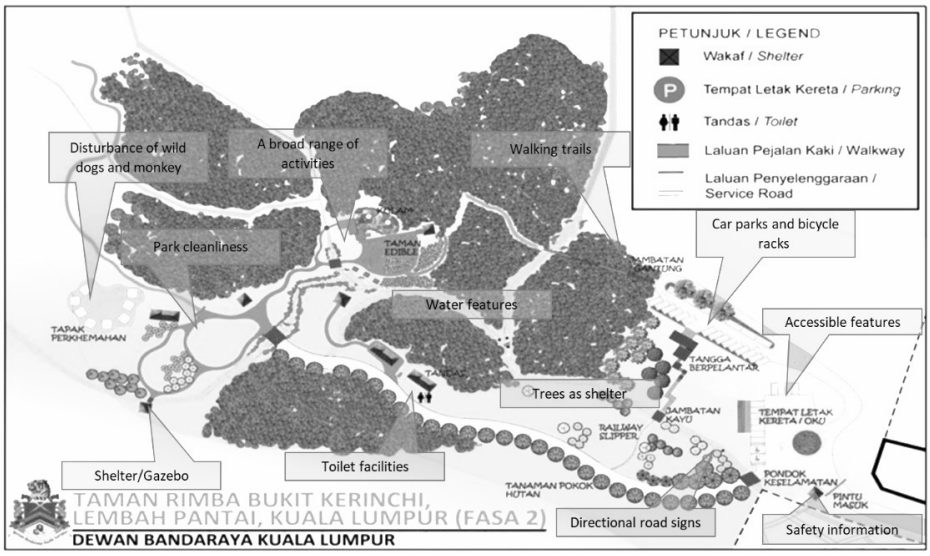


Figure 2: Park elements in Rimba Bukit Kerinchi Park
Source: Kuala Lumpur City Council, 2020

A number of n=176 questionnaires out of 382 samples returned from the survey were distributed to the low-income communities living at the PPR around Rimba Bukit Kerinchi Park based on a 50,000 catchment population—the age range for the sample starts from 12 years old and above. To avoid bias in data collection, the residents received the questionnaire survey at their house units and were emailed by the recruited researchers. This process is to identify the visitation to the park from the residents if they visit or do not visit the park. The construction of the questionnaire included demographic questions and park facilities that improve stress and attract visitors from the literature. Moreover, the usage of layman's words and avoidance of the scientific terms in the questionnaire delivered an understandable statement for the park users to comprehend excellently. The adapting and adopting methods from pre-existing questionnaires are applied to this questionnaire to increase the reliability and validity. The questionnaire comprised four sections: demographic, park visitation pattern, Perceived Stress Scale (PSS), and park facilities assessment which consist of 33 questions items. From the descriptive analysis, the authors measured the scale and analysed the statements according to the low-income urbanites' satisfaction variables. As a part of the study, the data gathered were analysed using the SPSS (Statistical Package for the Social Sciences) program. Survey questionnaires were distributed to identify stress levels and park facilities correlating with the park's visitation. Figure 3 shows the flow chart in preparing the survey.

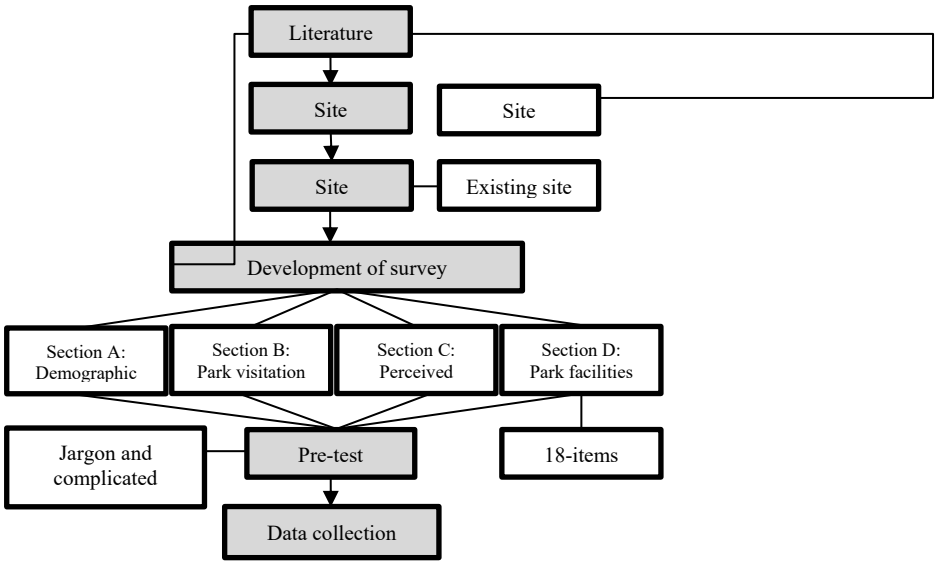


Figure 3: Flow chart of survey questionnaire at Rimba Bukit Kerinchi Park

RESULTS

Demographics of Respondents

In the first section, the respondents' demographic background is to ensure that the data from targeted respondents are gathered. Women respondents participated in more than half (64.8%) of the participation of men, 35.2%. People aged 20 to 29 were the most likely to visit the parks (31.3%), and those aged 56 years old and above were the least used parks, with only 7.3%. The Malay ethnicity dominated park visits with 86.6%, followed by the other ethnic minorities in Malaysia, namely the Indians (8.9%), others (4.5%), and none of the Chinese respondents participated. Most of the respondents are working, and most of the respondents have a good health record, 73.2%. The household income for each respondent shows they are in the B40 community as their data indicate 95.5% earn RM 3,860 and below in a month.

Park visitation data

The questionnaire's second section identifies the low-income urbanites' park visitation pattern at Rimba Bukit Kerinchi Park. The majority of respondents (33%) visited the park two to three times a week, and the most frequent visiting time was in the evening, with 77.1%. Regarding duration, 36.9% of respondents visited the park and spent two to four hours.

Perceived Stress Scale (PSS) score

The third section collects the stress level data of respondents by adopting PSS-14 items in the questionnaire. The PPS is a psychological instrument that identifies

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stress based on daily experiences in the past two weeks. According to Cohen *et al.* (1983), the scale assesses "the degree to which situations in one's life are appraised as stressful". This scale uses the Likert scale, where the respondents can indicate what they feel if the situations are too much to take, impulsive and overwhelming. For the PSS score, three levels are shown to identify the stress severity, including high perceived stress (range 27 to 40 points), moderate stress (range 14 to 26 points) and low stress (range 0 to 13 points). Approximately 78% of respondents of low-income urbanites (n=135) categorised in 'moderate stress' level, 19% low-stress level (n=33) and 3% high-stress level (n=6) based on the self-reported questionnaire. The indication of stress level is important to identify low-income urbanites' visitation to the park based on their perception towards park facilities.

Park facilities assessment

The fourth section identifies the park facilities at Rimba Bukit Kerinchi Park to recognise their satisfaction that may correlate with park visitation. Using the Likert scale, the respondents will be guided with the level of satisfaction towards park facilities from very unsatisfied to very satisfied. The response for the park facilities assessment score shows the low-income urbanites being satisfied to very satisfied with the proper directional road signs (39.1%); clean, well-maintained park (49.7%); a sufficient number of car parks and bicycle racks (39.1%); provided shaded area structure (e.g. gazebo) (40.2%); able to enjoy nature in the park (49.2%); trees as a shelter (43%). Besides that, low-income urbanites are satisfied with the broad range of activities available at Rimba Bukit Kerinchi Park. Good natural lighting, clear information about user safety and feeling safe in the park show satisfaction with these three elements with 41.3%. Moreover, the low-income urbanites were satisfied with the accessibility for people with disabilities, children, and seniors (33%) and the travel distance from the park to the residential (37.4%). The highlighted percentage in Table 1 indicates the satisfying score on each Rimba Bukit Kerinchi Parks park element.

Table 1: Park facilities assessment at Rimba Bukit Kerinchi Park

Likert-scale								
0	**1**	**2**		**3**		**4**		
Very Unsatisfied	**Unsatisfied**	**Neutral**		**Satisfied**		**Very satisfied**		
No	**Park facilities**	**0**	**1**	**2**	**3**	**4**	**Mean**	**Sd.**
		Percentage %						
1	Proper directional road signs	17.3	10.1	21.2	39.1	12.3	2.19	1.284
2	Toilet facilities access	23.5	16.8	30.2	22.9	6.7	1.73	1.240
3	Clean, well-maintained park	7.8	8.9	14.5	49.7	19.0	2.63	1.126
4	Well-designed and maintained walking trails	6.1	10.6	14.5	43.6	25.1	2.71	1.139
5	Sufficient car parks and bicycle racks	6.1	7.8	22.9	39.1	24.0	2.67	1.111
6	Provided shaded area structure	3.9	10.1	16.8	40.2	29.1	2.80	1.087
7	Sufficient seating area	3.9	6.1	27.9	38.0	24.0	2.72	1.022

Likert-scale								
0	**1**	**2**		**3**		**4**		
Very Unsatisfied	**Unsatisfied**	**Neutral**		**Satisfied**		**Very satisfied**		
No	**Park facilities**	**0**	**1**	**2**	**3**	**4**	**Mean**	**Sd.**
		Percentage %						
8	Able to enjoy nature in the park	3.9	4.5	12.8	49.2	29.6	2.96	.979
9	Disturbance of wild dogs and monkey	15.1	10.1	36.9	22.9	15.1	2.13	1.236
10	Water feature (river, stream, or pool)	26.3	10.1	30.7	19.6	13.4	1.84	1.366
11	Trees as a shelter at the park	5.6	5.0	15.1	43.0	31.3	2.89	1.078
12	A broad range of activities available	7.3	10.1	16.2	36.3	30.2	2.72	1.204
13	Good natural lighting	2.2	5.0	12.3	39.1	41.3	3.12	.964
14	Clear information about user safety	2.2	5.0	12.3	39.1	41.3	2.39	1.321
15	Feeling safe in the park	2.2	5.0	12.3	39.1	41.3	2.43	1.156
16	Number of other visitors present	8.9	8.9	36.3	32.4	13.4	2.32	1.100
17	Accessible features for people with disabilities, children, and seniors	20.7	9.5	25.1	33.0	11.7	2.06	1.314
18	Distance from park to residential	5.6	6.7	16.2	37.4	34.1	2.88	1.125

Source: Author's Calculation

Correlation analysis between the frequency of park visitors and park facilities score at Rimba Bukit Kerinchi

Spearman's Rho correlation analysis showed a weak positive correlation at the 0.01 level (2-tailed) between park visitors' frequency and park facilities score at Rimba Bukit Kerinchi Park ($r = .222$, $p < .01$). Local authorities provide proper directional road signs, a well-maintained park, ample car parks and bicycle racks, shaded structures like gazebos, and a range of activities. The park's proper setting allows low-income urbanites to enjoy nature with tree shelter. Park preferences depend on various features and elements (Ishak *et al*., 2018). Respondents reported satisfaction with park safety, good natural lighting, and clear information. The park is accessible for people with disabilities, children, and seniors, and its distance from residential areas is suitable. Longer travel distances to parks can reduce visits (Tu *et al.,* 2020). The highest mean score was for natural and artificial lighting ($m = 3.12$; s.d. = .964). A weak positive correlation exists between gender and stress level score ($r = .149$, $p < .05$). Unsatisfactory park facilities included toilet facilities ($m = 1.73$; $s.d = 1.24$). Table 2 shows correlation on park facilities score.

Table 2: Spearman Rho's rank correlation table

			Park visit frequency	**Stress level**	**Period visits to the park**
Spearman Rho's	Park facilities score	Correlation Coefficient	.222**	.051	.002
		Sig. (2-tailed)	.003	.494	.982
		N	176	176	176

**. Correlation is significant at the 0.01 level (2-tailed). *Source: Author's Calculation*

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The respondents' stress levels did not significantly correlate with park facilities data. However, according to the question of the low-income urbanites during the survey questionnaire, 92.6% (n=163) have indicated that park visitation can relieve their stress. The results have the chances of bias due to self-reported data.

DISCUSSION

Females, teenagers, and residents living close to Rimba Bukit Kerinchi Park visit the park most often. Park facilities, like toilet facilities, disturbances from stray dogs and monkeys, water features, and the low number of users, received neutral responses. Access issues can be severe for able-bodied individuals and worse for those with disabilities. Most low-income urbanites reported moderate stress levels using self-reported PSS, with stress levels significantly but weakly correlated with females. Male respondents visited the park less frequently, with less than 50% visiting, likely due to work commitments and lack of time for recreation. Low-income urbanites face barriers and lack motivation to visit parks, as supported by Bakar *et al.* (2016) and Munson (1994). Park facilities influence visitation rates, with limited time, safety concerns, and inadequate equipment deterring regular visits. Gender preferences influence park visits for various purposes. Men and boys used physical activity related park amenities such as sports fields (Sun *et al.,* 2025; Cohen *et al.,* 2007). In contrast, women tend to use parks less compared to men due to safety (Derose *et al.,* 2018). However, Ho *et al.,* (2005) has shown no notable gender differences in visit patterns or perceived benefits. Satisfied park facilities, as highlighted in Table 1, can increase park visits, although they do not affect stress levels. Improvements in park facilities like seating, water features, children's play areas, and trees can improve mental health, according to Subiza-Pérez *et al.* (2020). Figure 4 categorizes park facilities into three groups.

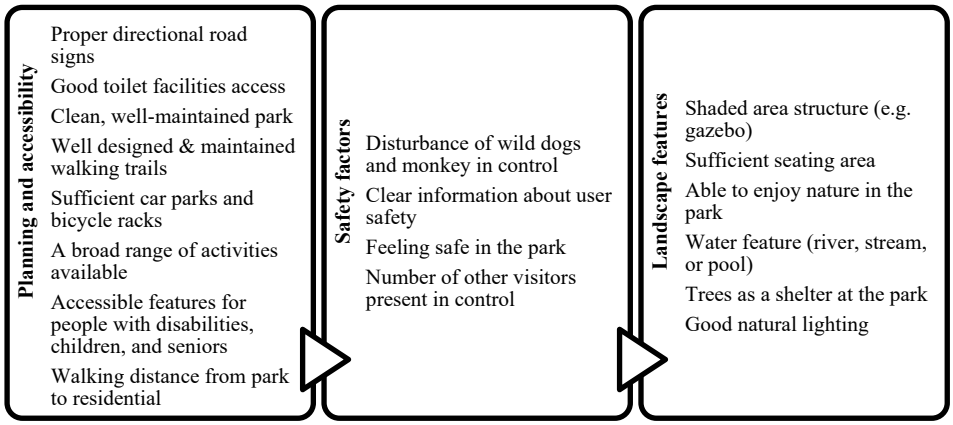


Figure 4: Suggestions for improvement at parks in low-income urbanite neighbourhood

This study highlights the importance of understanding the park facilities preferred by low-income urban residents to improve their mental health. Natural settings with fewer artificial features attract these individuals to parks. Although park facilities primarily influence park visitation, those that satisfy visitors still help reduce stress, as indicated by the data. Additionally, the high demand for cleanliness and well-maintained parks suggests that these improvements can guide park designs for this group. Future studies should involve professionals, local authorities, and the community in park proposal design and planning. Regular meetings with low-income urban residents can help develop proposals for improving and adding to existing facilities. Furthermore, organizing on-field events and activities, like park cleaning programs involving various age groups, can increase visitation rates and improve stress levels.

Government actions in applying professional suggestions and ideas to park development are essential to ensure that parks offer equal opportunities for low-income urban residents. This can help create better, more inclusive parks in Malaysia, which can improve stress levels. The limited living conditions in PPR often prevent residents from accessing fresh air, highlighting the importance of nearby parks. Parks can serve as a medium for low-income urban residents to reduce stress. To improve future studies, increasing the number of respondents will yield better and more precise data, reducing bias. Additionally, researchers should use clinically measured stress levels for a better understanding, rather than relying solely on self-reported data. This approach will provide more accurate information and avoid overestimating mental health status.

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EXPLORING CAPACITY DEVELOPMENT INITIATIVES FOR PROMOTING GROWTH AND SUSTAINABILITY OF SMALL AND MEDIUM-SIZED QUANTITY SURVEYING FIRMS IN MALAYSIA

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Abstract

The challenges faced by small and medium-sized quantity surveying (SME QS) consulting firms in Malaysia highlight the need for a structured and effective capacity development framework to ensure their sustainability and competitiveness. Despite the existence of various capacity development initiatives (CDIs), SME QS firms continue to struggle with financial constraints, limited market access, slow technology adoption, and skill development gaps. This paper seeks to explore the awareness and participation of SME quantity surveying consulting firms in capacity development initiatives (CDIs) and recommend relevant enhancements. Interviews with eight SME QS firm directors and principals were thematically analysed, revealing core challenges in capacity development, particularly gaps in financial accessibility, training participation, and networking opportunities. The results of the study indicate that while CDIs exist, many firms are either unaware of the existing initiatives or do not actively participate due to various barriers. Findings suggest that improvements in financial assistance, targeted professional development, and structured networking opportunities are essential to fostering a more resilient SME QS sector. This study reveals underexplored gaps in SME QS capacity development, highlighting the need for stronger policy enhancements and enforcement mechanisms to sustain competitiveness in Malaysia's transforming construction industry.

Keywords: quantity surveying, capacity development initiatives, SME quantity surveying consulting firms, financial constraints, professional development

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INTRODUCTION

SMEs play a vital role in the Malaysian economy, contributing significantly to employment and national GDP (Loo et al., 2023). According to OECD (2022), the small and medium-sized enterprises (SMEs) play a crucial role in the Malaysian economic landscape, constituting 97.2% of all business establishments, which contributes 38.2% to the national GDP and serving as employers for 7.3 million individuals. Over the past few decades, there has been a concerted effort to establish a robust financing ecosystem, encompassing a wide array of funding options for SMEs from both public and private entities. This strategic development has empowered Malaysian SMEs with access to a diverse range of financing sources, ensuring they can effectively meet their financial requirements across different stages of their developmental journey.

Ramdav and Harinarain (2020) suggest that the quantity surveying profession needs a strategic framework to address its threats and weaknesses while leveraging its strengths and opportunities, ensuring its survival and relevance in the ever-evolving construction industry. The increasing complexity of managing small and medium-sized quantity surveying consulting firms in Malaysia has further highlighted the need for a structured capacity development initiative (Wong et al., 2025). However, quantity surveying consulting firms face several challenges that hinder their growth, including financial constraints (Lee et al., 2020), limited access to networking opportunities (Yuen & Ng, 2021), slow adoption of technology (Ahmed et al., 2024), and inadequate governance structures (Islam et al., 2025).

Several capacity development initiatives (CDIs) have been introduced by governmental and non-governmental organizations, such as the Construction Industry Development Board (CIDB) (CIDB Malaysia, 2022), Malaysia Digital Economy Corporation (MDEC) (Linde et al., 2021), and Human Resource Development Corporation (HRD Corp) (Lee et al., 2020). These initiatives aim to enhance SME sustainability and competitiveness through financial assistance, professional training, and technology adoption. However, studies have indicated that existing initiatives are insufficient, leaving gaps in addressing key issues such as funding accessibility, business networking, and skills development (Dehdasht et al., 2022).

Several studies have argued that, despite the presence of capacity development initiatives, SME quantity surveying consulting firms continue to struggle with sustainability and industry competitiveness (Shari et al., 2024). The lack of enforceable policies, inadequate financial support, and limited engagement from key stakeholders have prevented SMEs from fully utilizing available initiatives (Lee et al., 2020). Additionally, disparities exist between the objectives of CDIs and their practical implementation, resulting in ineffective support for quantity surveying consulting firms (Mulei & Gachengo, 2021).

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This study aims to explore the awareness and engagement of SME quantity surveying consulting firms with capacity development initiatives (CDIs) and propose necessary improvements. Ultimately, the study provides an overview of whether current CDIs are adequate to support the growth, competitiveness, and long-term sustainability of these firms in Malaysia.

LITERATURE REVIEW

Theories Underpinning the Study

The critical use of appropriate theories is important to support the study of CDIs in small and medium-sized consultation quantity surveying practices (CQSP) in Malaysia. Theories provide a framework through which to interpret innovation adoption and transformation of learning systems, particularly in dynamic and resource-scarce fields for this research. The theoretical foundation of this study is built on three key perspectives: Diffusion of Innovation Theory (Rogers, 2003), Transformative Learning Theory (Mezirow, 1991), and the Theory of Constraints (Goldratt, 1990).

The Diffusion of Innovation Theory explains how new technologies or practices are introduced and adopted within professional networks, influenced by stages such as awareness, decision-making, and implementation. This is particularly relevant to how consulting quantity surveying practices (CQSPs) in Malaysia adopt tools like BIM, cost software, and digital collaboration platforms. Meanwhile, Transformative Learning Theory focuses on internal change, highlighting the importance of critical reflection, mindset shifts, and value alignment in driving long-term learning and adaptation. It supports the idea that true capacity development must go beyond technical training to include ethical, strategic, and behavioural transformation. Complementing these two perspectives, the Theory of Constraints (TOC) focuses on identifying internal bottlenecks that limit performance in resource-constrained environments such as SMEs. It offers a practical approach to diagnosing and resolving inefficiencies like limited manpower, poor workflows, or resistance to change, which can hinder the success of capacity development initiatives (CDIs). When integrated, these three theories provide a comprehensive view: innovation diffusion shows how change is introduced; transformative learning explains how individuals and organisations internalise it; and TOC ensures that systems are optimised to sustain the change.

Capacity Development Initiatives (CDIs)

Capacity development initiatives, also known as capacity building initiatives, encompass a wide range of activities aimed at enhancing the abilities of individuals, organizations, and societies to perform functions, solve problems, and achieve their objectives (Pichler et al., 2019). It is essential to recognize that

capacity development goes beyond mere training and technical assistance; it involves nurturing knowledge, skills, attitudes, agency, and affordances required to achieve individual goals while addressing various barriers to change (Lussier, 2016). These initiatives are crucial for addressing institutional deficiencies and building the necessary skills and knowledge for sustainable development, particularly in developing countries (Ebohon et al., 1997). The initiatives offer intervention, often beginning with mapping exercises to design effective strategies and frameworks for monitoring and evaluating impact (LaFond et al., 2002). It is not a one-size-fits-all approach but rather a dynamic process that evolves through different stages of readiness, necessitating tailored interventions to enhance capacity effectively (Goodman et al., 1998).

Capacity development is a critical element in the sustainability and competitiveness of small and medium-sized enterprises (SMEs) within the Malaysian construction industry (Dehdasht et al., 2022). As a professional service sector, quantity surveying consulting firms play a significant role in managing costs, contracts, and project efficiencies throughout the construction lifecycle (Osunsanwo & Dada, 2020). However, many SME quantity surveying firms struggle to sustain growth due to financial limitations (Singh & Hanafi, 2020), lack of skilled manpower (Mustafa et al., 2023), slow adoption of technology (Saka & Chan, 2021), and limited access to structured business support (Loo et al., 2023).

The Malaysian government and various professional bodies have introduced several capacity development initiatives (CDIs) to enhance the competency and resilience of SMEs, including training programs (HRD Corp, 2022), financial assistance (CIDB Malaysia, 2022), digital transformation incentives (MDEC, 2022), and networking opportunities (MATRADE, 2022). Despite these efforts, the effectiveness of CDIs remains questionable, as SME quantity surveying firms continue to face barriers in funding accessibility, skill development, and industry integration (Islam & Aldaihani, 2022).

Challenges Constraining SME Quantity Surveying Consulting Firms

Capital and Financial Constraints

Financial barriers have been consistently identified as one of the most significant challenges limiting the growth of SME quantity surveying firms (Al Mamun et al., 2021). These firms rely heavily on internal funding, with limited access to bank loans or government grants due to stringent eligibility requirements (Gebreselassie, 2020). A survey conducted among SMEs in Malaysia found that more than half of loan applications from small firms were rejected, highlighting the difficulty in securing external funding for business expansion and technology investment (Islam et al., 2025).

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Additionally, the high cost of software and hardware for digital transformation presents a challenge for SME quantity surveying firms (Ahmed et al., 2024). Building Information Modeling (BIM), which is increasingly demanded by clients and regulators, requires substantial investment in software licensing, hardware upgrades, and employee training (CIDB Malaysia, 2022). Firms that fail to adopt BIM and other digital tools face reduced competitiveness, as they are unable to secure projects that require advanced cost estimation and management tools (Saka & Chan, 2021).

Workforce and Competency Development

The shortage of skilled professionals within SME quantity surveying firms hinders their ability to compete with larger consultancies (Spellacy et al., 2021). The lack of structured training programs and career development pathways leads to high employee turnover and a shortage of experienced quantity surveyors (Mustafa et al., 2023). Studies have shown that many SME QS firms struggle to retain talent, as qualified professionals often leave for higher salaries and better career progression opportunities in larger firms (Osunsanwo & Dada, 2020). In addition to adopting new technologies like BIM and AI-related tools, enhancing knowledge in sustainability, including green building practices and ESG, is also crucial for preparing the SME firms with a skilled and competent workforce, enabling them to explore new areas of specialization (Shayan et al., 2019; Zolkafli, 2021; Hamdan et al., 2025; Nizarudin & Zakariya, 2025).

Capacity development initiatives aimed at upskilling SME professionals exist but remain underutilized (HRD Corp, 2022). The Human Resource Development Corporation (HRD Corp), for instance, provides training grants and upskilling programs, but many SMEs lack awareness or find the application process too complex (Lee et al., 2020). This gap in professional development limits the long-term sustainability of SME QS firms, as they struggle to keep pace with industry advancements (Cheong et al., 2023).

Networking and Market Access

Networking opportunities are crucial for business growth, project acquisition, and industry recognition (Yuen & Ng, 2021). However, SME quantity surveying firms in Malaysia face difficulties in expanding their professional networks, particularly in securing large-scale projects and forming strategic partnerships with contractors and developers (Linde et al., 2021). While organizations such as the Malaysia External Trade Development Corporation (MATRADE) provide networking and business matching services for other industries (MATRADE, 2022), there is a lack of dedicated platforms for SME QS firms to connect with industry stakeholders (Saka & Chan, 2021). This hinders their ability to secure

high-value contracts, as networking plays a key role in project procurement and business development (Ramdav & Harinarain, 2020).

RESEARCH METHODOLOGY

This study adopted a qualitative research approach, utilizing semi-structured interviews to gather empirical data from industry practitioners. Given the exploratory nature of this research, a qualitative approach is deemed appropriate. The study focuses on small and medium-sized quantity surveying firms as the primary respondents. The qualitative method is chosen to gather insights into participants' experiences, perceptions, and perspectives on the research issues. DiCicco-Bloom and Crabtree (2006) assert that qualitative interviews are ideal for gaining an in-depth understanding of a specific research area, accurately documenting participants' thoughts and opinions.

According to Curry et al. (2009), qualitative research explores individuals' experiences, shedding light on the factors influencing their decision-making processes and how those decisions unfold. This study focuses on exploring SME quantity surveying consulting firms' awareness and engagement with capacity development initiatives (CDIs) and recommending necessary improvements. Hence, the qualitative method was chosen to provide a more comprehensive understanding of real-world constraints and opportunities (Ismail et al., 2017; Mohd Danuri et al., 2016), particularly as experienced by SME QS firms in this context.

According to the official website of Board of Quantity Surveyors Malaysia (BQSM), there are 150 registered firms in Selangor and 112 registered firms in Wilayah Persekutuan Kuala Lumpur (WPKL) which contribute a total of 262 registered firms in Selangor and WPKL out of the 412 registered quantity surveying firms in Malaysia under BQSM (BQSM, 2023). The research engaged eight directors and principals from SME QS firms operating within Selangor and Wilayah Persekutuan Kuala Lumpur (WPKL). These participants were selected through purposive sampling to ensure they had at least ten years of experience in the industry and that their firms had been operational for a minimum of three years. The study also employed snowball sampling, where participants referred other qualified respondents to contribute their perspectives.

For the purpose of this research, all necessary information about the targeted firms was obtained from the official website of the Board of Quantity Surveyors Malaysia (BQSM). The data collection process resulted in only eight completed interviews. While this relatively small number of participants may raise concerns about the generalizability of the findings, it is important to recognise that qualitative research emphasizes depth of understanding rather than breadth of representation. Braun and Clarke (2013) recommend a minimum of 12 interviews to reach data saturation, but they also caution against treating this as a

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rigid threshold. In practice, saturation is achieved when additional interviews fail to yield new insights. In this study, saturation was observed between the sixth and eighth interview, when recurring patterns and consistent narratives began to emerge.

The modest sample size can also be justified in light of prior methodological literature. In their seminal work, Guest et al. (2006) found that data saturation in qualitative interviews often emerges between six and twelve interviews. They noted that basic elements of themes can be discerned as early as the sixth interview, which is critical for informing data collection strategies in qualitative research. This finding aligns with the observations made by Hennink et al. (2016), who similarly identified that data saturation is typically reached within a comparable range of interviews (i.e., between seven and twelve), emphasizing the significance of recognizing the emergence of themes early in the interviewing process.

Moreover, Boddy (2016) supports this notion by asserting that qualitative studies often utilize smaller sample sizes not to achieve statistical representativeness but to attain analytical depth and richness in the data. This argument is reinforced by Malterud et al. (2016), who indicate that while there is no standard sample size for qualitative research, sizes around ten may suffice in certain homogeneous populations. The emphasis on depth rather than breadth further illustrates the qualitative research paradigm, as highlighted by Saunders et al. (2017), who discussed the relationship between sample size and the concept of saturation, proposing that the quality of data rather than its quantity primarily dictates the sufficiency of the sample. Thus, qualitative researchers often prioritize focused inquiry and thorough thematic exploration, reinforcing the validity and robustness of their findings.

Practical considerations further contextualize the sample size. SME quantity surveying firms which consist of 150 registered firms in Selangor and 112 registered firms in Wilayah Persekutuan Kuala Lumpur (WPKL) represent a niche and relatively small professional community, which makes participant access inherently challenging. Despite an initial outreach of 80 email invitations and five targeted LinkedIn invitations, only eight firms agreed to participate before the project deadline. This reflects a common challenge in organisational research, where participation rates are shaped by time pressures, workload demands, and perceived sensitivities around professional practices.

Although the limited number of respondents restricts the statistical generalizability of the findings, the study strengthens its credibility through analytical generalization. The consistent emergence of themes across interviews suggests that the insights are not isolated but are likely transferable to similar contexts. By prioritizing the richness and recurrence of perspectives over

numerical thresholds, the findings remain trustworthy and valid within the qualitative research paradigm.

Interviews were conducted in both physical and online formats to accommodate participant availability and convenience. The responses were recorded, transcribed, and subjected to thematic analysis, allowing key themes and trends to be identified. The thematic analysis provided a structured interpretation of the collected data, categorizing the findings into relevant areas that reflect the core challenges and areas for improvement in capacity development initiatives. The following section presents the study's findings, organized around key themes and sub-themes identified through the analysis.

FINDINGS AND DISCUSSION

SME QS firms' awareness and engagement with CDIs

The findings on SME QS firms' awareness and engagement with CDIs provided by governmental and non-governmental organizations indicate that many firms are either unaware of the existing initiatives or do not actively participate due to various barriers. The study found that despite the availability of subsidized training programs offered by organizations such as the Human Resource Development Corporation (HRD Corp), the Construction Industry Development Board (CIDB), and the Board of Quantity Surveyors Malaysia (BQSM), participation among SME QS firms remains low.

A significant number of firms reported being unaware of the specific training programs available to them, while others cited time constraints as a limiting factor in engaging with these initiatives. Many industry professionals prioritize project commitments over continuous learning, which results in low participation rates in professional development programs. Additionally, several respondents expressed concerns that existing training modules are often too generic and fail to address the specific challenges faced by SME QS firms, particularly in contract administration, cost control, and risk management. The findings are reported and illustrated in Figure 1.

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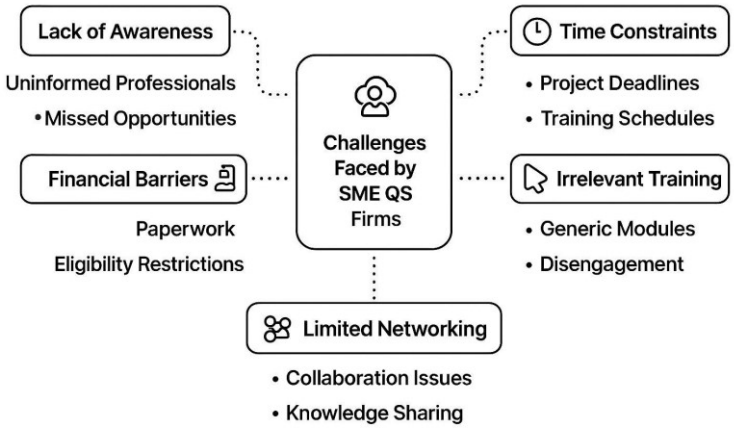


Figure 1: SME QS firms' awareness and engagement with CDIs
Note. Based on authors' research findings (2025).

Similarly, barriers to accessing financial assistance programs hinder the ability of SME QS firms to leverage government-backed loans and grants. While financial programs such as those offered by SME Bank Malaysia and Malaysia Digital Economy Corporation (MDEC) aim to support digital transformation and business expansion, many SME QS firms struggle to meet eligibility criteria. Interview participants highlighted that loan applications often require extensive documentation and collateral, making it difficult for smaller firms to qualify. Moreover, many financial aid schemes are primarily designed for manufacturing or technology-based SMEs, with limited provisions for professional consultancy firms within the construction industry.

Networking remains another unaddressed gap in CDIs. While industries such as manufacturing and export-oriented businesses benefit from structured trade fairs and business-matching events, there is a notable absence of dedicated networking platforms for SME QS firms. Without these opportunities, many firms struggle to establish connections with larger contractors and developers, limiting their access to new projects. Expanding professional networks is crucial for securing larger contracts and forming strategic partnerships, yet this remains a challenge for many SMEs in the quantity surveying sector.

Recommendations for Enhancing Capacity Development Initiatives

The findings further suggest that improvements in CDIs are necessary to support the long-term growth of SME QS firms. Several key enhancements were identified as crucial to overcoming the existing challenges in financial access,

skill development, and industry integration. Based on the findings, the following are the recommendations to enhance CBI are developed and shown in Figure 2.

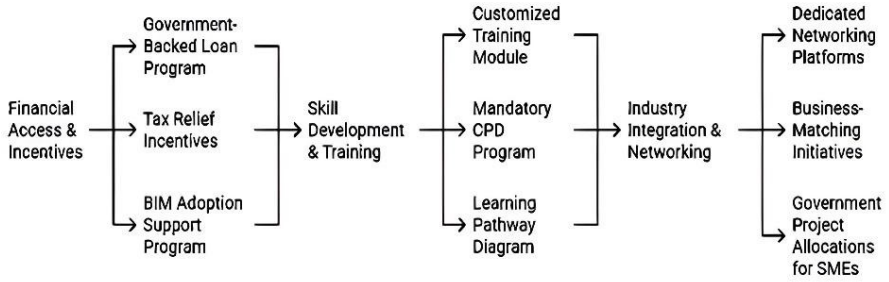


Figure 2: Recommendations for Enhancing Capacity Development Initiatives
Note. Based on authors' research findings (2025).

From a policy and regulatory perspective, the introduction of a standardized fee structure for quantity surveying consultancy services would ensure fair pricing and financial stability for SME firms. A more structured approach to taxation and financial incentives should also be considered, particularly by introducing tax relief programs for SME firms that invest in digital transformation and professional development. Expanding financial assistance programs is another critical area for improvement. Simplifying the loan application process and reducing bureaucratic barriers would enable more SME QS firms to access funding for business expansion and technology adoption. Additionally, introducing government-backed incentives for BIM adoption would encourage more firms to transition to digital tools, making them more competitive in the market.

Efforts should also be made to improve training and professional development programs. The development of industry-specific training modules tailored to SME QS firms would ensure that capacity development programs align with the actual needs of the industry. Continuous professional development (CPD) programs should also be made mandatory for SME QS firms, ensuring that employees receive ongoing training in contract administration, digital project management, and cost estimation techniques.

Furthermore, the establishment of structured networking platforms would help SME QS firms expand their business opportunities. Industry-focused networking events, business-matching programs, and strategic partnership initiatives should be introduced to connect SME QS firms with larger industry players, government agencies, and international markets. The allocation of specific government projects to SMEs would also ensure fair competition within

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the quantity surveying sector, allowing smaller firms to secure larger consultancy contracts.

The findings on SME QS firms' awareness and engagement with CDIs can be more clearly interpreted through relevant theoretical perspectives. From the perspective of Diffusion of Innovation Theory (Rogers, 2003), the low uptake of subsidized training and financial programs reflects barriers in knowledge dissemination and perceived relative advantage, where many firms do not see immediate value or remain unaware of available innovations. Transformative Learning Theory (Mezirow, 1991) helps explain why generic training programs fail to engage QS professionals, as transformative learning requires industry-specific, experience-based reflection to shift existing mindsets and practices. Finally, constraints such as time pressures, complex loan requirements, and limited networking opportunities reflect the Theory of Constraints (Goldratt, 1990), where systemic bottlenecks prevent firms from fully leveraging CDIs. Together, these theories provide a stronger conceptual grounding for understanding the limited participation of SME QS firms in CDIs and highlight areas for targeted improvement.

CONCLUSION

This study has been able to explore the capacity development initiatives (CDIs) necessary for small and medium-sized quantity surveying consulting firms in Malaysia. Thus far, this study finds that despite the availability and implementation of capacity development initiatives, their adoption and impact remain limited. The accessibility and effectiveness of CDIs require further enhancements to better serve SME QS firms in overcoming financial, technological, and competency-related barriers. There remains a need for more structured financial support mechanisms, targeted training programs, enforced digital transformation policies, and improved industry networking opportunities to strengthen the overall growth and competitiveness of SME QS firms.

The analysis concludes that the most common constraints hindering SME QS firms include the lack of financial accessibility for technology adoption, insufficient professional upskilling opportunities, and weak industry linkages. Despite the presence of financial grants, training programs, and digital transformation incentives, many SME QS firms struggle to utilize these initiatives due to complex application processes, low awareness, and mismatched program objectives. Regulatory bodies such as CIDB, MDEC, HRD Corp, and BQSM play a crucial role in facilitating these initiatives, but greater enforcement and monitoring are needed to ensure that CDIs effectively reach and benefit SME QS firms.

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As the construction industry in Malaysia continues to evolve and integrate digital transformation, the government and industry stakeholders are expected to enhance capacity development efforts to ensure that SME QS firms remain competitive and sustainable. Stronger enforcement of financial support accessibility, digitalization policies, and competency development programs is necessary to bridge the gaps in the existing capacity development initiatives. Further study is required for future policy refinements and the development of a more integrated, inclusive, and effective capacity development ecosystem for SME quantity surveying consulting firms in Malaysia.

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MULTI-SENSORY ATTRIBUTES IN PERCEIVING CAMPUS OPEN SPACES IN AN URBAN UNIVERSITY IN THE HOT-HUMID CLIMATE

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Abstract

Insufficient outdoor activity leads to physical inactivity, endangering the physical and mental wellbeing of urban residents. This is particularly evident in urban universities within hot-humid climates, where a prevalence of sedentary indoor lifestyles has been linked to increased depression and stress among campus users. Stimulating pleasant sensory experiences can enhance interactive participation in campus green spaces, thereby fostering wellbeing. While the structure of sensory perception plays a crucial role in shaping these outdoor experiences, limited research has explored its multi-sensory dimensions in campus open spaces. This study aims to identify the multi-sensory dimensions of environmental perception in these areas. Using on-site observations and interviews, the research elaborates on the phenomenology of environmental perception. The findings identify key landscape properties and sensory attributes specific to campus open spaces in hot-humid urban universities and establish that these multi-sensory dimensions are positively associated with improved outdoor experiences. However, the tangible manifestation of user engagement stimulated by multi-sensory perception remains uncertain. Further research should, therefore, explore user participation within these environmental settings to facilitate optimal utilisation.

Keywords: Campus open space; multi-sensory perception; outdoor experience; urban university; wellbeing

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INTRODUCTION

Urban citizens who exercise or relax in green spaces regularly are estimated to have fewer health risks than those who engage in physical activities in non-natural venues (Spence, 2020; Ward Thompson et al., 2019; Ellis, 2011). However, due to insufficient green spaces, inadequate interactions with nature have shaped urban residents' living habits into sedentary lifestyles and physical inactivity (De Bell et al., 2020; Ling et al., 2020). Comparatively, university campus users are more likely to be physically inactive, as they are often confined to indoor work and spend less time on outdoor activities (Hazren, 2022; Schultz, 2018). Moreover, the lack of outdoor experience is more prevalent in hot-humid regions due to climatic and habitual reasons (Alattar & Indraganti, 2023). This issue highlights the need for environmental-behavioural interventions to cope with sedentary behaviour, high levels of stress and depression in urban universities (He et al., 2022; Schultz, 2018).

Positive behavioural changes are elaborated through the phenomenology of environmental perception (Gilloran, 2018; Seamon, 2013). This theoretical framework demonstrates the process from perception to reaction, which fosters a sense of place in frequently used open spaces. Landscapes are holistic units that provide stimuli for all senses (Deng et al., 2020). Consequently, multi-sensory perception is key to understanding the ecological phenomenology of the people-place relationship within campus open spaces (Fan et al., 2020). Open spaces adjacent to buildings are particularly important activity areas in hot-humid regions due to their proximity to indoors and high accessibility (Elaouzy & El Fadar, 2022; Harun et al., 2020). These adjacent spaces afford a sense of familiarity and belonging by integrating landscape elements and thoughtful spatial organisation (Spence, 2020). However, the sensory perception of environmental features remains inadequately defined in the context of campus open spaces (Fan et al., 2020). There is a lack of pragmatic evidence exploring how sensory experiences stimulate engagement from the users' perspective. This gap raises a central question: What are the defining attributes of multi-sensory experiences in existing campus open spaces? Accordingly, this investigation aims to reveal the attributes of the multi-sensory perceptual structure in campus open spaces at an urban university in a hot-humid climate. The objectives include 1) to define the environmental settings in selected campus open spaces and 2) to establish users' perceptions of the multi-sensory features afforded by the environmental settings. Figure 1 shows the process from identifying the problem to developing research objectives.

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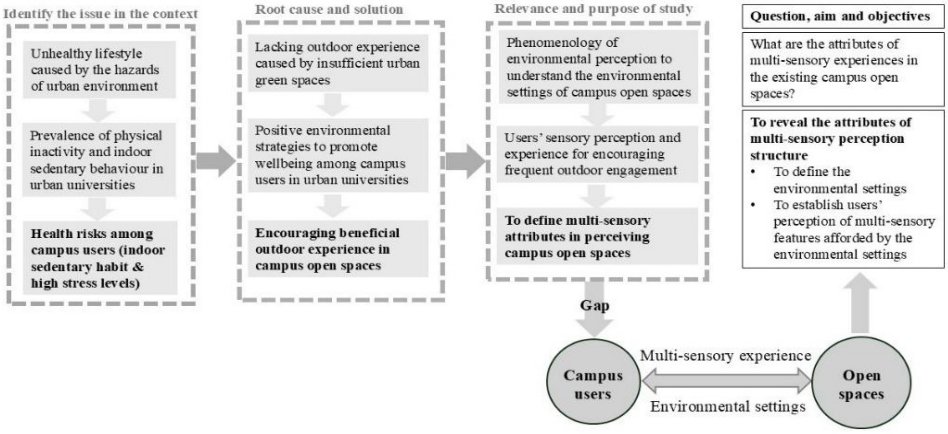


Figure 1: Problem statement, gap, and objectives
Source: Authors

RESEARCH BACKGROUND

The stimulation of multi-sensory perception shapes users' repetitive engagement with campus open spaces. This occurs because sensory stimuli lead to a pervasive, enduring, and dynamic coherence in environmental perception (Abusaada, 2020). Human senses are fundamental to the perceptual comprehensibility of environmental settings (Spence, 2020). Sources of human perception include the five biological senses, in addition to higher-order sensory abilities related to space and atmosphere (Omar & Hussein, 2017; Spence, 2020). Correspondingly, the sensory dimensions of perceptual attributes encompass visual, auditory, olfactory, and tactile perceptions (Gilloran, 2018). For example, the colour and shape of plants' foliage serve as visual attractions in urban parks (Ward Thompson et al., 2019). The texture of finely cut leaves affords a delicate, airy feel, attracting both visual and tactile attention (Lyu et al., 2022; Ellis, 2011). Natural soundscapes, such as those featuring water elements, birdsong, and insect buzzing, elicit pleasant auditory experiences (Li & Lau, 2020). Olfactory perceptions capture the scent of nature, such as fragrances emitted from plant materials (Taylor, 2021). From the perspective of ecological phenomenology, these dimensions of sensory perception construct place memory through continual participation (Gilloran, 2018), resulting in what is known as placeness or a sense of place. Therefore, the sensory attractions in campus open spaces provide pleasant experiences that encourage beneficial outdoor participation as part of users' daily routines.

Optimal sensory perception cultivates wellbeing-beneficial interactions within campus open spaces (Spence, 2020; Ward Thompson et al., 2019). These environmental settings, which incorporate landscape components and spatial

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qualities, determine a specific green space's aesthetic values and functional use (Taylor, 2021; Ellis, 2011). A harmonious balance of hardscape and softscape enables landscape elements to become appealing sensory features (Omar & Hussein, 2017). For example, the sensory attractiveness of vegetation and water features is a cornerstone of sensory gardens (Ellis, 2011; He et al., 2022), as are integrated design elements such as wildlife attractors and supportive facilities (Darkhani et al., 2019). In particular, spatial strategies such as shielding conditions and enclosure are emphasised in sensory design to encourage participation during extreme weather (Spence, 2020). Interacting with these environmental settings stimulates multi-sensory experiences, which in turn form a sense of place that reorients users' recognition of the settings themselves (Li et al., 2023; Seamon, 2013). Therefore, clearly defining both the environmental settings and the dimensions of perceived sensory features can help to elaborate the perception-reaction cycle within campus open spaces at urban universities in hot-humid climates. The theoretical framework for sensory perception in campus open spaces is presented in Figure 2. As illustrated, the study is supported by the integration of sensory perception theory and the phenomenology of environmental perception. This framework is constructed by the perception of physical properties and the subsequent responses to sensory attributes, which together shape multi-sensory experiences in campus open spaces.

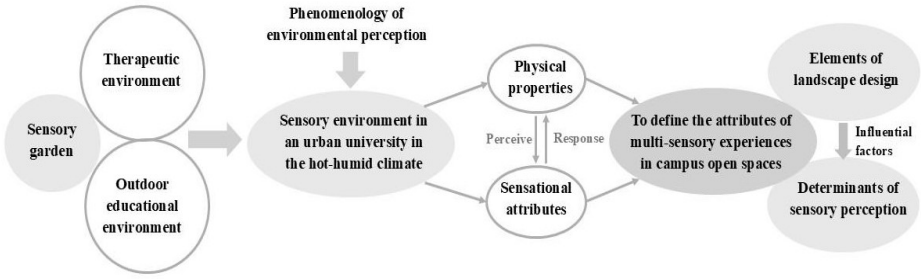


Figure 2: Underpinnings of the multi-sensory attribute in campus open spaces
Source: Authors

METHODOLOGY

Case Study Selection

In Malaysia, passive design strategies for the built environment are strongly supported by local policies (Alattar & Indraganti, 2023). The optimal arrangement of open spaces between buildings is crucial for the success of passive building design (Elaouzy & El Fadar, 2022; Harun et al., 2020). Such spaces within building layouts facilitate climatic adaptation and optimize building performance in hot-humid climates (Chen et al., 2021; López-Pérez et

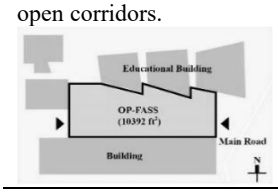
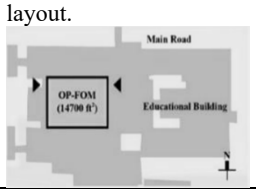
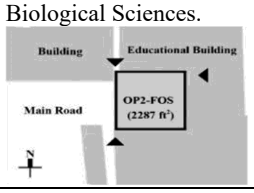
al., 2019). Due to these climatic influences, their design features are more likely to evoke pleasant sensory experiences and form positive user associations. However, this relationship has not been sufficiently investigated in the context of urban universities in hot-humid climates. Given the lack of literature, the primary aim was to establish clear case study selection criteria. Consequently, a preliminary site study was conducted in Kuala Lumpur. As the capital city, it represents typical urban design strategies and experiences a hot-humid climate (Harun et al., 2020). This study compared the physical environments of several urban universities in Kuala Lumpur to explore the environmental and perceptual attributes of their campus open spaces. The criteria for selecting an urban university campus were based on 1) Location and urban environment (Alattar & Indraganti, 2023); 2) Amount and layout of green space (Elaouzy & El Fadar, 2022; Dzhambov, 2018); 3) Development of vegetation (Harun et al., 2020); and 4) Settings of the educational environment (Dzhambov, 2018; Jamaludin et al., 2018). Eventually, the campus of Universiti Malaya (UM) was selected as the case study due to its external environment, history, layout, and academic focus on the physical campus.

The UM campus is a well-known green space within the high-density urban environment of Kuala Lumpur city centre (Bakhshi et al., 2015). Despite its integration with the city's transportation system, which has decreased the time students spend on outdoor exercise on campus (Hazren, 2022), it remains a significant urban oasis. As the oldest university in Malaysia with a history spanning more than five decades, the campus has preserved extensive green spaces within the city centre. Its physical environment is a recognized representation of the green campus concept (Bakhshi et al., 2015). Adjacent open spaces, such as gardens and courtyards, are integral to the campus design, improving daylighting and natural ventilation in residential colleges (Jamaludin et al., 2018). Consequently, the campus has been frequently used as a case study in various investigations aiming to establish an academic focus on sustainable campus environments. These characteristics facilitate more effective data collection regarding the sensory qualities of campus open spaces. Notably, the educational zone—where the core of daily campus life occurs—represents the most significant aspect of the physical campus design (López-Pérez et al., 2019). The open spaces surrounding these educational buildings are the most frequently used and are therefore most likely to represent the daily engaged outdoor environment (Fakourian & Asefi, 2019). This evidence supports the application of a case study focused on these specific sites to investigate the sensory qualities of outdoor environments in urban universities within hot-humid climates. Furthermore, three courtyards adjacent to faculty buildings were selected as case-study sites. The selection was based on several criteria, including size, available amenities, accessibility, location, thermal comfort, safety, proximity to and occupancy levels of educational buildings, and façade design (Elaouzy & El

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Fadar, 2022; Chen et al., 2021; Jamaludin et al., 2018). The layouts of the three selected case-study open spaces are presented in Table 1.

Table 1: Selected open spaces on the UM campus

Case Study 1	Case Study 2	Case Study 3
Located in the Faculty of Arts and Social Science, it is a courtyard surrounded by open corridors.	Located in the Faculty of Medicine, this is a courtyard in the middle of the building layout.	Located in the Faculty of Science, this is a courtyard yard in the Institute of Biological Sciences.
		

Source: Authors

Research Methods and Data Collection

The mixed-methods research strategy began with a preliminary site study to establish case-study selection criteria and develop research instruments. The initial step involved conducting on-site observation, a primary method for evaluating 'sensory function' (Omar & Hussein, 2017; Spence, 2020). This process included field visits and systematic record-keeping (Deng et al., 2020; Hussein, 2012) at the three selected sites to assess and understand the features of their environmental settings. The observation sessions were scheduled during daytime hours on weekdays. Data collected during the observations included narrative notes, videos, photographs, a structured recording checklist, and observation guidelines (Darkhani et al., 2019; Chen et al., 2021). These guidelines covered the physical properties of the selected open spaces—including location, size, layout, types of settings, and user interactions—generating both qualitative and quantitative data. Descriptive analysis was then used to identify the independent factors contributing to the sensory experience. Simultaneously, on-site interviews were conducted with a purposive sample of users who frequently used the selected courtyards. This method effectively captured emotions and behaviours while maintaining the interviewees' focus, sourcing users' self-reported evaluations of sensory quality (Fakourian & Asefi, 2019; Ward Thompson et al., 2019). The interview questions pertained to descriptions of sensory qualities, perceptions of the settings, and preferences for utilisation. A semantic analysis of the resulting qualitative data was conducted to interpret users' sensory perceptions of landscape and spatial qualities. The overall research strategy and methods used to identify the multi-sensory dimensions of the perceptual structure are illustrated in Figure 3.

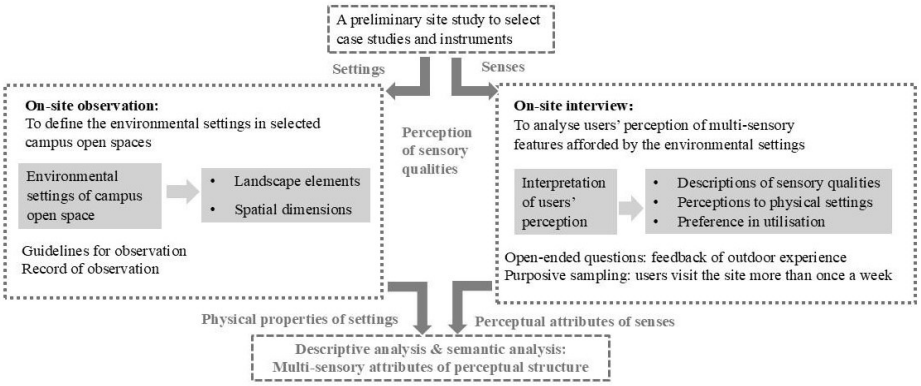


Figure 3: Methods to identify the attributes of multi-sensory experiences
Source: Authors

RESULTS AND ANALYSIS

The selected open spaces are courtyards integrated within faculty buildings, serving multiple educational purposes that include studios and offices. Observations revealed that all three courtyards contained ornamental plants and decorative furniture, which functioned as key attractions supporting outdoor engagement. A detailed inventory of the hardscape and softscape elements present in these spaces is provided in Table 2. The features of these environmental settings and their associated sensory qualities are illustrated in Figures 4 to 6. These figures highlight the specific sensory attributes of landscape elements and spatial qualities that collectively created an appealing atmosphere. As evidenced by the data in Table 2 and Figures 4 to 6, vegetation (functioning as softscapes)—such as shady trees, herbs, and groundcovers—offered pleasant multi-sensory experiences characterized by greenery, naturalness, and freshness. Similarly, the surface textures of furniture and pavements provided tactile satisfaction and invited opportunities for physical interaction and participation. Furthermore, the spatial qualities of the courtyards, particularly the sense of enclosure created by adjacent buildings and walls, enhanced users' sense of belonging and safety by providing defined environmental protection.

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Table 2: Environmental settings in the selected open spaces

Code of site	Types of hardscapes	Types of softscapes
Case Study 1	Footpaths with stairs, wooden benches, four pavilions and couches	Two lawn patches with slopes, matrix-grouped trees, shade trees and shrubs
Case Study 2	Pathways, brick perimeter walls, a stone pergola, a sunken platform with stairs, a central plaza, a decorative flowerpot, two pavilions, four sets of tables and chairs	Shady trees, hedges, shrubs with fragrant flowers and sloping grassland
Case Study 3	Pathways, covered corridors, steps, iron stairs, faculty logo, two sets of tables and chairs	Trees, hedges, shrubs, herbs, and potted flowers

Source: Authors

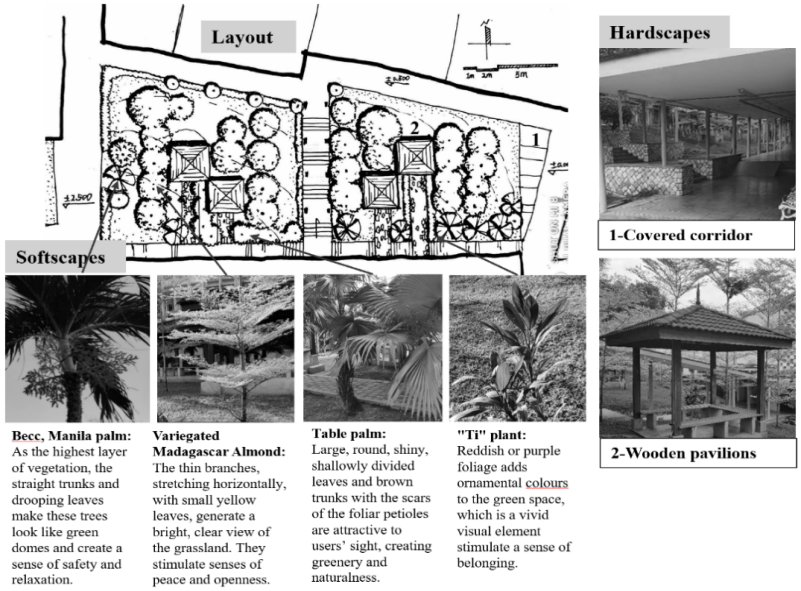


Figure 4: Qualities of environmental settings in Case Study 1
Source: Author

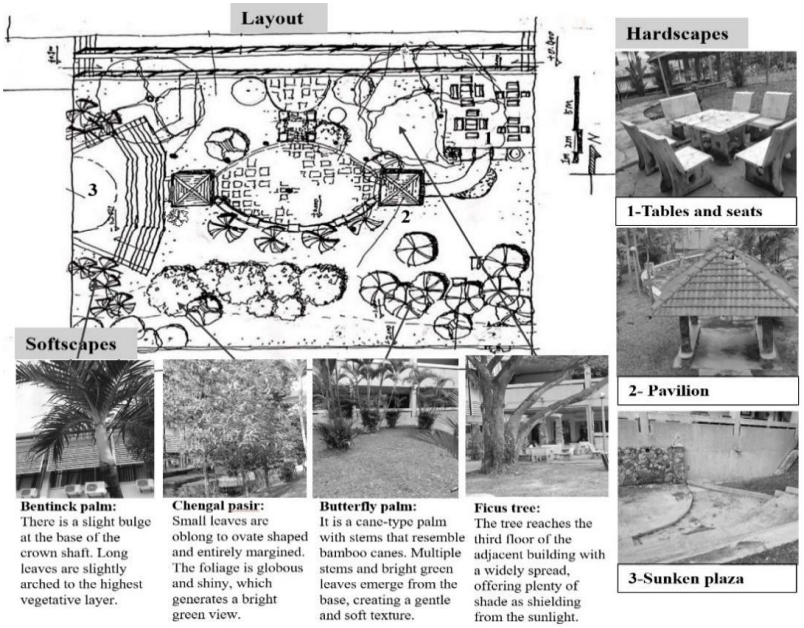


Figure 5: Qualities of environmental settings in Case Study 2
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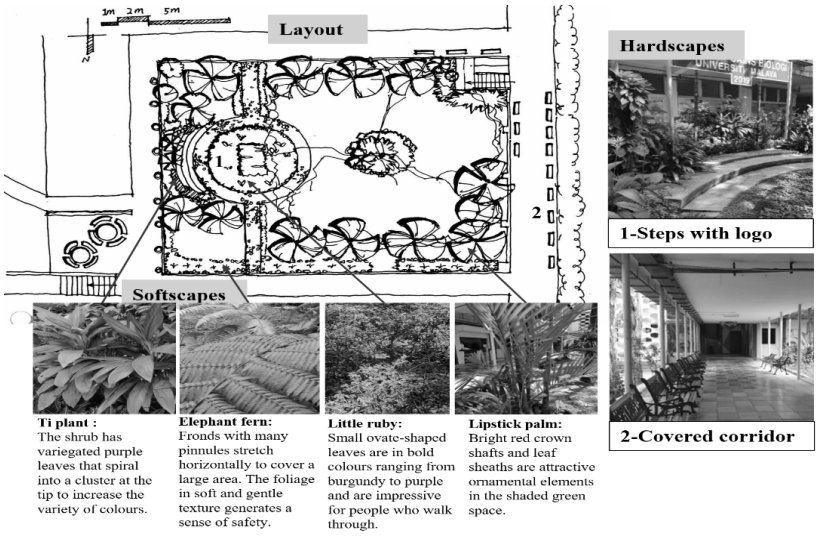


Figure 6: Qualities of environmental settings in Case Study 3
Source: Author

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The interview results regarding the perception of sensory features in the case-study open spaces are presented in Table 3. As the data indicate, the identified dimensions of sensory features stimulate a sense of place, fostering feelings of familiarity and belonging. These positive associations between user perception and the physical settings represent new sensibilities cultivated through repetitive engagement. The prevalence of these positive emotions in the responses denotes the significant wellbeing potential of outdoor engagement in these open spaces.

Table 3: Sensory perceptions of environmental settings

Settings	**Perception**	Vision	Micro-climate	Texture /Touch	Smell	Sound	Aroused emotions
Spatial qualities	External context	*			*	*	Placeness: Familiarity Sense of belonging Feelings: Relaxation Less stress Calmness Restoration Recovery Enjoyment
	Spatial layout	*	*				
	Building façade	*	*			*	
Hardscapes	Corridors		*	*			
	Wooden pavilions	*	*	*			
	Seats & tables	*		*			
	Pavements	*		*			
	Steps & paths	*		*			
Softscapes	(Shady) trees	*	*		*	*	
	Shrubs & hedges	*	*	*	*	*	
	Flowers & herbs	*			*	*	
	Groundcover	*		*	*		

Source: Authors

DISCUSSION

The environmental features and physical properties shape the multi-sensory perceptual structure, as illustrated in Figure 7. Visual perceptions of landscape components, such as the form and colour of plants, served as primary attractions (Deng et al., 2020), motivating users' outdoor engagement. This finding confirms the view of Lyu et al. (2022) that vegetative landscapes are among the most attractive elements. However, the role of other senses differed from previous studies. Unlike Ellis's (2011) assertion that the texture of shrubs and herbs functions primarily as a vivid visual attraction in sensory gardens, in these campus open spaces, elements like texture and microclimate were perceived largely through tactile means. The adjacent walls and shady trees provided crucial shielding conditions to ameliorate the microclimate (Lyu et al., 2022), a necessary adaptation as climatic demands shift the focus of comfort needs. Furthermore, interview results indicated that the textures of furniture and pavements offered tangible participation opportunities, enhancing the accessibility of these spaces. The interviews also revealed complexities in auditory perception, contrasting with Li and Lau (2020). The sounds captured in the campus open spaces were not always pleasurable. While rustling leaves stimulated a sense of freshness and naturalness, noise pollution from external surroundings—such as automobiles

and machinery—degraded the overall quality of the auditory environment. Olfactory perceptions also played a key role. Vegetation provided distinctive olfactory information, such as the fragrance of flowers and the scent of fresh-cut grass, which contributed to a pleasant atmosphere (Taylor, 2021). Collectively, both sound and smell were found to play significant roles in constructing sensory comfort and cultivating place memory (Gilloran, 2018; Abu-Ghazzeh, 1999). These findings indicate that campus users are highly aware of multi-sensory experiences and that a pleasant microclimate, achieved through strategic shading and enclosure, is a fundamental prerequisite for enabling them.

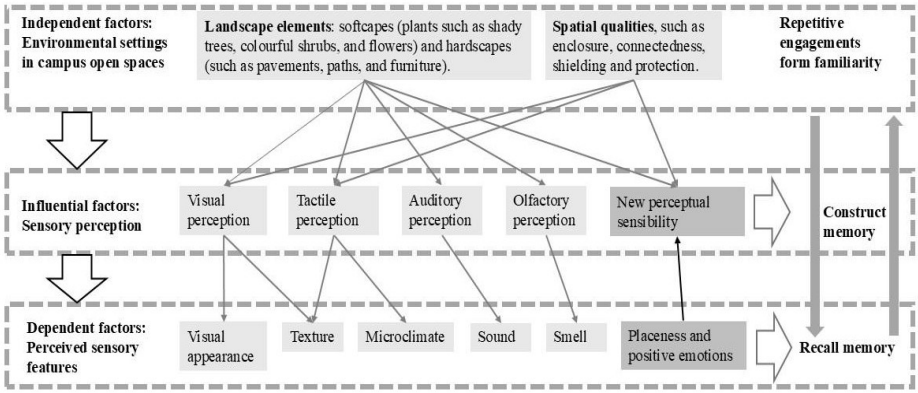


Figure 7: Multi-sensory attributes in campus open spaces
Source: Authors

As shown in Table 3 and Figure 7, familiarity evoked a sense of belonging, which in turn enhanced positive emotions, aligning with the findings of Gilloran (2018). Through this process, placeness and emotional arousal developed as new sensibilities forged through the experience of campus open spaces (Fan et al., 2020; Omar & Hussein, 2017; Seamon, 2013). The stimulation of these pleasurable sensory experiences serves to motivate optimal participation (Abusaada, 2020; Ward Thompson et al., 2019). This intervention ultimately helps to offset the negative wellbeing outcomes caused by physical inactivity and indoor sedentary behaviour, such as depression and stress (Alattar & Indraganti, 2023). Within this framework, environmental settings functioned as independent variables shaping the perception of sensory features. Elements such as the shape and colour of landscape components were identified as features with significant aesthetic value (Spence, 2020; Ward Thompson et al., 2019; Gilloran, 2018). However, interview data revealed that these visually attractive features did not, by themselves, reliably lead to the desired behavioural interactions with the settings. This result suggests that aesthetic value alone is insufficient to support sustained outdoor activities among campus users (Deng et al., 2020).

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In contrast, shaded areas with fewer overt visual attractions provided better shielding conditions, which is a critical factor in a hot-humid climate (Chen et al., 2021; Jamaludin et al., 2018). These environmental protections created more comfortable microclimates, which were a primary factor in attracting users (Fakourian & Asefi, 2019). This pleasurable sensory experience—centered on thermal comfort—supports the functional use of enclosed open spaces. Consequently, this finding suggests that in hot-humid climates, campus users prioritize sensory comforts, particularly microclimatic comfort, over purely aesthetic qualities in the environmental settings of these open spaces.

Consequently, vegetation emerged as the most critical element in creating a desired atmosphere (He et al., 2022; Ellis, 2011), primarily because plants stimulated sensations of freshness and naturalness in the campus open spaces. However, interviewees reported that water features were among the least desired landscape components, often due to associated thermal discomforts, such as increased humidity. This finding contrasts with Li et al. (2023), who identified water features as highly appealing natural elements. This discrepancy can be attributed to variations in climatic conditions, underscoring the critical importance of climate-adaptive design (Chen et al., 2021; Jamaludin et al., 2018) for optimising users' sensory satisfaction. The spatial dimensions of courtyards surrounding educational buildings provide optimal shielding and protection from weather hazards. The enclosure created by adjacent buildings enhances outdoor engagement in hot-humid climates by offering refuge from sun and rain (Fakourian & Asefi, 2019; López-Pérez et al., 2019). Consequently, these courtyards function as both behaviour-interactive and climate-adaptive spaces. Contrary to Tafti et al. (2018), who emphasized that enclosure promotes safety and privacy, this study found that in a hot-humid context, the primary driver for engagement is the protection from weather hazards that enclosure provides. This finding denotes that the same behavioural setting—enclosure—can evoke different sensory perceptions and functional values depending on its spatial and climatic milieu.

CONCLUSION

The multi-sensory perceptual structure comprises three core components: environmental settings, sensory perception, and perceived sensory features. Environmental settings—including spatial qualities, softscapes, and hardscapes—function as independent variables that shape the perception of sensory features. These features are categorized into six perceptual dimensions: visual appearance, texture, microclimate, sound, smell, and a higher-order dimension of new sensibility, which encompasses placeness and positive emotions. The process of perception is mediated by individual sensory channels, primarily visual, tactile, auditory, and olfactory. This integrated process constitutes the multi-sensory perceptual structure for campus open spaces. This

structure elucidates the cause-effect cycle of multi-sensory stimulation, grounded in the phenomenology of environmental perception. Ultimately, this dynamic model provides landscape architects with an evidence-based framework for designing interactive and engaging campus open spaces that actively promote user wellbeing.

The perception of desirable environmental qualities contributes to pleasurable sensory experiences, which foster positive associations that, in turn, encourage repeated outdoor participation. This occurs because a satisfying outdoor experience enhances campus users' psychological wellbeing by providing sensory-comfort qualities in frequently used open spaces. Over time, this pleasurable sensory perception is optimized through repetitive engagement, forming a sense of familiarity that stimulates placeness and positive emotions. However, despite these insights, there remains a limited understanding of the specific patterns of user participation. Therefore, further research is needed to explore and quantify users' behavioural interactions within existing open spaces at urban universities. Based on these findings, it is recommended that campus planners and administrators of higher education institutions prioritize both the climatic adaptiveness of campus landscapes and users' subjective sensory perceptions to effectively promote beneficial outdoor engagement.

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EXPLORING AFFORDANCES IN CHILD-FRIENDLY URBAN GREEN SPACES: IMPACTS ON ACTIVITY PATTERNS AND DEVELOPMENTAL NEEDS

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Abstract

Child-friendly urban green spaces (UGS) are outdoor environments that offer diverse opportunities for play and support children's holistic development. From an ecological perspective, these spaces provide rich affordances that encourage autonomous exploration and interaction. However, planning and design remain predominantly adult-driven, often resulting in a misalignment between the affordances available and those perceived or used by children. This study investigates how different types of affordances in UGS shape children's activity patterns and behaviours. Using behavioural mapping in three distinct UGS settings, the research systematically examines the relationship between children's activity preferences and environmental attributes. Findings show that children actively explore their surroundings, discovering actual affordances while gradually recognising potential ones and transforming them into new utilisable opportunities. Their needs for environmental attributes vary, and they adjust their engagement by balancing support and challenge in line with ability levels and developmental goals. These dynamics highlight the critical role of affordance-rich UGS in fostering children's adaptive development and underscore the importance of designing spaces that align with children's perspectives.

Keywords: Affordance, Behavioural Mapping, Children's Behaviour, Urban Green Spaces

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INTRODUCTION

The relationship between children and their environment is established primarily through active interaction (Altman, 2012). As children engage in outdoor activities, they gradually form personal connections with their surroundings (Slingerland et al., 2020). These interactions are influenced by the distinct physical, social, and cultural contexts that evolve across time and space. In recent decades, however, children's independent mobility has markedly declined, particularly in China, where numerous factors constrain their freedom of movement (Tang et al., 2023) . A key driver of change in child-environment relations is the emergence of the child-friendly cities agenda (Cordero-Vinueza et al., 2023; Guo et al., 2022).

Extensive research consistently demonstrates a robust correlation between frequent engagement with green spaces during childhood and improved mental health in adulthood (Lanza et al., 2021; Tandon et al., 2021). Regular interaction with nature reduces stress, enhances emotional regulation, and fosters long-term psychological well-being (Li et al., 2022). Conversely, the rising use of electronic devices and social media contributes to sedentary behaviour and may exacerbate behavioural difficulties (Girela-Serrano *et al.*, 2024; Warda *et al*., 2023). At the same time, structured and intensive academic commitments have reduced children's opportunities for unstructured outdoor activity (Holland, 1997; Masarik & Conger, 2017).

Despite these benefits, children's opportunities to interact with nature are declining under accelerating global urbanisation (Kusumo Dewi et al., 2020; Vidal & Castro, 2022) . Soga et al. (2016) observed that diminished interaction with nature remains underexplored despite its negative implications for health and well-being. Limited outdoor experiences can generate fear or hesitation toward natural environments (Mustapa et al., 2020), reinforcing misconceptions about safety. Reduced contact also decreases the likelihood of children developing an affinity with nature, weakening future motivation to protect it (Barrable et al., 2021; Leung et al., 2022) .

Urban green spaces (UGS) play a critical role in reversing this trend by providing diverse opportunities for physical activity (Bao et al., 2023), stimulating imagination (Song et al., 2018), and encouraging constructive play (El-Kholy et al., 2022). Engagement is particularly strong when natural elements are integrated into play spaces rather than treated as separate features (Aminpour, 2021). Recognising children as primary users of UGS underscores the importance of understanding their behavioural patterns, which can inform design and planning practices.

This study employs behavioural mapping to document children's activity patterns in UGS. Behavioural mapping objectively links observed activity with spatial characteristics (Cheuk, 2016) and has been widely applied in

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urban streets, childcare centres, schools, hospitals, and community open spaces (Blennerhassett et al., 2018; Onojeghuo et al., 2019). In child-focused research, it provides a particularly effective tool for capturing the complexity and variability of children's behaviours (Onojeghuo et al., 2019).

The analytical framework is grounded in affordance theory, which highlights the relationship between environmental attributes and the behavioural opportunities they present (Gibson, 1983; Kyttä, 2004). Affordances are directly perceived by individuals, allowing for immediate recognition of potential uses. Applying this framework enables a deeper understanding of how attributes of UGS facilitate different activities. Building on this foundation, the study explores how behavioural mapping can reveal the complexities inherent in child–environment interactions and generate insights for policies and interventions that support the design of genuinely child-friendly UGS.

RESEARCH METHODOLOGY

Case Study Site

Shanghai, one of China's fastest-developing cities, has recently introduced a series of urban development initiatives aimed at creating a more child-friendly environment. Guided by the Shanghai Ecological Space Plan (2021–2035), the city envisions itself as a global metropolis distinguished by innovation, culture, and ecological sustainability (Shanghai Landscaping and City Appearance Administrative Bureau, 2021). Within this framework, the development of child-friendly cities has become a key priority for enhancing Shanghai's human-centred urban environment.

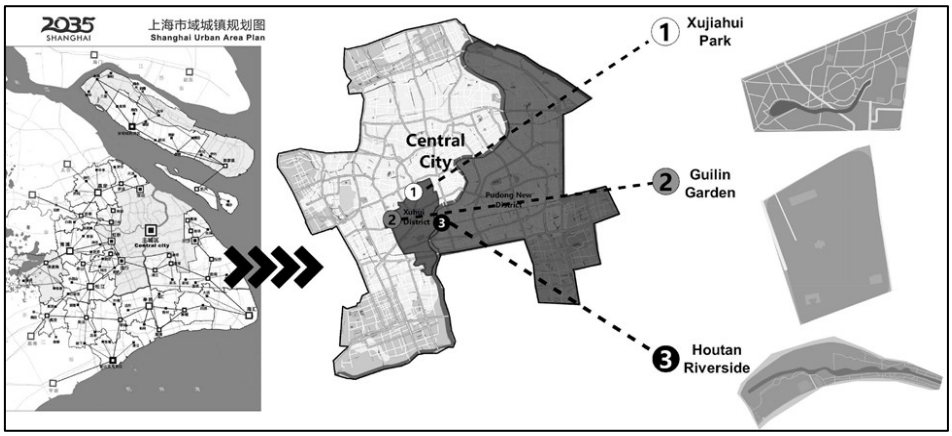


Figure 1: The location of Guilin Garden, Xujiahui Park, and Houtan Riverside in the centre of Shanghai
(Source: Author 2025)

This study focuses on the central urban districts of Shanghai (Figure), selecting high-density UGS that are representative of the environments children commonly access in their daily lives. According to the Standard for Classification of Urban Green Space of China (CJJ/T85-2017), UGS comprise both natural and artificial vegetation and provide ecological, aesthetic, and recreational benefits, offering residents high-quality green environments (Ministry of Housing and Urban-Rural Development of China, 2017).

A preliminary survey of UGS across the central districts was conducted to evaluate variations in landscape features and facility conditions. To capture the diversity of Shanghai's UGS, three representative sites were selected: Xujiahui Park, a modern park located in a bustling commercial hub; Guilin Garden, which exemplifies the aesthetics of traditional Chinese gardens; and Houtan Riverside, a waterfront park along the Huangpu River that integrates distinctive ecological landscapes with urban design. All three sites maintain steady visitor flows and well-established facilities, making them suitable for examining children's activities and interactions with their environments.

Categories Affordances and Attributes of UGS

The study adopts an affordance classification framework adapted from Kyttä's (2002) typology of child-environment affordances (Table). In research on human-environment interactions, reclassifying physical environment attributes within different specific analytical frameworks is a common and valuable approach. Such categorisation refines understanding of how environmental characteristics shape behaviour, thereby supporting more effective alignment between environmental design and human use.

Table 1: Categories of Children's Environmental Affordances (adapted from Kyttä, 2002; Niu, 2024)

Affordance Categories by Kyttä (2002)		**Affordance Categories in UGS by Niu (2024)**		
Affordances Categories	**Affords**	**Attributes**	**Affordances Categories**	**Physical Elements**
1. Flat, relatively smooth surfaces	Cycling, running, skipping, skating, hopscotch, skiing, playing (e.g., football, ice hockey, tennis, badminton)	1. Accessibility	Flat, relatively smooth surfaces	Paths, flat ground, wooden boardwalks, lawns, muddy ground, gravel, woodchip surfaces, curbs
2. Relatively smooth slopes	Coasting down, skateboarding		Relatively smooth slopes	Accessible paths, ramped steps, stairs, hillsides

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Affordance Categories by Kyttä (2002)		**Affordance Categories in UGS by Niu (2024)**		
Affordances Categories	**Affords**	**Attributes**	**Affordances Categories**	**Physical Elements**
3. Graspable/ detached objects	Throwing, digging, building, playing with animals, using plants in play	2. Activities	Climbable features	Big rocks, rockeries, slides, flower beds, tree branches
4. Attached objects	Jumping over jumping down from		Mouldable materials	Soil, sand, loose leaves, loose bark
5. Non-rigid, attached objects	Swinging, hanging	3. Aesthetics	Attached objects	Animals, plants, sculptures, flower beds
6. Climbable features	Climbing, looking out from		Ponds, rivers	Ponds, rivers, water features
7. Shelter	Hiding, being in peace and quiet	4. Amenities	Attached objects	Benches
8. Mouldable materials	Molding something, building of snow structures		Shelter	Pavilions, covered walkways
9. Water	Swimming, fishing, play	5. Safety	Attached objects	Fences, streetlights
10. Affordances for sociality	Role-play, rule games, playing house, noisy, following/sharing adults			

Accessibility attributes include “Flat, relatively smooth surfaces” and “Relatively smooth slopes.” These elements improve inclusivity by reducing physical barriers and enabling children of differing abilities to engage in varied activities. They are therefore fundamental to ensuring access and broad participation.

Activities include “Non-rigid, attached objects”; “Climbable feature” and “Mouldable materials.” These features encourage play and exploration, supporting development that ranges from simple physical engagement to more complex emotional and cognitive growth.

Aesthetics draws on “Attached objects” (e.g., animals, plants, sculptures, flower beds), “Water” (e.g., pools, rivers), and “Shelter” (e.g., pavilions, covered walkways). Together, they enrich visual and sensory appeal and promote psychological comfort in UGS.

Amenities are represented by “Attached objects” (e.g., benches) and “Shelter,” which provide comfort and convenience for users.

Safety is reflected in fences and streetlights, essential for ensuring security and reducing risks.

Data Collection

Behavioural mapping was conducted between May and August 2023. The initial phase involved on-site measurements to produce detailed maps of the selected UGS, incorporating recent construction and maintenance works. Preliminary site observations were then carried out to determine suitable observation areas and points. These were selected according to criteria requiring unobstructed visibility of relevant site features while ensuring observer inconspicuousness, thereby minimising disturbance to children's behaviour (Engelen *et al*., 2018; Baker, 2006). Establishing these observation points enabled accurate documentation of children's interactions with the UGS (Romero-Ternero et al., 2022).

Prior to formal data collection, an A3-sized observation checklist was prepared. The upper section contained a detailed printed map of each study site, while the lower section listed categories of children's behaviours linked to UGS affordances (Hussein, 2009). The checklist was designed to capture contextual details such as activity location, timing, and weather conditions. To ensure data accuracy, the researcher maintained sufficient distance from children to avoid influencing their behaviour. This unobtrusive approach aimed to record spontaneous behaviours within UGS and to emphasise behavioural characteristics rather than participant numbers. This distinction was important, as the study's primary aim was to identify the types of affordances present, and the validity of the analysis did not depend on the exact number of children observed.

ANALYSIS AND DISCUSSION

Preliminary Results

From the organisation and statistical analysis of observational data, the study assessed the affordance levels available to children across the three case study sites (Figure). A total of 2,237 affordance instances were recorded, categorised into perceived affordances (PA), utilised affordances (UA), and shaped affordances (SA). Children's behaviours, central to cognitive development, were observed to progress in successive stages: beginning with practice activities (repetitive movements like running or climbing), advancing to symbolic activities (using objects imaginatively, such as a stick as a sword), and culminating in games governed by rules. For these developmental transitions to occur, the functional attributes of the environment must align with the children's evolving capabilities and maturity.

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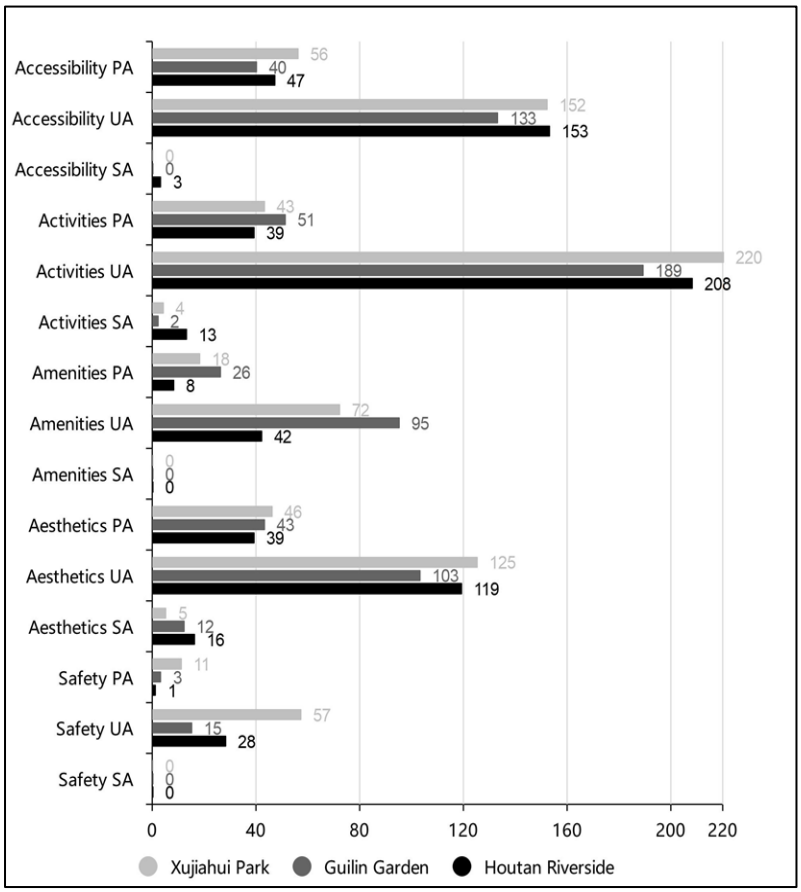


Figure 2: Distribution of perceived, utilised, and shaped affordances across attributes in the three case study sites
(Source: Author 2024)

Among the three sites, Xujiahui Park demonstrated clear advantages, recording the highest frequencies of both utilised (626 instances) and perceived (174 instances) affordances. This pattern indicates a wide diversity of perceptible features and highlights the park's capacity to provide abundant opportunities for interaction and activity. By contrast, Houtan Riverside exhibited the highest frequency of shaped affordances (32 instances), suggesting that its open and natural characteristics create greater opportunities for children to influence and modify their environment. Guilin Garden demonstrated a more balanced distribution across perceived, utilised, and shaped affordances, although the frequencies were slightly lower in each category compared with the other two sites.

Activities

This study investigates which UGS attributes provide children with the most diverse affordance experiences. The results indicate that activity-related attributes offer the richest opportunities. Children's interactions with green spaces are strongly shaped by climbable and malleable features such as boulders, rockeries, and tree planters. These features were frequently chosen as preferred sites for rest and play. Within them, children engaged in varied activities, including climbing, jumping, and standing on elevated points to experience height and speed. Such physical and sensory experiences enhanced participation and deepened engagement with UGS.

These findings align with recent research: Fajrie *et al.* (2024) observed that natural or nature-inspired elements (such as rocks) enrich children's sensory experiences and support artistic learning. However, this study also identifies limitations in these features compared with purpose-built activity facilities, particularly in functionality and safety. Previous studies show that professionally designed climbing structures more effectively promote the development of advanced motor skills (Bergen, 2021). While the boulders and rockeries stimulated exploration, they were not designed with children's needs or varying skill levels in mind.

Because the study sites generally lacked facilities specifically intended for children, their play behaviours largely represented passive adaptations to existing conditions. This reflects spatial constraints rather than a positive developmental trend.

Accessibility

As the most fundamental physical attribute encountered by children outdoors, ground surfaces significantly shape the quality and diversity of their activities. Across the three study sites, the predominant surfaces included paved brick, concrete, lawn, soil, sand, cobblestone, wooden boardwalks, and rubberised surfaces. Children's activities on these surfaces ranged from walking and observing to running, racing, and socialising with peers.

Observations revealed a clear preference for smooth and even surfaces, valued for the safety and comfort they provide. Such surfaces enable children to participate more confidently in a wide range of activities, including cycling, scooter riding, and running games.

At the same time, textured surfaces, such as pebbles, bark chips, and cobblestones, were also appealing. Their distinctive shapes and malleability often triggered spontaneous play behaviours, with children picking up loose fragments to build small towers or arrange patterns. These diverse ground materials created conditions for both high-intensity physical activities (e.g., running and cycling)

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and low-intensity exploratory behaviours (e.g., digging in sand and collecting pebbles).

Amenities

The primary function of amenities in UGS is to provide essential services such as restrooms, drinking water stations, and seating areas. Observations from this study revealed that facilities were generally designed with adult users in mind, often overlooking children's physical dimensions and behavioural characteristics. This limited accessibility and usability underscores the importance of designing amenities that consider children's physical size, movement patterns, and cognitive abilities (Islam et al., 2016; Jansson et al., 2022).

Pavilions and covered corridors, common features in Chinese UGS, extend beyond their intended purpose of providing shade and shelter. They emerged as key spaces for children's rest, leisure, and social interaction. For example, the pavilion in Xujiahui Park, adjacent to Huijin Lake, functioned as a primary gathering point where children shared snacks, played with toys, and engaged in peer social activities. Zhao *et al.* (2023) noted that semi-open facilities of this kind enhance children's sense of belonging and security, while also supporting social connections.

Children frequently engaged in creative "unintended uses" of these amenities. Pavilion benches, for example, became launch pads for long-jump contests or hiding spots during games of hide-and-seek. Such adaptations highlight children's active reinterpretation of environmental functions, demonstrating the flexibility of amenities as play resources (Dinkel et al., 2019; Parrott & Cohen, 2020).

Safety

Safety attributes in UGS are typically ensured through surveillance cameras, security personnel, and fences. Observational data, however, showed that fences were the only feature with which children interacted directly. Fences, while serving as physical boundaries, displayed notable functional ambiguity(Perry et al., 2018; Taylor et al., 2019) . Specifically, children crawled under, climbed over, or attempted to lift them. These behaviours illustrate both children's developing understanding of spatial boundaries and their instinctive drive to test and explore their surroundings.

Fences also became focal points for social play, inspiring group activities such as chasing games and obstacle races. This indicates that, beyond their safety function, fences contribute to peer interaction and cooperative play. The findings suggest that child-friendly fence design should balance basic protective functions with opportunities for active engagement.

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Aesthetics

From an aesthetic perspective, UGS function as dynamic environments that stimulate children's sensory and imaginative development. Plants, such as sturdy tree trunks or fallen leaves, provided opportunities for climbing, collecting, and creative play. Some boys showed a particular preference for collecting longer branches to use as walking sticks or play props, highlighting the multifunctionality of these materials as tools for drawing in the soil, props for role-playing, or instruments for tapping various surfaces.

Similarly, the presence of animals and water transformed landscapes from passive scenery into interactive settings. In particular, the presence of animals such as goldfish, turtles, and swans in ponds garners substantial attention from children, who can close observe and directly with these species through activities like feeding or attempts to capture them. These interactive experiences not only satisfy children's inherent curiosity and desire to explore natural environments but also deepen their understanding and awareness of biodiversity. Beery & Jørgensen (2018) highlighted that animals encounters within UGS substantially strengthen children's connection to nature and enhance their environmental awareness, aligning closely with this study's findings regarding the fulfilment of children's exploratory needs. Moreover, Melson et al. (2025) emphasized that biodiversity within UGS positively influences children's psychological well-being and emotional development.

At the same time, tensions emerged between these natural affordances and safety concerns. While unstructured interaction with plants, animals, and water is crucial for children's cognitive, emotional, and ecological development, parental restrictions often limit such experiences. This tension highlights the need to balance safety considerations with opportunities for free exploration to fully realise the aesthetic and developmental value of UGS for children.

CONCLUSION

Child-friendly UGS are outdoor environments that offer diverse opportunities for children's activities. From an ecological perspective, these spaces should provide rich affordances. However, current planning and design practices remain largely adult-driven, often overlooking children's actual needs. This disconnects results in a misalignment between the affordances intended by designers and those children perceive and use.

This study demonstrates that children actively explore UGS, seeking challenges through interactions with available affordances. Over time, such engagement enables them to recognise latent affordances and transform them into new, utilisable ones.

The findings highlight a clear imperative for urban planners and policymakers: to move beyond adult-centric approaches and deliberately create

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environments responsive to children's needs and rights. Providing rich, dynamic, and non-prescriptive spaces supports autonomous exploration, which is essential for healthy development. Such transformation is not simply a matter of adding amenities but of reorienting urban design towards equity, inclusion, and sustainability.

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KEY FACTORS IN DEVELOPING TOURIST PEDESTRIAN ROUTES IN THE HISTORICAL CITY OF KHIVA

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Abstract

Optimizing pedestrian routes in historical cities is crucial for balancing heritage preservation and tourism accessibility. Despite growing interest in structured tourist pedestrian routes (TPRs), studies on pedestrian movement in heritage sites often lack quantitative analysis of efficiency and infrastructure deficiencies. This study addresses these gaps by analysing pedestrian flow dynamics in Khiva's historic centre using field observations, pedestrian flow modelling, and regression analysis. Results indicate that inadequate infrastructure, unprotected walkways, and insufficient safety measures hinder movement efficiency, especially at key intersections during peak evening hours. Regression analysis demonstrates that increased pedestrian density reduces mobility, emphasizing the need for simulation-based planning. Findings highlight the complexity of pedestrian behaviour and the importance of strategic urban design. This study provides recommendations for designated pedestrian corridors, improved safety features, and inclusive infrastructure, contributing to sustainable urban planning and tourism management while preserving cultural heritage in Uzbekistan's historical cities.

Keywords: Tourist Pedestrian Routes (TPR), urban planning, pedestrian flow modelling, historical city infrastructure, sustainable tourism development

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INTRODUCTION

Uzbekistan has prioritized the development of its tourism sector through a series of national policies and strategic frameworks. The Decree of the President of the Republic of Uzbekistan No. PF-5781 (2019) and the Resolution No. PQ-4755 (2020) emphasizes the expansion of tourism infrastructure while ensuring compliance with safety regulations (Kakhkharov et al., 2020). Additionally, the Central Asia Regional Economic Cooperation (CAREC) Tourism Strategy 2030 outlines long-term goals to position the region as a prominent tourism destination (*CAREC Tourism Strategy 2030*, 2020). Despite significant investments in Uzbekistan's tourism industry, research on optimizing pedestrian routes in historical cities remains limited (Dai et al., 2024). While cities like Samarkand and Bukhara have established tourist pedestrian routes (TPRs) 4, Khiva's unique urban fabric presents distinct challenges, including narrow streets, congestion hotspots, and inadequate pedestrian infrastructure. Islamic art and architecture, with their intricate geometric patterns and calligraphic inscriptions, play a vital role in defining the cultural and aesthetic identity of these historical cities, making their preservation crucial for both heritage conservation and tourism development (Baydoun et al., 2023, 2024; Dariyadi et al., 2022). Existing studies focus broadly on tourism development but lack detailed investigations into how pedestrian movement efficiency is affected by urban design constraints in historical areas (Baydoun et al., 2025). Addressing these gaps is essential for ensuring sustainable and accessible tourism experiences in Khiva (Jamshid, 2024). This study aims to analyse the key factors influencing the pedestrian movement in Khiva's historic centre, particularly within Ichan Qala. By employing field observations, pedestrian flow modelling, and regression analysis, the findings from this study will support policymakers in implementing evidence-based improvements for sustainable tourism management in Uzbekistan's historical cities. Previous studies on pedestrian flow in heritage cities have employed diverse methods, such as social force modelling (Helbing & Molnár, 1995), agent-based simulations (Johansson, 2009), and case studies in Asian heritage towns (Chen, Dong, & Zheng, 2018). Referring to these approaches strengthens the methodological basis for the present study.

METHODOLOGY

This study employs a mixed-methods approach, combining qualitative and quantitative techniques to analyse pedestrian movement efficiency in Khiva's historical centre. The research integrates a literature review, field observations, mathematical statistics, and correlation regression analysis to assess key factors influencing pedestrian mobility.

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Data Collection
Pedestrian movement in Ichan Qala was tracked via visual observation and video analysis at six high-traffic intersections over three weeks. Footage provided data on density, speed, and movement, validated by manual counts at peak and off-peak hours.

Regression Analysis
A correlation regression analysis was performed to examine the relationship between pedestrian density and walking speed. The regression model considered variables such as time of day, infrastructure quality (e.g., sidewalk width, surface conditions), and pedestrian density per square meter. This approach allowed for a comprehensive assessment of how spatial and environmental factors influence pedestrian flow within Ichan Qala.

Sample Selection Rationale
The study focused on high-traffic pedestrian zones in Ichan Qala, where movement bottlenecks and congestion are most evident. Site selection was based on historical significance, tourist footfall, and accessibility challenges. The chosen intersections include entry and exit points, key tourist attractions, and commercial zones to ensure a representative analysis of pedestrian mobility patterns.

Tourist Movement and activities
Survey data links pedestrian behavior to tourism trends. In Uzbekistan, 57.2% of tourists travel in groups, with higher rates among North American (85.0%), Asia-Pacific (81.0%), European (78.1%), and Middle Eastern (72.0%) visitors. Solo travel is more common among Central Asian (50.5%) and CIS (46.0%) tourists. Popular activities include shopping, museums, walking tours, and historical excursions, with Central Asians favoring shopping (39.7%) and walking tours (31.9%), while Europeans prefer museums (77.5%), excursions (60.6%), and historical tours (54.1%).

Regional Distribution
Tashkent remains the most visited destination in Uzbekistan, with 58.0% of tourists reporting overnight stays. Other major destinations include Samarkand (31.0%) and Bukhara (25.6%), while Khiva accounts for 13.3% of tourist visits 888. By incorporating these methodological refinements, the study provides a structured and data-driven approach to understanding pedestrian movement in Khiva, ensuring greater clarity in data collection, analysis, and site selection.

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TOURIST ROUTES IN UZBEKISTAN

Tourist routes in Tashkent city

Tashkent blends modern and historical attractions, with most tourist sites in the Old City, which preserves the city's cultural heritage amid urbanization (Doniyorov & Karimov, 2024). Visitors explore its traditional homes, mosques, markets, and Soviet-era landmarks like the Tashkent TV Tower and Independence Square. Tour agencies offer excursions from $30 to $200, with options ranging from bus tours to walking tours focused on the Old City, while the metro connects key sites.

Tourist routes in Samarkand city

Samarkand, a top tourist destination, boasts rich history, unique architecture, and a favorable climate (Khamroev, 2024). Its layout evolved through various eras, from lush gardens and canals in ancient times to Timurid grandeur and Russian-influenced planning. The city features a radial-circular street pattern, with Abromovsky Boulevard once marking the old-new city divide. Restoration efforts since 1918 preserve landmarks like Gur-e-Amir and Registan, with pedestrian routes enhancing visitor experiences (Sukma & Telaumbanua, 2024).

Tourist routes in Bukhara city

Bukhara's historic center, anchored by the Poi-Kalyan complex and Toqi Zargaron trading dome, preserves its cultural identity (Bolikulovich, 2021). The Ulughbek and Abdulazizkhan madrasahs stand to the east, while Lab-i Hauz, with its octagonal pool, reflects medieval planning. Once dense with caravanserais and trading hubs, the city's layout evolved within narrow streets and domed corridors, though demolitions have altered its cohesiveness. Each Uzbek city possesses a distinct urban style, historical landmarks, and planning principles (Yakhyayev et al., 2024). While similarities exist, a closer study reveals fundamental differences. Khiva, for instance, has its own unique characteristics but faces greater challenges due to its compact layout and extreme climate. This research, therefore, focuses on solutions and proposals tailored to Khiva’s specific conditions. Compared to Samarkand and Bukhara, Khiva’s compact urban form and narrow alleys increase congestion risks, making it more vulnerable during peak tourist hours. This contrast underscores the need for solutions tailored specifically to Khiva’s unique morphology.

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ORGANIZING TOURIST PEDESTRIAN ROUTES BASED ON THE HISTORICAL DEVELOPMENT MORPHOLOGY OF KHIVA CITY

Khiva, known for its ancient walls and minarets, was named the Tourism Capital of the Islamic World for 2024 (Kuldashev & Karimov, 2024). Archaeological studies since the mid-20th century have uncovered deep historical layers in Ichan Qala, the city's historic core. Khiva expanded significantly during the Khorezmshahs period (12th–13th centuries) and became the Khiva Khanate's capital by the 17th century (Nematov, 2024). The late 19th and early 20th centuries introduced modern infrastructure, contrasting with the unchanged historic quarters. The city's radial-ring layout evolved from fortress walls, with restoration efforts preserving its heritage. Today, Khiva remains a cultural hub, hosting major events and celebrations (Sartori & Sartori, 2021).

Analysis of Khiva City's Historical Tourism Routes and Existing Tourist Pedestrian Routes (TPR)

Khiva's tourism infrastructure lags behind Samarkand and Bukhara, highlighting the need for improved pedestrian routes. Ichan Qala, surrounded by historic landmarks, lacks well-organized pathways, with safety concerns from vehicular encroachment, poor surfaces, and high curbs (Niri, n.d.). Limited accessibility, visual clutter from stalls and signage, and disorganized landscaping further hinder the experience. Enhancing pedestrian infrastructure through strategic planning will improve walkability, accessibility, and tourism appeal while preserving Khiva's historical charm (Saltarin-Molino et al., 2023). Figure 1 shows a few Touristic pedestrian areas in Khiva.

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Figure 1: Touristic pedestrian areas in Khiva

MODELING PEDESTRIAN MOVEMENT IN HISTORICAL TOURIST CENTERS

Field studies measured pedestrian movement around Ichan Qala to model flow patterns. Given the complexity of pedestrian behavior, modeling optimizes routes and movement. The Level of Service (LOS) framework, widely used in transportation engineering, evaluates infrastructure performance, including sidewalks, waiting areas, and stairways, based on comfort and efficiency criteria. The LOS methodology categorizes the pedestrian movement environment into three primary elements: sidewalks, waiting areas, and stairways. Each of these elements is assigned a specific level of service based on numerical criteria and calculation methods that define pedestrian comfort and safety. The fundamental relationships between pedestrian flow parameters within the LOS framework can be described mathematically as follows:

$$P = \frac{V}{M}$$

where: P= pedestrian movement intensity (persons/m*min),
V= average pedestrian flow speed (m/min),
M = dynamic space per pedestrian (m²/person).

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Additionally, pedestrian movement intensity can be expressed in terms of pedestrian density:

$$P = V \times D$$

where: D = pedestrian density (persons/m²).

A key parameter for assessing pedestrian comfort is the dynamic space available per individual, which directly influences the degree of freedom in movement. Empirical studies suggest that pedestrians naturally maintain a clearance of approximately 0.4 meters from any contact element. Consequently, the effective width of a pedestrian pathway is typically 0.8 meters less than its total width. The optimal pedestrian flow capacity is estimated at 1.65 m² per person.

In Tourist Pedestrian Routes (TPRs), sufficient pedestrian space must be ensured to accommodate:

- Walking at a comfortable pace without obstruction,
- Seamless movement of individuals with limited mobility or strollers,
- The avoidance of collisions with oncoming pedestrians,
- A safe and secure walking environment.

When designing TPRs, it is critical to account for peak pedestrian flow periods. A 15-minute interval is recommended for determining maximum pedestrian density and flow rates. Since pedestrian movement varies based on demographic factors such as age, flow composition, and travel purpose, the "average speed" parameter is utilized, typically measured in meters per minute.

Globally, free movement speeds on horizontal pathways and descending stairs range between 48 m/min and 155 m/min. Speeds below 48 m/min indicate restricted movement, while speeds above 155 m/min are characteristic of running conditions. Research indicates that pedestrian speeds between 90–155 m/min are typical during emergencies or peak congestion periods. For ascending staircases, movement speeds range from 12 to 80 m/min, with high-activity scenarios occurring at 50–80 m/min. For general pedestrian network planning, an average movement speed of 4.2 km/h (70 m/min) is recommended.

The experimental analysis was conducted using a predefined methodology to obtain precise pedestrian movement data. The required width of pedestrian walkways can be determined using the following formula:

$$B = \frac{b_1 N_f k}{P}$$

where:

B = required pedestrian walkway width (m),

b_1 = standard width of a single-lane pedestrian walkway (0.75 m),

N_f = intensity level of two-way pedestrian movement (persons/hour),

k = coefficient for projected changes in pedestrian intensity (derived from urban development analysis),

P = standard capacity of a single pedestrian movement lane (persons/hour).

The standard capacity of a single-lane pedestrian walkway varies based on its integration within the urban movement network and is given in Table 1. This study's findings contribute to a data-driven approach for optimizing pedestrian pathways in historical tourist centers, ensuring an efficient, accessible, and safe pedestrian environment within the Ichan Qala complex.

Table 1: The standard capacity of a single-lane pedestrian walkway

Elements of Pedestrian Communication Systems	The capacity of a single lane, persons/hour
If shops are located along the red lines	700
When separated from shops by green lines	700 - 800
Within green spaces	800 - 1000
Walking and pedestrian paths	600 - 700
Level intersections along the road	1200 - 1500

The authors propose a methodology for determining walkway widths to optimize pedestrian flow in urban planning. Using modelling techniques, the study analyses pedestrian movement in tourist areas, comparing empirical data with modelled flow. It assesses pedestrian conditions in historical centres, focusing on key sites in Khiva near essential services like hotels and restaurants. Additionally, the study considers existing tourist pedestrian pathways to ensure a comprehensive analysis as shown in Figure 2.

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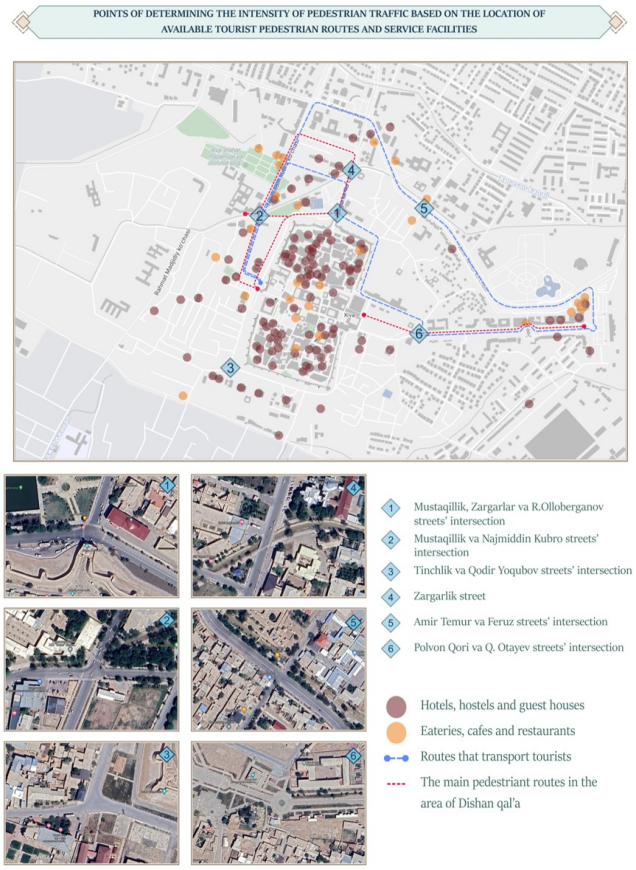
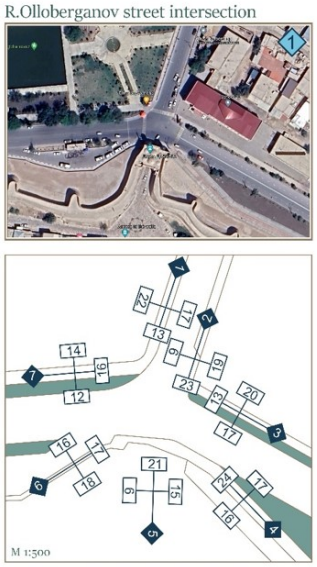


Figure 2: Points for Determining Pedestrian Movement Intensity

As of January 4, 2024, Khiva had 152 hotels (4,075 guests/day), with 440,300 foreign tourists in 2023, reflecting high pedestrian traffic. This study assesses pedestrian intensity, tourist dwell time, and accessibility to optimize walkways. Observations at six intersections found Mustaqillik and Zargarlar Streets busiest (468 pedestrians), with peak movement in the evening. Speed and density variations highlight the need for inclusive infrastructure. Figures 3–8 show pedestrian movement at key points. Figures 3, 4, 5, 6, 7, and 8 show the Pedestrian movement in point 1, 2, 3, 4, 5, and 6 respectively.

Unlike Samarkand and Bukhara, where broader streets reduce bottlenecks, Khiva's compact form amplifies congestion pressures during evening peaks.

Mustaqillik, Zargarlar va
R.Olloberganov street intersection



Pedestrian				
Direction	Left	Straight	Right	Total
1	22	13	17	52
2	9	23	19	51
3	17	13	20	50
4	16	24	17	57
5	6	21	15	42
6	16	17	18	51
7	14	16	12	42

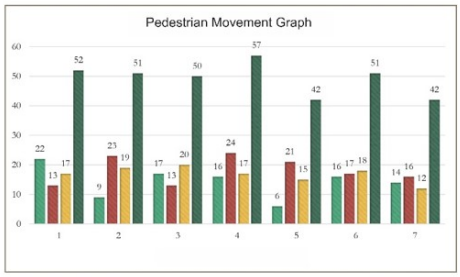
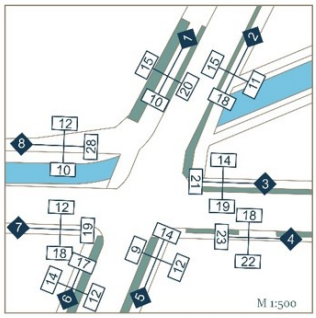


Figure 3: Pedestrian movement in point 1

Mustaqillik va Najmiddin Kubro
street intersection





Pedestrian				
Direction	Left	Straight	Right	Total
1	15	10	20	45
2	15	18	11	44
3	14	21	19	54
4	18	23	22	63
5	12	14	9	35
6	14	17	12	43
7	12	19	18	49
8	12	28	10	50

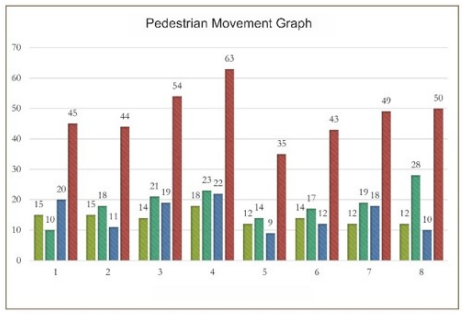
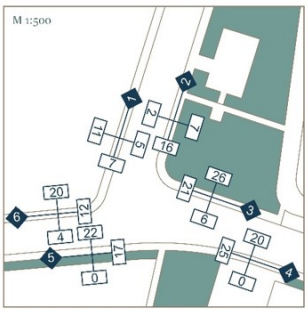


Figure 4: Pedestrian movement in points 2.

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Tinchlik and Qodir Yoqubov
Street intersection





Pedestrian				
Direction	Left	Straight	Right	Total
1	11	7	5	23
2	2	16	7	25
3	6	21	26	53
4	0	25	20	45
5	22	17	0	39
6	20	12	4	36

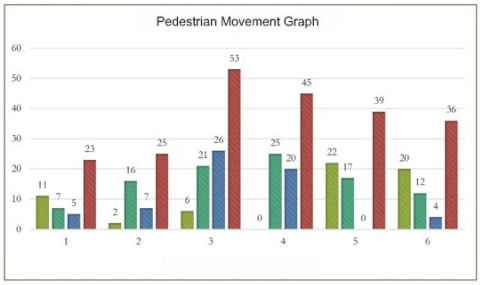
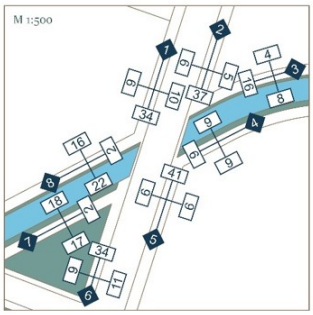


Figure 5: Pedestrian movement in point 3.

Zargarlik Street





Pedestrian				
Direction	Left	Straight	Right	Total
1	10	34	6	50
2	5	37	6	48
3	8	16	4	28
4	9	6	9	24
5	6	41	6	53
6	9	34	11	54
7	18	2	17	37
8	22	2	16	40

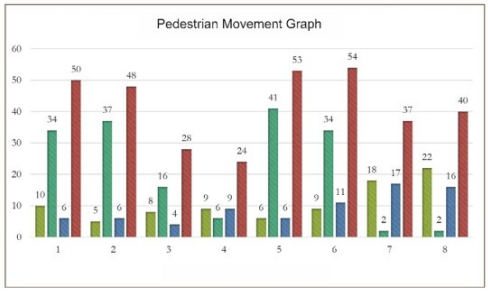
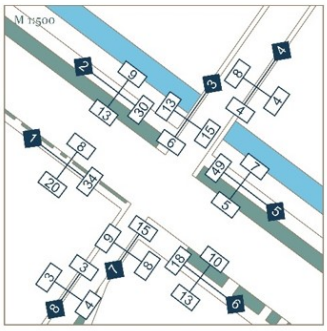


Figure 6: Pedestrian movement in point 4

Amir Temur and Feruz
Street intersection





Pedestrian				
Direction	Left	Straight	Right	Total
1	8	34	20	62
2	9	30	13	52
3	15	6	13	34
4	4	4	8	16
5	5	49	7	61
6	13	18	10	41
7	9	15	8	32
8	3	3	4	10

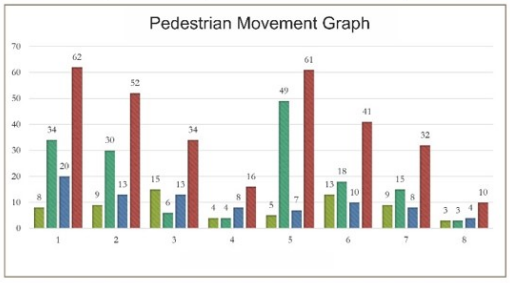
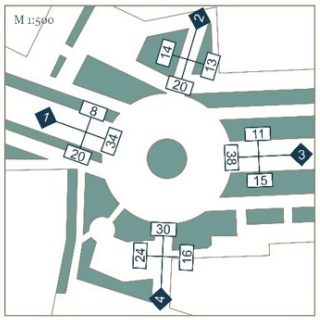


Figure 7: Pedestrian movement in point 5

Polvon Qori and Q. Otayev
Street intersection





Pedestrian				
Direction	Left	Straight	Right	Total
1	8	34	20	62
2	13	20	14	47
3	15	36	11	62
4	24	30	16	70

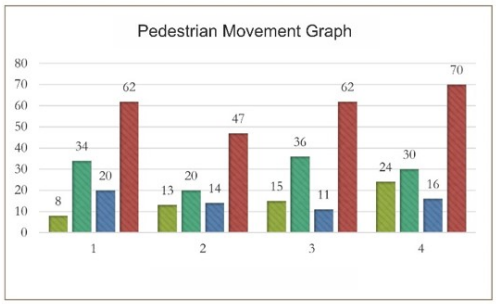


Figure 8: Pedestrian movement in point 6

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The analysis of pedestrian movement in Khiva revealed distinct trends in age distribution across different times and locations as shown in Figures 9, 10, 11, 12, 13, and 14. Individuals aged 20–40 dominate pedestrian flow (32%–45%), followed by those aged 10–20 (27%–37%). Children under 10 and adults over 40 make up 10%–23%. These trends emphasize the need to tailor tourist pedestrian routes to younger and middle-aged visitors.

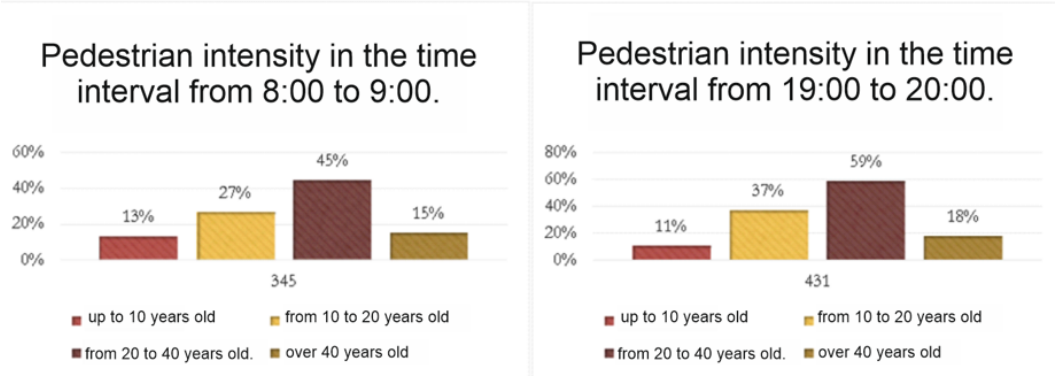


Figure 9: Pedestrian intensity at the intersection of Mustaqillik, Zargarlar, and R. Olloberganov streets



Figure 10: Pedestrian intensity at the intersection of Mustaqillik and Najmiddin Kubro streets

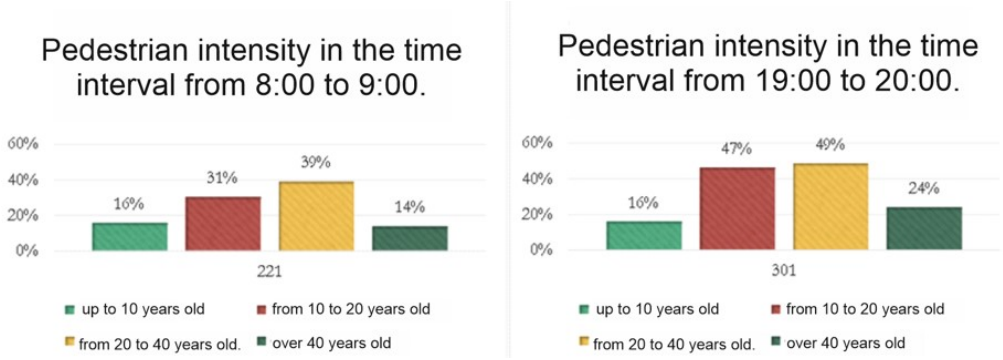


Figure 11: Pedestrian intensity at the intersection of Tinchlik and Qodir Yoqubov streets.



Figure 12: Pedestrian intensity on Zargarlik Street and the traffic section along the canal.



Figure 13: Pedestrian intensity at the intersection of Amir Temur and Feruz streets.

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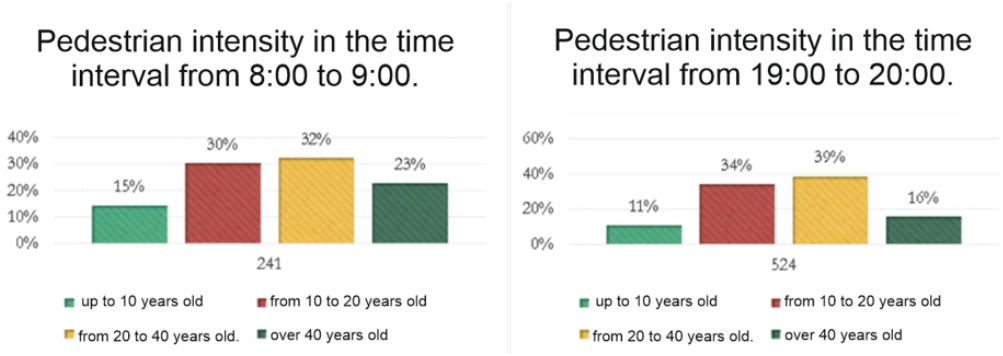


Figure 14: Pedestrian intensity at the intersection of Polvon Qori and Q. Otayev streets.

This study examined the movement patterns and composition of pedestrian flows across different age groups. Experimental findings indicate that individuals aged 20 to 40 comprised 39% of the total pedestrian flow as shown in Figure 15. The analysis also revealed that a pedestrian's free movement speed unimpeded by interactions with others follows a normal distribution and declines as flow intensity increases. Given that age significantly impacts walking speed, these findings provide a basis for future research on the relationship between pedestrian density and movement dynamics.

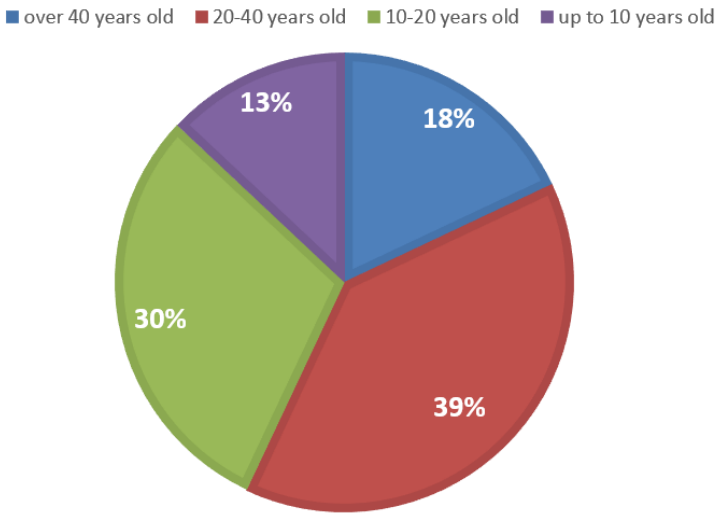


Figure 15: Overall age distribution of pedestrian composition.

MODEL OF THE RELATIONSHIP BETWEEN PEDESTRIAN FLOW SPEED AND PEDESTRIAN DENSITY

Understanding the relationship between pedestrian flow speed and density is essential for effective crowd management in high-traffic environments. Using regression analysis, a predictive model was developed based on experimental data. The pedestrian speed (V) was analyzed in relation to pedestrian density (D), applying the least squares method for parameter estimation. Table 2 shows the number of pedestrians, their age, and speed.

Table 2: The number of pedestrians, their age, and speed.

No.	X1-intensity (number of pedestrians).	X2-composition (age)	V-speed (m/s)
1	25	5	0,7
2	67	15	1,7
3	118	25	1,6
4	91	35	1,4
5	40	45	0,9
6	29	55	0,8
7	13	65	0,5

For multiple regression analysis, pedestrian speed was modeled as:

$$Y(X) = 0.69 + 0.009X1 - 0.005X2$$

where X1 represents pedestrian intensity (number of pedestrians), and X2 represents age composition. The model was validated with an unbiased error of 6.9%, confirming its reliability.

A second regression model was developed to represent the relationship between pedestrian speed and density. Table 3 shows the Pedestrian speed (V) and pedestrian density (D).

Table 3: Pedestrian speed (V) and pedestrian density (D).

No.	D (Density)	V (Speed)
1	0,1	0,8
2	0,3	0,7
3	0,5	0,67
4	1	0,65
5	1,5	0,6
6	1,8	0,55
7	2	0,5

$$Y(X) = 0.768 - 0.126D$$

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with a multiple correlation coefficient R=0.957R, indicating a strong predictive capability. The model's statistical significance was verified using the t-test and variance analysis. The results demonstrate that pedestrian speed decreases as density increases, aligning with established pedestrian flow theories as shown in Figure 16.

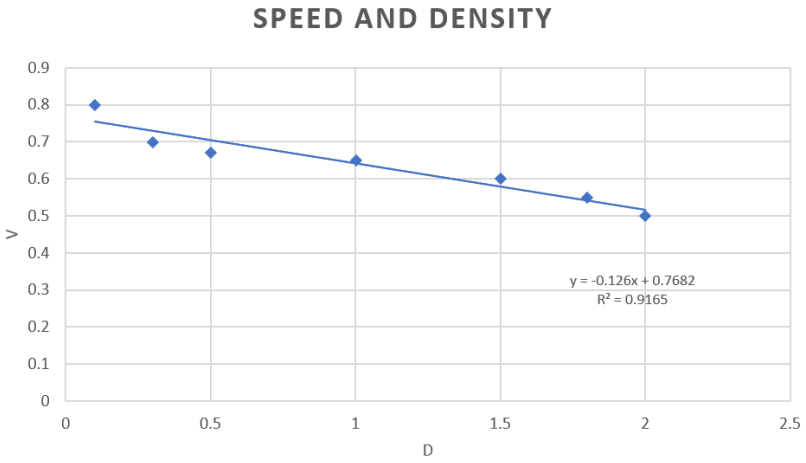


Figure 16: Model of the relationship between pedestrian flow speed and pedestrian density

The findings are shaped by Khiva's specific morphology and may not directly apply to other historical cities with different urban forms or seasonal conditions. Future studies should test the models in diverse contexts to improve transferability.

While this study identifies key infrastructure needs, future work should include schematic sketches or diagrams of pedestrian corridors and safety measures to better communicate design proposals to policymakers.

CONCLUSION

This study analyzes pedestrian dynamics in Uzbekistan's key tourist destinations. Surveys show 57.2% of tourists travel in groups, primarily for shopping. Tashkent attracts 58% of visitors, followed by Samarkand (31%), Bukhara (25%), and Khiva (13.3%). While Tashkent blends historical and modern sites, Samarkand follows a structured Tourist Pedestrian Route, and Bukhara has defined corridors around Lab-i Hauz. In contrast, Khiva faces pedestrian safety issues, poor inclusivity, and disorganized circulation. An empirical study in Dishan Qala recorded the highest foot traffic (468 pedestrians) at the Mustaqillik-Zargarlar intersection, mainly in the evening. A mathematical model was developed to optimize pedestrian flow. Future research should integrate smart

mobility tools, such as real-time pedestrian monitoring and IoT-based design features, to improve safety and accessibility in Khiva while preserving its heritage fabric.

ACKNOWLEDGEMENT

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ENHANCING PERFORMANCE OF ENERGY MANAGEMENT SYSTEMS: EXPERIENCE OF FACILITIES MANAGEMENT CONTRACTS FROM DEVELOPING ECONOMIC GOVERNMENT

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Abstract

The Energy Management Systems (EnMS) has seen rapid evolvement and development much to the effects of greenhouse gases. In Malaysia, EnMS is conceptualized as an integrated approach involving mechanical, electrical, and architectural components to achieve effective energy use and greater efficiency in buildings. The Malaysian Government have committed to achieve a Building Energy Index less than 150kWh/m²/year, but this remains a big challenge, with more than half of government contracts failing to meet the benchmark. This performance gap indicates that technical measures alone are insufficient, and that organisational and behavioural factors within facilities management contracts may strongly influence EnMS outcomes. To address this gap, this study evaluates the performance of EnMS in behavioural perspectives for Government facilities management contracts - focusing on the relationship of 15 factors in terms of its level of importance and implementation of EnMS. This research adopted an empirical study through a sequential mixed method (exploratory approach), validated questionnaires survey on 31 contracts, which was responded by the subject matter expert (energy manager) and the survey data was analysed using the Spearman Rank Order correlation (rho). Out of 15 factors tested, the results revealed that only eight is found to have significant correlation with EnMS performance. These are also supported by cross experts' interviews. A performance matrix was developed by integrating all 8 significant factors. By incorporating international BEI practices from Europe, Singapore, Japan, and the United States, this study not only offers insights for enhancing Malaysia's EnMS performance but also positions the findings within a global benchmarking context.

Keywords: High-rise Residential, Strata Residential, Commissioner of Building, Strata Management Body

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INTRODUCTION

The energy consumption saving practices applied over the years prioritised one-off cutting measures and rapid transformation (Yuriev & Boiral, 2018). Such efforts have been in place since the late 70s, whereby the managers enable low-cost solutions by educating building users to turn off unused lights and adjusting air-conditioning system (Introna *et al.*, 2014). The effort for above statement found to be more systematic and holistic under the Energy Management System (EnMS) (Abdelaziz *et al.*, 2011). With increasing environmental pressures, more organisations have begun to adopt energy management systems in their business practices (ISO, 2015).

Studies shows that several factors directly influence the performance of energy management system through the end results reporting status for buildings. Among the important drive factors mentioned above, were relationship building towards the stakeholders and regulatory compliance (Wee and Siong, 2017). Meanwhile, the studies in Putrajaya buildings found that measuring and reporting principles for energy used currently requires in contract documentation, whilst CO_2 emission reporting is upon stakeholder's request (Wang, 2017). This is against the EnMS principal standards, which requires commitment of top management's involvement in this system.

The Sustainability Energy Development Authority of Malaysia has stressed that energy management is the way to tackle source CO_2 emission, especially during the operation stage. In line with this, the Malaysian government revealed their commitment in implementing a comprehensive energy management system in government buildings designed to be energy efficient (SEDA, 2019; Lim and Tee, 2018). BEI results for Putrajaya buildings from year 2015-2018, found that there are 55% building contracts which were unable to achieve BEI less than 150kWh/m²/year (JKR, 2018). This shows that there are persistent factors affecting the current energy management system in buildings in Putrajaya. This study seeks to identify the factors that act as barriers to reducing BEI in Putrajaya buildings, and how a deeper understanding of these factors may lead to an improvement in the performance of existing energy management systems.

LITERATURE REVIEW

A study by IEA (2014) defined that the energy demand will increase by 37% in the next 25 years. This rising demand has driven many countries to start implementing other incentives or mandatory programmes such as EnMS (Du Plessis, 2015). The Malaysian Government has committed to be a part of this effort to minimise energy consumption and usage. According to Perbadanan Putrajaya (2015), the Government had set and lead by an example for Putrajaya buildings whereby had overcome existing floor area coverage is much higher

(33.6%) for Government office building compared to the commercial buildings (8.8%). This was followed by enforcement of a mandatory EnMS in the Government Facilities Management and Maintenance (FMM) contract which applies to all the 31 Government building contracts in Putrajaya (JKR, 2018). However, 17 Government agencies building contract in Putrajaya still unable to achieve a BEI less than 150kWh/m²/year (JKR, 2018). This research seeks to determine the factors which affect the implementation and success of EnMS systems.

The findings from this research compare BEI data from Government agency buildings in Putrajaya, to identify where there are failures in meeting Key Performance Index (KPI). The outcomes inform the Malaysian Government (building stakeholders) in developing improvements to the current system and ensuring that the energy management system loop is complete.

Driving Elements Influencing Performance of Energy Management Systems

According to Centobelli *et al.* (2018), the efficiency for an energy management system, is influenced by either drivers (positive) or barriers (negative). Similarly, Siciliano et al (2015) identified that under the ISO 50001 environment, several driving factors which influence the success of an EnMS. These factors are illustrated in Figure 1 and can be summarised as:

- Policy intervention: Approach for stakeholders to engage and performance requirement as their policy.
- Enterprise management activities: Strategic planning and commitment level.
- Institutional support: The effectiveness of training programmes and reporting system.
- Technology and methodology push: The involvement of service provider innovation.

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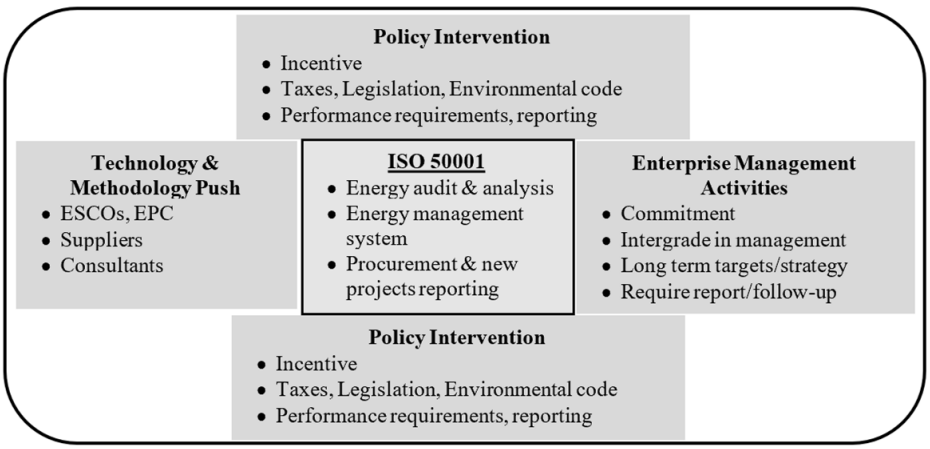


Figure 1: Favourable factor driving for Energy Management System (Siciliano et al., 2015)

Regulatory Compliance and Leadership

Regulatory compliance is critical factor in the effective implementation of an Energy Management System (EnMS) (Okereke, 2007). Stakeholder engagement further ensures the voluntary adaptation of EnMS, as emphasized by Wee and Siong (2017). Strong leadership is essential in managing and negotiating changes with stakeholders (Nishida & Hua, 2011). Effective stakeholder engagement enhances program execution (Chakraborty & Roy, 2013), whereas poor engagement leads to overlooked energy management initiatives (Halkos & Skouloudis, 2016). Aligning strategic vision with energy initiatives fosters cultural engagement (Huang, 2018; Farneti & Guthrie, 2009).

Compared to developed nations, Malaysia's progress in energy efficiency policies been relatively slow. The country's energy intensity remains high, indicating a need for more effective policy implementation and international collaboration (El-Awad, 2006). The absence of a specific legal framework for energy efficiency in Malaysia highlights a gap that many countries have addressed through comprehensive legislation. Implementing such a framework could enhance Malaysia's energy management efforts (Ghazali et al., 2023). Countries like China have implemented aggressive carbon pricing strategies, leading to significant energy consumption reductions. Malaysia's decarbonization efforts, while ambitious, face challenges in achieving similar outcomes due to structural and financial barriers (Gunawan et al., 2023).

Energy Cost Saving and Performance Evaluation

Organizations that adopt EnMS recognize the link between energy management and cost reduction (Wee & Siong, 2017; Wong & Zapantis, 2013). Cost-saving initiatives include BEI reduction, CAPEX and APEX savings, ROI across

different timeframes, and long-term asset benefits of retrofitting. Performance evaluation is vital, with clear KPIs and periodic reviews ensuring continuous improvement (Thollander & Palm, 2013; Huang, 2018). Top management plays a key role in maintaining the plan's effectiveness.

Building Reputation, Stakeholder Relations, and Environmental Awareness
EnMS implementation enhances an organization's reputation, competitiveness, and productivity (Pellegrini-Masini & Leishman, 2011; McCarty et al., 2011). Strong stakeholder relationships support energy program execution and investment in sustainability (Chakraborty & Roy, 2013), while weak engagement limits energy reporting (Halkos & Skouloudis, 2016). Cultural awareness of energy management impacts CO2 reduction and environmental responsibility (Scholtens & Kleinsmann, 2011; Shaari et al., 2020; Ali et al., 2019). Organizational values and attitudes play a role in adopting best practices (Nakamura et al., 2001; Huang, 2018; Wee & Siong, 2017).

Scope of Area and Energy Management Personnel
ISO 50001:2018 aims to improve energy performance by defining controlled coverage areas (Huang, 2018). Large coverage areas may reduce efficiency, necessitating zonal energy committees (Aldhshan et al., 2021; Centobelli et al., 2018). Designating energy controllers at various levels helps optimize energy use (Thollander & Palm, 2013). Intelligent systems can enhance EnMS effectiveness (Parvin et al., 2021; Mohd Aman et al., 2021). The competency of energy managers, determined by education, experience, and continuous training, is critical to EnMS success (Huang, 2018; Basri et al., 2021). A dedicated energy manager role is necessary for efficiency (Thollander & Palm, 2013).

Energy Planning, Budgeting, and Organizational Support
EnMS planning involves reviewing current practices, identifying risks and opportunities, and developing strategic outputs (Huang, 2018; Johansson & Thollander, 2018). Sufficient budgeting based on sub-metering calculations, rather than per square meter or occupancy, is essential to avoid investment barriers (Johansson & Thollander, 2018; Centobelli et al., 2018). Full top management support ensures resource allocation for EnMS objectives (Centobelli et al., 2018; Hamdan et al., 2025).

Simplicity, Visualization, and Energy Awareness
Simpler EnMS frameworks are more effective in achieving baseline goals (Huang, 2018), while complex technological systems may hinder adoption (Centobelli et al., 2018). Visualizing energy efficiency outcomes raises awareness, and energy-saving competitions with rewards enhance engagement

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(Johansson & Thollander, 2018; Muszaffarsham, 2022). These initiatives contribute to reducing greenhouse gas emissions and promoting sustainable energy practices.

RESEARCH METHODOLOGY

Exploratory Sequential Mixed Method

This study employed an exploratory sequential mixed-method approach for data collection and analysis. This design is particularly suited for studies that begin with qualitative exploration to identify key issues, followed by quantitative analysis to validate findings. Such an approach provides both flexibility and depth, allowing researchers to uncover root causes of complex problems while ensuring empirical validation. These attributes have been widely recognised in methodological literature (Cooper et al., 2006; Zikmund, 2003). In the context of this research, the method was used to identify and validate factors influencing EnMS performance by incorporating the perspectives of certified energy managers through energy audit reports, validation interviews, and a structured survey.

The Malaysian Government contracts require energy audit reports to be submitted and audited by the third independent competent Energy Service Company (ESCo) for every year in the contract. A total of 31 contracts collected over 4 years were reviewed to identify factors leading to positive BEI performance results. From these reports, the top five BEI performers were identified for expert interviews based on the five best BEI reduction. This selection process allowed for recommendations from the successful energy managers on achieving best performance in energy management.

Expert Interview

A total of five certified energy managers were selected for interview. They were chosen from organizations representing the five best BEI performers (out of total 31 contracts), This constituted a sample size of 16% of the 31 contracts collected as per recommended by Creswell (2002). The additional criteria including possession of a valid Certified Energy Manager (CEM) credential, a minimum of five years of professional experience in building energy management, direct involvement in implementing energy conservation measures, and an active role in organizational decision-making related to energy efficiency.

The interviewees were asked to verify the factors influencing BEI highlighted as part of the literature review and further identify any other contributing factors which influence the performance of energy management systems. Additionally, the interview served as a pre-test for the questionnaire, to avoid misleading information or misinterpretation of the results for phase three of the study.

Structured Questionnaire Survey

Information drawn from the expert interview was used to improve the questionnaire survey. Bernard (1994) identifies that for questionnaires to inform the results of a study, the sample should include experts with experience in their field. According to this a total of 31 energy managers were selected to undertake the questionnaire in a face-to-face environment. Prior to completing the questionnaire, participants were invited to watch an EnMS training video via YouTube as per shown by BSEEP (2017), in order to generate ideas on the performance of EnMS being applied by Public Work Department (PWD). The questionnaires were divided into three sections: Section 1: Demographic Background of Respondents and Scope of Building; Section 2: General Information on Performance of Energy Management Application; and Section 3: Effect of Main Factors on Energy Management Performance. The questionnaires survey is tabulated in 5-point Likert scales which allows the respondent to pick a choice according to their working condition. Data was analysed using the Statistical Package for the Social Sciences (SPSS) software version 24. Ranking Analysis, Correlation Analysis and Spearman, were conducted in order to examine the relationship between factors and the performance of an energy management system.

ANALYSIS AND DISCUSSION

Data Analysis

The statistical analysis presented in this section was derived from the structured questionnaire survey conducted with 31 certified energy managers, each representing one government facilities management contract in Putrajaya. Data was analysed through descriptive statistic (ranking analysis) and inferential statistic (correlation analysis) using the SPSS version 24 by interpreting the primary data base on the mean, mode, median, variance and standard deviation. In order to examine the relationship between factors, the inferential statistic was carried out using correlation analysis. Spearman's rank order correlation was used for the analysis of the questionnaire. Interview data, by contrast, were analysed qualitatively and used primarily to validate and cross-check the survey findings, rather than being subjected to statistical testing.

Result by Each Factor

The Spearman's correlation results for significant value (p) and correlation coefficient (rho) are shown in Table 1. In total 8 factors were identified as having a significant influence on the relationship between the importance of and the level of implementation for an EnMS performance. Therefore, all 8 factors were considered in making recommendations. These results indicate that 3 strong and

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positive relationship are regulation compliance, energy cost saving and performance evaluation.

Table 1: Results for Each Factor of Spearman's Correlation

Factor Tested	Significant	Retain/ Reject	Rho	Description
1) Energy Planning Process	0.509	Reject	0.123	-
2) Correct Energy Cost Allocation	0.050	Retain	0.352	*
3) Regulation Compliance	0.000	Retain	0.686	**
4) Scope of Area	0.037	Retain	0.376	*
5) Energy Controller	0.288	Reject	0.197	-
6) Healthy Competition	0.800	Reject	0.047	-
7) Energy Cost Saving	0.001	Retain	0.575	**
8) Performance Evaluation	0.001	Retain	0.570	**
9) Leadership	0.074	Retain	0.325	Selected since have relationship base on rho value
10) Relationship with Stakeholder	0.030	Retain	0.391	*
11) Organisation Support	0.310	Reject	0.188	-
12) Competency Level	0.326	Reject	0.182	-
13) Environmental Awareness	0.170	Reject	0.253	-
14) Building Reputation	0.460	Reject	0.138	-
15) Simplicity in Technology	0.024	Retain	0.405	*

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Results by Key Group

The summary results for key group as shown in Table 2 revealed that only 3 key groups were identified to be significant; planning, monitoring and measurement, and management at the level of 0.05 and 0.01 receptively. Furthermore, the key group of monitoring and measurement has a strong and positive relationship (rho) .658 between the importance and the level of implementation for EnMS performance.

Table 2: Results for Key Group of Spearman's Correlation

Factor Tested	Significant	Retain/ Reject	Correlation Coefficient (rho)	Description
1) Planning	0.004	Retain	0.497	**
2) Operation	0.075	Reject	0.325	-
3) Monitoring and Measurement	0.000	Retain	0.658	**
4) Management	0.038	Retain	0.374	*
5) Training and Development	0.106	Reject	0.296	-
6) Technology	0.366	Reject	0.168	-

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Result by 8 Selected Significant Factor Only

As displayed in Table 3, the significant level was identified to be stronger when tested for Spearman's correlation involved only 8 selected significant factors. The results indicate at a level of 0.01 between the variables. The strong relationship (rho) of .557 had showed that all these 8 variables were most crucial of this research.

Table 3: Result for 8 Selected Significant Factor Only of Spearman's Correlation

Factor Tested	Significant	Retain/ Reject	Correlation Coefficient (rho)	Description
1) Significant Factor only (8 factors)	0.001	Retain	0.557	**

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Current Energy Management Performance Matrix

The energy management matrix developed as part of this research is used to identify the current state of energy management in an organisation. The current energy management performance of an organisation can be tabulated using the AEMAS energy management matrix (Quyen and Le, 2012). The AEMAS energy management matrix can be adapted for this research to measure the performance level of implementation for EnMS by using the analysis results for correlation coefficient value in order to demonstrate the current performance.

In the current AEMAS matrix, rows describe levels of sophistication whilst columns show key management. The matrix was modified such that rows represent correlation coefficient value (rho) and columns describe the 8 significant key factors which were chosen for discussion and recommendation purposes. As shown in Figure 4, the pattern for current performance matrix of energy management revealed that unbalanced shape can be seen from the 8 significant factors. Corresponding to that, the current energy management matrix proves that the unbalanced shape tallies with Government commitment to achieve BEI less than 150kWh/m²/year. This unbalanced pattern requires several recommendations, in order to close the gap between the actual implementation and energy management literature.

The findings identify distinct barriers in Malaysian government buildings that elucidate why over half of the Putrajaya contracts failed to achieve the BEI target. Cultural barriers consist of limited awareness among users, perceiving energy-saving practices as temporary rather than ingrained. Organizational barriers stem from fragmented agency responsibilities and inadequate training budgets, impeding the growth of specialized knowledge among energy managers. Barriers that pertain to policy stem from the differences

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observed in national objectives (like BEI being less than 150 kWh/m²/year) compared to the enforcement of FM contracts, which suffer from poor monitoring and insufficient penalties for non-adherence. By embedding these impediments within cultural, organizational, and policy structures, the analysis frames statistical outcomes and emphasizes the hurdles of converting governmental pledges into practical application.

These challenges align with existing research. Yuriev and Boiral (2018) indicated that energy-saving initiatives often lack depth due to insufficient integration, reinforcing identified cultural barriers. Wee and Siong (2017) found that in Malaysia, fragmented organizations and inadequate reporting hinder effective EnMS implementation, reflecting the organizational limitations discovered in this study. Likewise, Okereke (2007) and Nishida & Hua (2011) underscored that policy objectives often falter without robust enforcement and stakeholder engagement, paralleling the disparity between Malaysia's BEI goals and their actualization in FM contracts. All in all, the blending of these revelations with historical data suggests that overcoming these issues demands technological growth, cultural adjustments, organizational solidarity, and stricter enforcement of regulations to foster significant development in energy management.

Solution Diagram

Based on the detailed findings from the significant factors identified in the survey analysis, supported by expert interview outcomes and verification against relevant provisions of the PWD Facilities Management contract specifications, several targeted suggestions were proposed to enhance the performance of EnMS. Each suggestion reflects a combination of significant factors, as emphasised by experts, who highlighted that integrated management across these factors is necessary to achieve better performance. This relationship is further illustrated in the Solution Diagram (Figure 4), which simplifies the suggestions and demonstrates how the significant factors influence the research.

The adapted performance matrix from AEMAS serves as a diagnostic tool for analyzing EnMS implementation in governmental FM contracts. The matrix's rows depict correlation coefficients (rho) that signify the relationship strength between importance and implementation, while the columns represent eight critical factors, including regulatory compliance and stakeholder relations. The matrix's unbalanced configuration reveals implementation asymmetries, with regulatory compliance being robust and technology adoption lacking.

The solution diagram enhances the matrix by consolidating the eight factors into a unified framework, demonstrating their interactions on EnMS performance. For instance, leadership enhances compliance and organizational support, whereas appropriate budgeting facilitates accurate cost allocation and performance evaluation. This integrated viewpoint reinforces the essential

requirement of a varied strategy to enhance EnMS outcomes, supplying policymakers and facility supervisors with a hands-on guide for targeted progress.

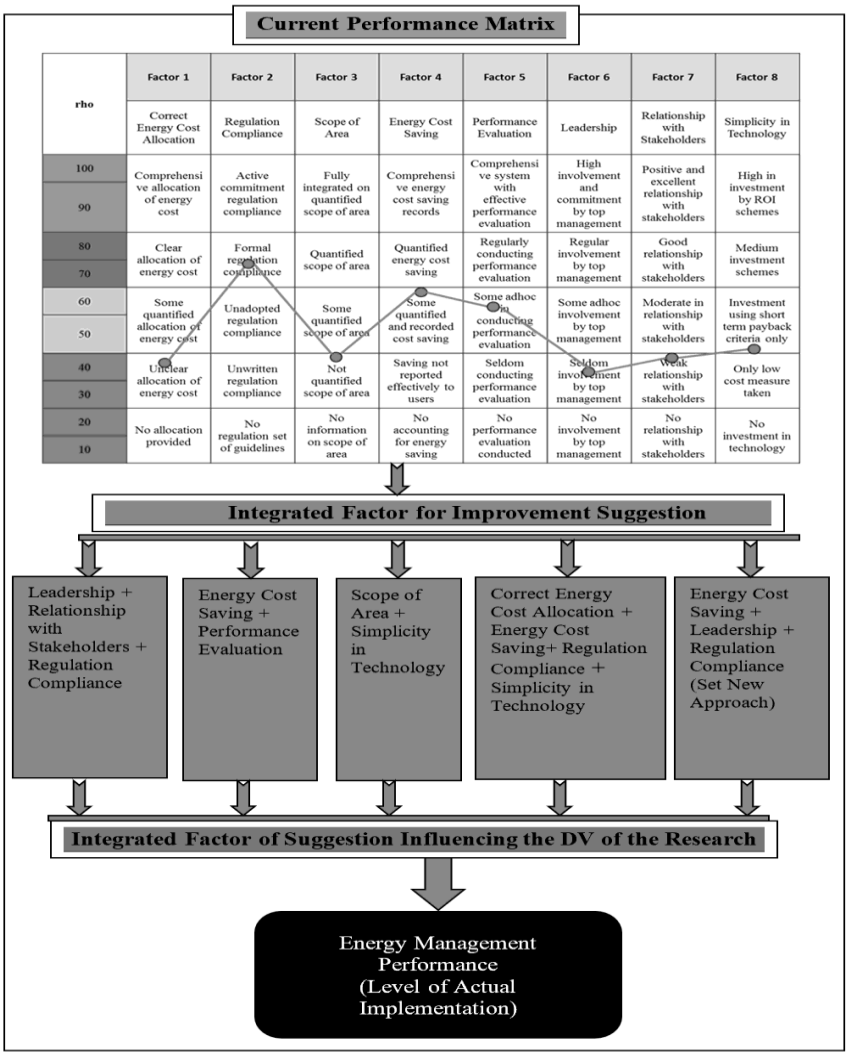


Figure 2: Solution Diagram illustrating the integration of significant factors influencing EnMS performance, based on survey results, expert interviews, and PWD contract verification.

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CONCLUSION

This study established a behavioural framework for EnMS performance in government FM contracts, identifying eight key factors influencing implementation. The results reveal that successful leadership, involvement of stakeholders, and awareness of cultural factors are key to advancing regulatory compliance, performance assessments, and financial savings in Malaysian public buildings. A performance matrix and solution diagram serve as both diagnostic instruments and actionable improvement roadmaps. Nonetheless, the study faces limitations. It is confined to government buildings in Putrajaya, and the limited sample of 31 contracts may not adequately reflect practices in other regions or sectors. Additionally, the focus on behavioural aspects may neglect potential advancements from emerging technologies. Later research must broaden its view to take into account diverse construction types and regions, and delve into how intelligent systems like AI and IoT could optimize the effectiveness of EnMS. Comparative analyses between developing and developed nations would also augment the generalizability of the results and offer valuable insights for Malaysia and other nations aiming for sustainable energy management.

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URBAN MORPHOLOGY AND PASSIVE DESIGN: STRATEGIES TO MITIGATE URBAN HEAT ISLAND AND IMPROVE THERMAL COMFORT IN KUALA LUMPUR

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Abstract

Rapid urbanization in Kuala Lumpur has intensified the Urban Heat Island (UHI) effect, compromising thermal comfort and increasing environmental stress. This study examines how urban morphology and passive building design influence microclimatic conditions in three contrasting areas: Kampung Baru (suburban), Bukit Bintang (dense urban), and KLCC Park (green zone). Field measurements of air temperature, relative humidity, wind speed, and PM2.5 were collected using mobile equipment. Results show that compact urban districts experience elevated temperatures and reduced ventilation, while vegetated and water-adjacent areas provide notable cooling. Findings are evaluated against thermal comfort benchmarks (ASHRAE 55; MS1525), underscoring the need for climate-responsive urban planning. Mitigation strategies include expanding green infrastructure, applying reflective materials, and strengthening passive design features to enhance thermal comfort in high-density tropical cities. The study acknowledges limitations of short-term mobile measurements and recommends future research involving long-term monitoring and simulation modeling to strengthen understanding of UHI dynamics.

Keywords: Urban Heat Island, Thermal Comfort, Urban Configuration, Urban Microclimate, Green Building Design

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INTRODUCTION

Kuala Lumpur, Malaysia's rapidly growing capital, has seen major land use and population increases over the past five decades. This growth has made it one of Southeast Asia's most urbanized cities, but also brought challenges such as the Urban Heat Island (UHI) effect, air pollution, and thermal discomfort (Wang et al., 2019). Rapid urban development has altered the city's microclimate, creating risks for both the environment and human health (Yola, 2018; Ibrahim et al., 2014). The Urban Heat Island (UHI) effect occurs when urban areas are hotter than nearby rural regions due to vegetation loss and the use of heat-retaining materials like concrete and asphalt (Rajagopalan et al., 2014). As green space decreases and built-up areas expand, Kuala Lumpur's ability to regulate temperature weakens, intensifying UHI and reducing environmental resilience (Harun et al., 2020).

Anthropogenic heat from transport, industry, and building energy use raises urban temperatures while releasing greenhouse gases like CO_2 and methane, which trap heat and intensify the UHI effect. Open burning and deforestation further add to this problem (Elsayed, 2012; Malaysian Meteorological Department, 2009). Urban morphology strongly influences heat distribution. Tall buildings and narrow streets create urban canyons that trap heat and block air circulation. These canyons absorb and re-radiate long-wave heat, reducing natural ventilation and limiting nighttime cooling, which raises surface and air temperatures (Rajagopalan, Lim & Jamei, 2014).

The UHI effect is a major global issue, especially in tropical cities like Kuala Lumpur. Higher thermal loads increase heat stress and energy demand for cooling (Elsayed, 2012), while long-term exposure raises risks of heatstroke, respiratory illness, and cardiovascular problems, particularly for vulnerable groups such as children, the elderly, and people with pre-existing conditions (Mohajerani, Bakaric & Jeffrey-Bailey, 2017; United States Environmental Protection Agency, 2020; Shahmohamadi et al., 2011). Urban vegetation is a key mitigation strategy. Parks, urban forests, and rooftop gardens reduce surface and air temperatures through shading and evapotranspiration (Yoshida et al., 2015; Marando et al., 2022). Increasing greenery also improves thermal comfort, lowers pollution, and reduces cardiovascular-related mortality (Shen & Lung, 2016; Devi Kanniah, 2017). The placement and design of green spaces are critical for shaping microclimates.

Material properties also affect UHI. Construction materials with high heat absorption, such as pavements and dark roofs, intensify localized warming (Sreedhar & Biligiri, 2016; Li, 2015). In contrast, cool pavements and reflective surfaces help lower temperatures and improve comfort (Senevirathne et al., 2021; Mohajerani et al., 2017). Malaysia's urban policies now promote sustainability, with tools like the Green Building Index (GBI) encouraging energy efficiency,

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natural ventilation, and thermal comfort in climate-responsive development (GBI Township Tool, 2017).

Urban Heat Island (UHI) has become a growing concern in rapidly urbanizing cities. While many studies have examined UHI in temperate regions, there is still limited research on UHI dynamics in tropical cities like Kuala Lumpur, particularly regarding how urban morphology, wind flow, and air quality interact to influence microclimatic conditions.

This research addresses these gaps by examining how wind speed, temperature, and UHI intensity vary across different urban forms in Kuala Lumpur. It also assesses the relationship between PM2.5 levels, air quality, urban morphology, and vegetation to better understand microclimatic impacts. In addition, the study identifies key urban design factors that can help mitigate UHI while improving thermal comfort. Finally, it provides evidence-based recommendations to support sustainable and climate-responsive urban design in Malaysia.

This study builds on past research by analyzing urban, suburban, and green areas in Kuala Lumpur using field data on temperature, humidity, and wind. It shows how urban form shapes microclimate, thermal performance, and UHI effects, aiming to guide planning and passive design strategies that improve comfort and reduce energy use for sustainable city design.

Passive design strategies play a key role by enhancing ventilation and lowering heat. Building orientation, façade design, openings, and layouts that follow wind paths or improve sky view factors can reduce heat buildup and improve airflow (Aflaki et al., 2015; Siew et al., 2011; Gonzalez-Longo & Mohd Sahabuddin, 2019; Zhang et al., 2022; Choi et al., 2018). Courtyards, light-wells, and shading devices also help cut solar gain and support thermal comfort (Yola, 2020; Sahabuddin & Gonzalez-Longo, 2017).

Case Study Areas, Methodology and Limitations

This study examines three sites in Kuala Lumpur: Kampung Baru (low-rise suburb beside high-rises), Bukit Bintang (dense commercial zone), and KLCC Park (green space with vegetation and water). These locations represent different urban forms, enabling comparison of how built form and greenery influence microclimate and the Urban Heat Island (UHI) effect (Figure 1). The goal is to understand how planning and physical features shape thermal conditions and to test passive strategies such as shading, orientation, façade design, and spatial layout for UHI reduction. Mobile measurements of temperature, humidity, wind speed, and PM2.5 were taken at two points per site—one green and one urban—under different routes, weather, and times of day. While mobile data collection has limits, such as short-term weather effects and handling errors, it still provides

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valuable fine-scale insights into pedestrian-level microclimate, complementing broader meteorological data.

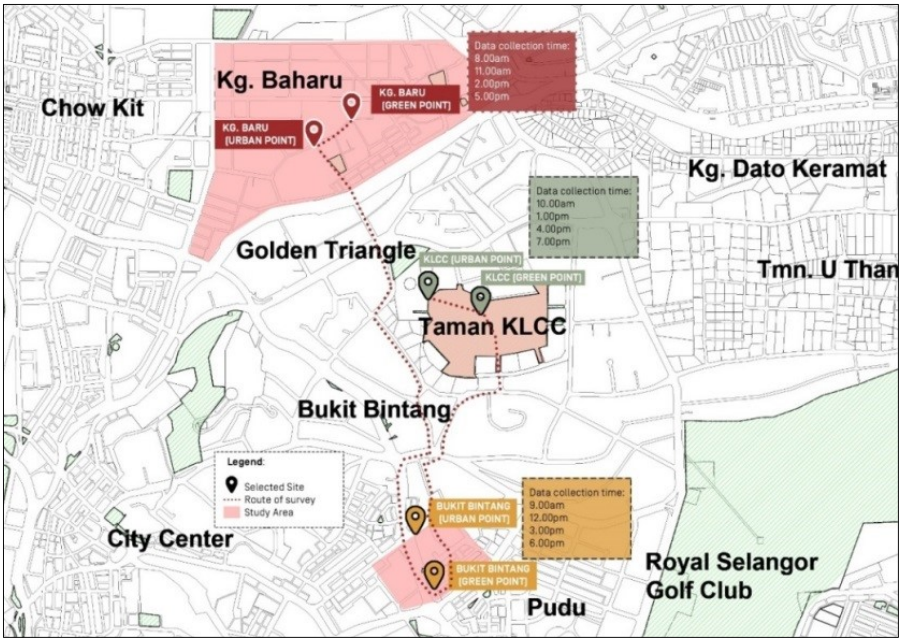


Figure 1: Location of the mobile measurement survey routes during data collection

Requirements for Thermal Comfort

In Malaysia, thermal comfort and indoor air quality (IAQ) are regulated by MS1525, which follows the ASHRAE 55 guidelines (Turner et al., 2010). For Kuala Lumpur's climate, the recommended comfort range is 24–28°C air temperature, 40–70% relative humidity, and 0.15–0.50 m/s wind speed. Air quality is also critical, with the WHO Air Quality Guidelines (2021) setting PM2.5 limits at <25 µg/m³ annually and <50 µg/m³ for 24-hour exposure to reduce health risks (Table 1).

Table 1: Parameters, limits and requirements of thermal comfort and IAQ

Parameters	**ASHRAE 55 (2013)**	**MS1525 (2014)**
Air Temperature	24.0 -28.4°C	24 -26°C
Relative Humidity	<65%	50-70%
Wind Speed	0.15 -0.8 m/s	0.15 -0.5m/s
PM2.5, WHO standard	annual < 25 µg/m3 and 24-hour limits < 50 µg/m3	

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IN-SITU FIELDWORK MEASUREMENTS

Key climatic parameters measured at all sites included air temperature, relative humidity, wind speed, and PM2.5, with surface temperature derived to analyze thermal patterns. Data were collected using a PMS5003 Air Quality Monitor and a Digital Anemometer Thermometer through mobile surveys in Kampung Baru, Bukit Bintang, and KLCC Park at different times of day to capture diurnal variations.

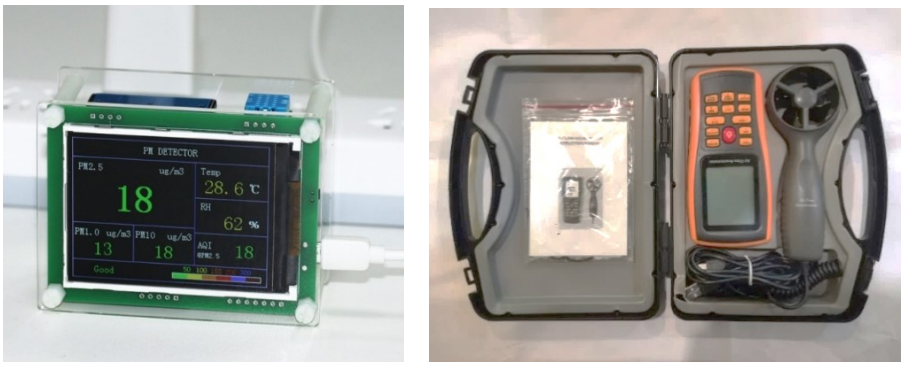


Figure 2: PMS5003 Particulate Matter (PM) Detector Air Quality Monitor Thermometer and Digital Air Flow Anemometer

Measurements were conducted over six days in November 2021 and February 2022, covering both weekdays and weekends, using handheld equipment to record real-time conditions (Figure 2). All surveys followed the ASHRAE research protocol, with instruments placed at pedestrian level (1.1–1.5 m) for outdoor comfort studies (ASHRAE, 2017). Equipment was calibrated before fieldwork, and spot checks were performed during data collection to minimize drift and handling errors.

Data were collected at three sites in Kuala Lumpur: Bukit Bintang (urban), Kampung Baru (suburban), and KLCC Park (green). Six settings were studied, including high- and low-rise housing in Kampung Baru, high- and low-density roads in Bukit Bintang, and hard and soft surfaces in KLCC Park. These site conditions affect temperature, humidity, wind speed, and PM2.5, depending on vegetation, materials, and ventilation.

Measurements in November and February captured seasonal variation during the Northeast Monsoon, which brings high humidity, rainfall, and flooding (Malaysian Meteorological Department, 2020). Kuala Lumpur's hot and humid rainforest climate further intensifies the UHI effect, especially in dense, low-vegetation areas (Ghaffarianhoseini et al., 2019).

Weather patterns also shaped results. In November, Day 1 was sunnier with higher temperatures, while Days 2 and 3 were cloudy and cooler. In February, all three days were cloudy, but Day 2 recorded lower midday temperatures due to heavy rain. Afternoon (2:00–4:00 PM) readings were higher on sunny November days, while evening (5:00–7:00 PM) temperatures in both months were consistent under cloudy or rainy conditions.

FINDINGS

Air Temperature

During the study period, Kuala Lumpur recorded average maximum and minimum temperatures of 32.3°C and 24.7°C in November, and 31.0°C and 23.3°C in February, showing seasonal differences of about 1.3–1.4°C (Meteorological Terminal Air Report, 2021; 2022). These variations also affected humidity and wind speed. As shown in Figures 3 and 4, the lowest temperatures were measured at Kampung Baru green point and KLCC Park (24.3–26.5°C in November; 22.6–23.6°C in February), reflecting the cooling influence of vegetation and water.

By contrast, Kampung Baru's high-rise residential area recorded the highest temperatures, even surpassing Bukit Bintang. In November, temperatures reached 32.0°C in Kampung Baru compared to 29.0°C in Bukit Bintang. This is linked to the "canyon effect" caused by compact low-rise buildings surrounded by high-rises, which trap heat and restrict airflow, consistent with Tumini (2015). Elevated heat may also stem from nearby infrastructure, especially the Ampang–Kuala Lumpur Elevated Highway (AKLEH), where heavy traffic and dense development generate anthropogenic heat and pollutants (Ramakreshnan et al., 2019). With over 26 million vehicles annually and planned future expansion, the AKLEH further contributes to localized warming (Ministry of Works Malaysia, 2015).

ASHRAE 55 sets the comfort range at 24–28.4°C (Turner et al., 2010). While most readings in Kampung Baru, Bukit Bintang, and KLCC Park were within this range, urban points in Kampung Baru and Bukit Bintang often exceeded 28°C in the afternoon. Green areas, trees, and water bodies lowered temperatures by up to 2.2°C, highlighting their role in improving comfort.

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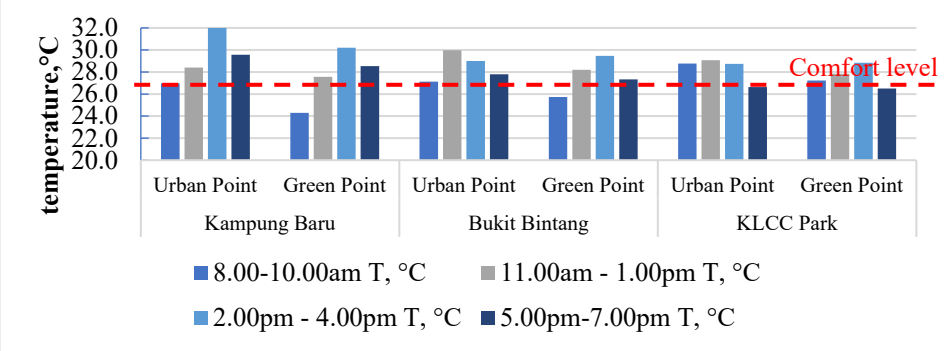


Figure 3: Results of Average Air Temperature in November

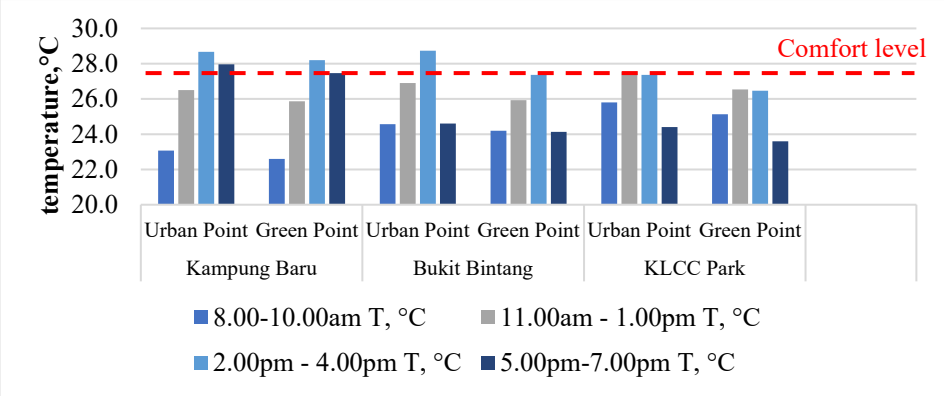


Figure 4: Results of Average Air Temperature in February

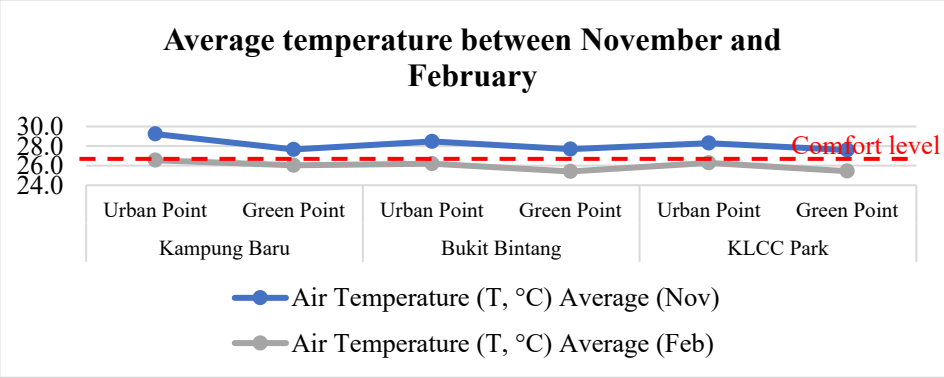


Figure 5: Average Air Temperature between November and February

Relative Humidity

The Malaysia Meteorological Department reported average relative humidity (RH) of 56% in November and 88% in February, due to persistent rainfall (Meteorological Terminal Air Report, 2021). RH is the ratio of water vapor in the air to its maximum capacity at a given temperature and pressure (Yahia, 2019; Djamila, Chu & Kumaresan, 2014). Figures 6–7 show the lowest RH (60–63.7%) in November at 2:00–4:00 PM in Kampung Baru and Bukit Bintang, while the lowest in February was 80.2% in Bukit Bintang. Early mornings had higher humidity: 70.0–87.3% (November) and 85.3–94.3% (February). This increase is linked to evaporative cooling, where water vapor from surfaces and vegetation raises humidity (Procházka et al., 2011).

Afternoon readings showed lower RH as higher temperatures reduced vapor pressure, intensifying the UHI effect. RH decreases as temperature rises (Clausius-Clapeyron relation), showing a negative correlation with UHI intensity (Kamma et al., 2020; Anibaba et al., 2019). Figure 8 shows an 11.8–13.6% RH difference between November and February, mainly due to heavier rainfall. For comfort, ASHRAE 55 recommends RH below 65% (Turner et al., 2010). High RH can lead to mold, while very low RH (<30%) causes discomfort (Djamila, Chu & Kumaresan, 2014). Green points in Kampung Baru, Bukit Bintang, and KLCC Park recorded higher RH than urban points (Figure 8), confirming that vegetation and water bodies raise humidity and provide cooling benefits (Du et al., 2021).

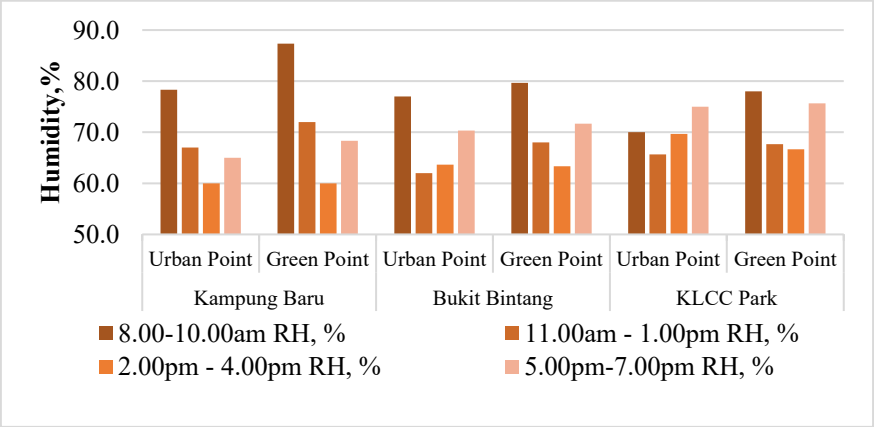


Figure 6: Results of Average Relative Humidity in November

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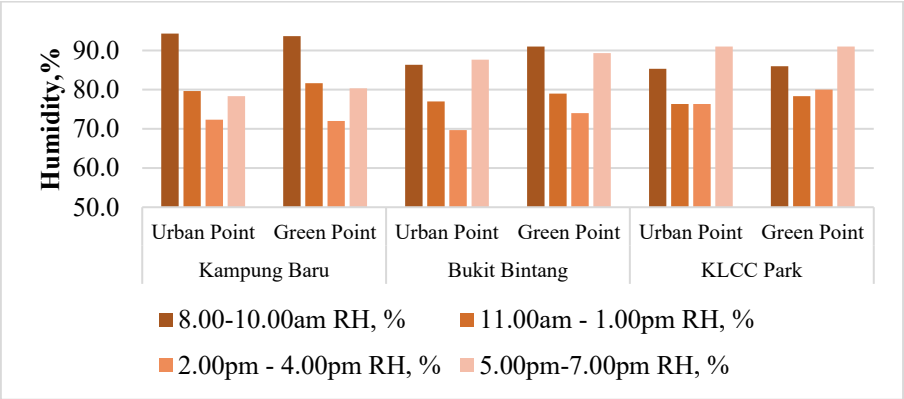


Figure 7: Results of Average Relative Humidity in February

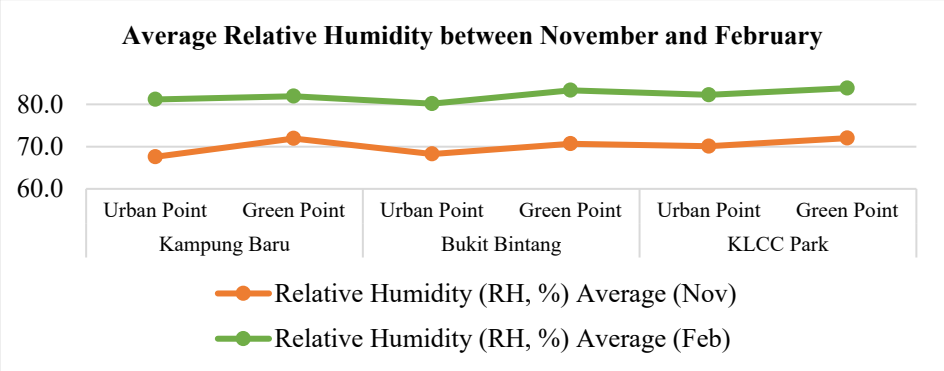


Figure 8: Average Relative Humidity between November and February

Wind Speed

In urban areas, wind speed affects health, thermal comfort, air quality, and UHI intensity more than ambient climate conditions (Anibaba et al., 2019). UHI formation occurs when surfaces release heat slowly under moderate wind conditions (Harun et al., 2020). The Malaysia Meteorological Department reported average wind speeds of 1.8 m/s in November and 1.6 m/s in February, with prevailing winds from the west in November and east in February (Meteorological Terminal Air Report, 2021).

Figures 9–10 show wind speed data for Kampung Baru, Bukit Bintang, and KLCC Park, recorded with a Digital Air Flow Anemometer. Higher wind speeds appeared near high-rises, water bodies, and landscaped areas, as building height and form influence airflow (Rodzi, Razak & Zaki, 2015). However, wind-blocking structures create "wind shadows," reducing ventilation and pedestrian comfort (Mironova, 2020).

Measured wind speeds were 0.8–1.3 m/s, slightly below the city's average, due to frictional drag from dense high-rise buildings (Gamesby, 2020). As expected, urban areas are less windy than rural surroundings (National Meteorological Library, 2019). Figure 11 shows that wind speeds ranged from 0.5–1.0 m/s in November and 0.1–0.3 m/s in February, with lower February values linked to rainy conditions.

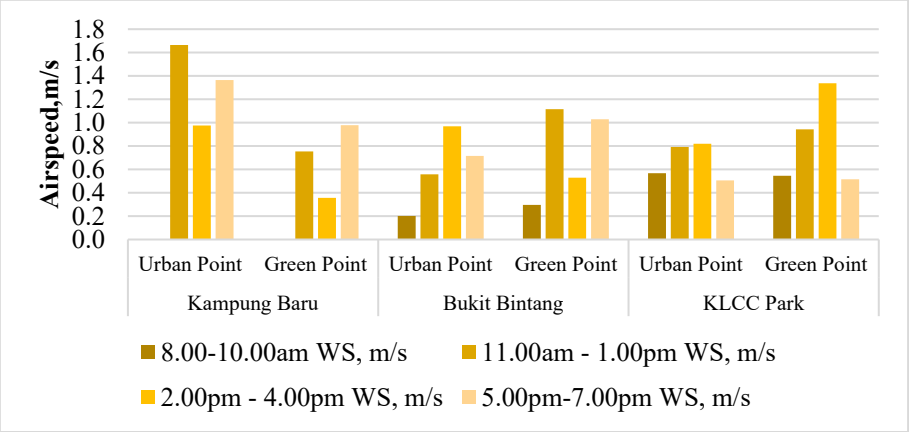


Figure 9: Results of Average Wind Speed in November

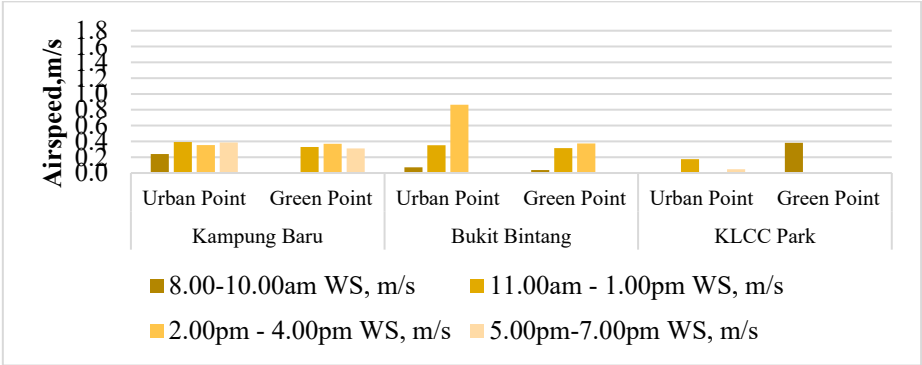


Figure 10: Results of Average Wind Speed in February

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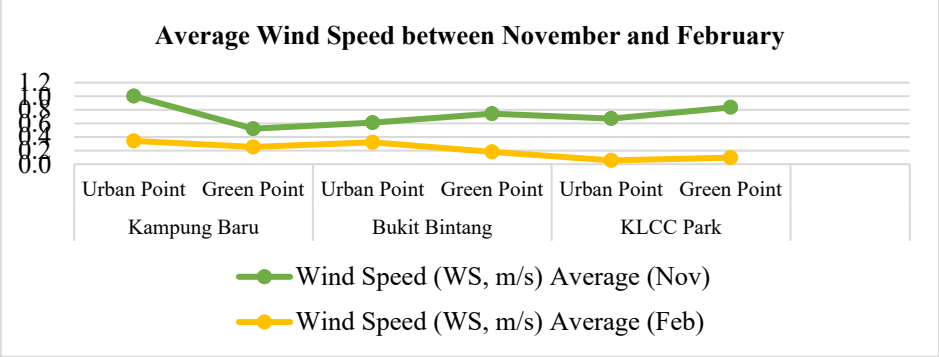


Figure 11: Average Wind Speed between November and February

In Kuala Lumpur, southwest winds are partly blocked at Kampung Baru by high-rises, causing stagnant air and discomfort. Yet, building corners and street canyons increase local wind speeds, with tall structures drawing winds downward. Stronger airflow helps reduce UHI by improving ventilation (Setio et al., 2020; Anibaba et al., 2019).

Particulate Matter (PM2.5)

Figures 13 and 14 show PM2.5 readings at Kampung Baru, Bukit Bintang, and KLCC Park. The highest levels were recorded at Bukit Bintang urban point (27.3 µg/m³ in November, 26.3 µg/m³ in February), linked to dense human activity, traffic, and commercial development (Wang, Guo & Han, 2021).

In contrast, KLCC Park green point showed the lowest PM2.5 levels (12.1 µg/m³ in November, 16.8 µg/m³ in February). This is due to dense vegetation and water bodies, which help filter air pollutants, absorb emissions, and reduce UHI impacts (Hewitt, Ashworth & MacKenzie, 2020). This underlines the need for green infrastructure in urban planning and building design.

Figures 15 confirms that all PM2.5 levels were below the Malaysian Ambient Air Quality Standard limit of 35 µg/m³ (Department of Environment, 2020). However, average levels were higher in February (Figure 18), mainly due to rainy conditions. During rain and high humidity, incomplete combustion from vehicles increases PM2.5 emissions (Zalakeviciute, López-Villada & Rybarczyk, 2018). The highest February values were again at Bukit Bintang, emphasizing how traffic congestion and humidity together raise PM2.5 concentrations.

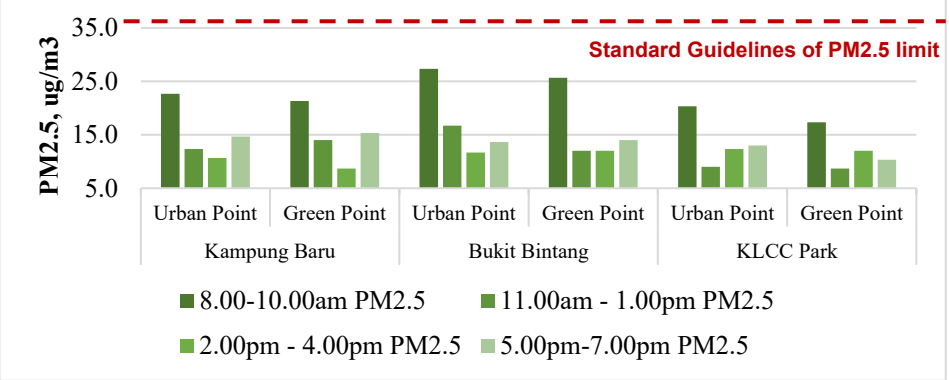


Figure 13: Results of Average Particulate Matter, PM 2.5 in November

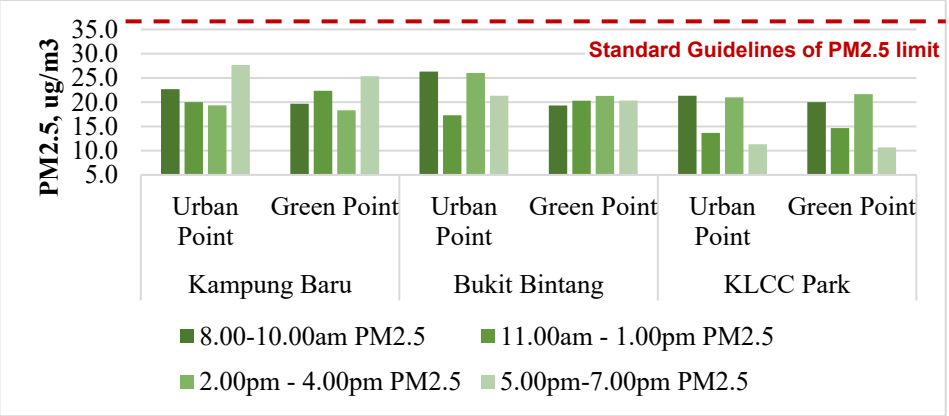


Figure 14: Results of Average Particulate Matter, PM 2.5 in February

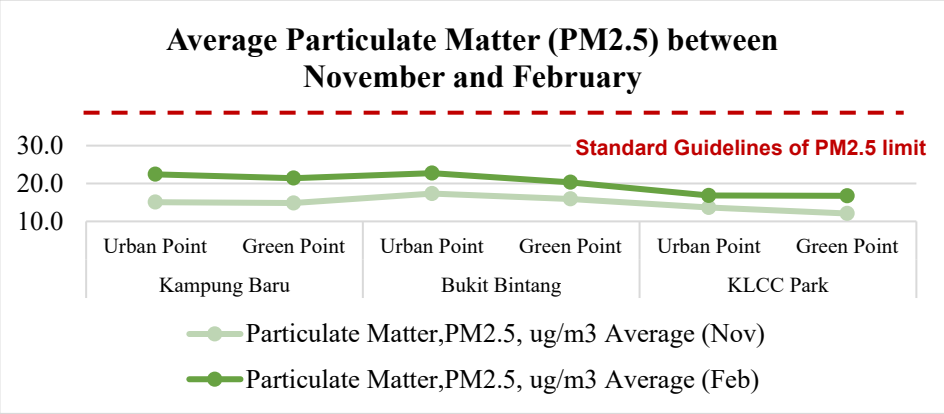


Figure 15: Average Particulate Matter, PM2.5 between November and February

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DISCUSSION

The results show clear impacts on pedestrian and occupant comfort. In Kampung Baru and Bukit Bintang, afternoon temperatures often exceeded the ASHRAE 55 comfort limit of 28°C (Turner et al., 2010), with humidity above 65%, creating severe discomfort for vulnerable groups such as children, the elderly, and those with health issues (Shahmohamadi et al., 2011; United States Environmental Protection Agency, 2020). Prolonged exposure raises risks of heat stress, reduced productivity, and higher reliance on air-conditioning.

These findings highlight the need to apply passive design in practice. Roadside trees, shaded walkways, high-albedo façades, and reflective pavements can improve comfort in dense districts, while green roofs provide cooling where space is limited. In residential areas like Kampung Baru, orientation, courtyards, light-wells, and aligned openings can lower indoor cooling loads and improve outdoor airflow (Aflaki et al., 2015; Gonzalez-Longo & Mohd Sahabuddin, 2019).

By linking field measurements with human comfort standards, the study underlines the importance of pedestrian-scale interventions and climate-responsive planning policies**.** These measures not only mitigate UHI but also support urban livability by making streets, open spaces, and buildings more thermally comfortable.

Table 2: Passive Design Strategies for UHI Mitigation and Thermal Comfort

Category	Strategies	Benefits
Green Infrastructure	Parks, trees, green roofs, rooftop gardens, shaded walkways	Cooling through shade/evapotranspiration, lowers temperatures, better comfort
Reflective Materials	High-albedo façades, cool roofs, reflective pavements	Less heat absorption, cooler surfaces, improved indoor/outdoor comfort
Building Orientation	Align with wind, façade treatments, operable windows, cross-ventilation	Better airflow, lower cooling demand, improved circulation
Urban Layout	Courtyards, atriums, light-wells, maintain sky view	Less solar gain, avoids heat trapping, supports cooling

Our findings align with planning research showing the value of nature-based solutions. Krishnamoorthy, Mohd Adnan, and Md Yassin (2024) found that pocket parks and green corridors improve microclimate and pedestrian comfort in dense areas, supporting our evidence on vegetation and water bodies.

Likewise, Nizarudin and Zakariya (2025) stress retrofitting green infrastructure to strengthen resilience and address policy gaps, echoing our call

for integrating green space, reflective materials, and passive design into urban planning.

CONCLUSION

This study set out to examine the relationship between **u**rban morphology, microclimate, and the Urban Heat Island (UHI) effect in Kuala Lumpur, with three specific objectives: (i) to assess how different urban forms influence thermal comfort and air quality, (ii) to evaluate the effectiveness of passive design strategies in mitigating UHI, and (iii) to provide recommendations for climate-responsive urban planning. Field measurements across Kampung Baru, Bukit Bintang, and KLCC Park demonstrated that green and water-integrated areas consistently achieved lower air temperatures and PM2.5 levels, whereas compact high-density districts experienced elevated heat loads and reduced ventilation.

The findings confirm the potential of green infrastructure, optimized building orientation, reflective materials, and passive ventilation strategies to improve both outdoor and indoor thermal comfort. Beyond design, the study highlights the need for urban policy frameworks—including the integration of the Green Building Index (GBI) and microclimate-sensitive zoning regulations—to guide sustainable development in tropical cities.

Looking ahead, future implementation pathways should focus on mainstreaming passive design at the master planning scale, enhancing tree canopy networks in pedestrian corridors, and mandating climate-responsive building codes. Further research involving long-term monitoring, seasonal data, and simulation modeling is essential to refine strategies and strengthen the evidence base for policy and practice. Ultimately, addressing UHI through integrated design and planning can significantly enhance **u**rban livability, environmental resilience, and public health in Kuala Lumpur.

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QUANTIFYING EMBODIED CARBON EXPENDITURE IN GREEN MAINTENANCE OF HERITAGE BUILDINGS: A CASE STUDY OF MARSEILLE CLAY ROOF TILES REPAIR

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Abstract

Green Maintenance (GM) inculcates sustainable planning and development of heritage buildings and the historic environment. It promotes practices in line with the Conference of the Parties of the United Nations Convention on Climate Change (UNFCCC) or COP and Sustainable Development Goals (SDGs) aspirations, thus underpinning decision-making in low-carbon repair options and supporting environmentally focused conservation. This paper aims to quantify embodied carbon expenditure in GM based on a carbon Life Cycle Assessment (LCA) and Environmental Maintenance Impact (EMI) evaluation in the conservation of a selected heritage building in the case of Marseille clay roof tiles repair. The research found that Marseille-Mornier tiles repair of Bangunan Sultan Abdul Samad contributed to 58,116.84 kgCO2e of the overall total EMI. The research results demonstrated that adopting carbon LCA and EMI enhanced understanding of the complex relationship between Marseille clay roof tile repair and its environmental impact and performance. More importantly, the adopted carbon LCA and EMI could be appreciated regarding CO2 emissions reduction and interdisciplinary heritage building conservation establishment.

Keywords: Embodied carbon expenditure, Green Maintenance (GM), Marseille clay roof tiles, Life Cycle Assessment (LCA), Environmental Maintenance Impact (EMI), low-carbon repair

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INTRODUCTION

Maintenance is all practical and technical measures to keep heritage buildings at a standard that permits enjoyment of their cultural significance and resources without damage (Burra Charter, 2013). Moreover, it is a self-correcting balance that puts heritage buildings' structure and elements into their original condition within the heritage preservation philosophical framework (British Standards Institution, 1998). Importantly, this is aligned with the Green Maintenance (GM) concept and methodology.

GM is gaining popularity in the sustainability domain, as evidenced by the growing trend in research and published works. GM is well known for its support of good maintenance and low-carbon repair strategy (Kayan et al., 2024) and sustainable planning and development of heritage buildings and the historic environment (Nursaniah et al., 2023; Mari et al., 2024). Moreover, GM is recognised for reducing embodied carbon expenditure from repair (Sari et al., 2023). Practically, GM is aligned with the aspirations of the 27th Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) or Conference of the Parties 27 (COP 27) (2022). In terms of environmental sustainability of heritage buildings, GM also embraces the U.N.'s Sustainable Development Goal 13 (SDG13), i.e. to combat the adverse impact of climate change, as well as Sustainable Development Goal 11 (SDG11). Despite this, efforts to quantify embodied carbon expenditure from building's elemental repair in heritage building conservation remained insufficient. For instance, there is a lack of attempts to quantify embodied carbon expenditure for Marseille clay roof tile repair in terms of life-cycle environmental performance. Likewise, quantification of embodied carbon expenditure for roof covering materials used in a tropical country like Malaysia is still lacking. Moreover, previous research largely focuses on the preservation of roof structures and materials (Hassan and Harun, 2013), assessment of production quality of roof covering (Abdullah, 2014) and modern application of roof materials (Nouri et al., 2021).

In response, this paper aims to show that quantifying embodied carbon expenditure in GM for roof elemental repair (in this case, Marseille clay roof tiles) via the application of a carbon Life Cycle Assessment (LCA) and Environmental Maintenance Impact (EMI) evaluation enables the achievement of low-carbon repair in heritage building conservation. Significantly, this could be appreciated in CO_2 emissions reduction and interdisciplinary heritage building conservation establishment.

LITERATURE REVIEW

This section gives an insight into an overview, focuses on historical background, traditional manufacturing processes, the profile, and common pathological and technical issues of Marseille clay roof tiles. The association and quantification

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of embodied carbon expenditure in the context of a sustainable repair approach, as well as recycling and salvaging options, aspired to through Green Maintenance, are also elaborated. Traditionally, the accepted conceptual model of sustainability is overlaid with three factors that influence the maintenance of heritage buildings: environment, cost, and philosophy. Those interventions that intersect with all three domains would potentially be considered as being the most sustainable concept and methodology for maintenance, i.e. "Green Maintenance" (GM).

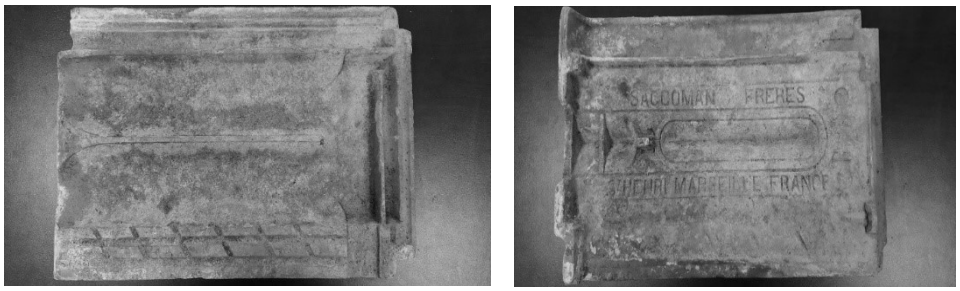
The frequency of maintenance interventions (such as this case repair to Marseille clay roof tiles) will eventually affect the level of CO_2 emissions. In most cases, the best repair techniques are twinned with sustainable low-carbon repair materials. Note that GM is parallel with the generally accepted model for the evaluation of 'sustainable' or 'green' maintenance interventions (Kayan, 2017; Sari et al., 2023). Significantly, this research associates maintenance interventions, e.g. repair to Marseille clay roof tiles, with a carbon LCA and EMI assessment of GM. The unifying concept and methodology of GM can be seen as a tool for promoting good maintenance interventions in terms of embodied carbon expenditure (CO_2 emissions) with minimal environmental impact, as well as promoting a sustainable repair approach for heritage buildings. This will become a key performance indicator in the good repair impact strategies.

Marseille Clay Roof Tiles: An Overview

Historical Background

Historically, Marseille clay roof tiles were popular worldwide. The earliest produced Marseille clay roof tiles of the French Gilardoni variety have been extensively used in Europe since the 1880s (ACAHUCH, 2025). In Australia, Saccoman of St Henry Marseille clay roof tiles were imported as early as the 1860s, and by the late 1880s began to appear on local buildings such as Alexander McCracken's House, and at 'North Park' (later 'Woodland's) at Essendon, Melbourne, in 1889) (Australasian Builder and Contractor's News Publishing Co., 1889). Remarkably, the initial production and usage of Marseille clay roof tiles globally is widespread; e.g. New Zealand (1900s), India (1880s), South America (1890s), and Singapore (1920s) (ACAHUCH, 2025). In Malaysia, the earliest usage of Marseille clay roof tiles was in the local heritage buildings of diverse functions and typologies. As early as the 1920s (similar to Singapore) they were frequently used in colonial buildings in Pulau Pinang (Ibrahim-Bell, 2019). Moreover, research by Ibrahim-Bell (2019) found that Saccoman Freres of St Henri Marseille tiles (commonly known as 19th-century French tiles) were used in historic bungalows and cottages in Fraser's Hill, Pahang. Characteristically, as shown in Figure 1, the flat interlocking Saccoman Freres of St Henri Marseille tiles are produced by two deep vertical grooves on the surface

that facilitate drainage, printed with the manufacturer's crest and batch on the back, and finished with holes at the top for nailing (usually two holes, with a dab of cement for added security, sometimes the tiles have a small knob with a hole through which wire can be inserted to secure the tile to the roof battens) (Grimmer & Williams, 1993). Despite the long historical background and usage in heritage buildings, attempts to quantify embodied carbon expenditure for Marseille clay roof tile repair in terms of life-cycle environmental performance remain lacking.



(a) (b)

Figure 1: Saccoman Freres, St Henri, Marseille, France tile pattern: (a) upper side, and (b) underside
Source: Authors (2025)

Traditional Manufacturing Processes

The traditional manufacturing processes of Marseille clay roof tiles involved four stages: first, the extraction and resourcing of clay; second, the main production/manufacturing; third, storage of the final product; and finally, distribution (transportation/delivery to the building site) (Figure 2).

The Profile

Marseille clay roof tiles have been around for centuries, proving their long-lasting durability, thermal conductivity and elegant attributes. The tiles are long-lasting, durable, watertight, and have good thermal conductivity (ACAHUCH, 2025). The tiles have an elegant look, are available in a wide variety of sizes, shapes, colours, profiles, patterns, and textures (Grimmer & Williams, 1993).

Common Pathological and Technical Issues

Despite its wide usage and application, Marseille clay roof tiles used in heritage buildings are affected by pathological and technical issues. Common pathological issues include weathering effects, pollution, microorganism attacks, overflowing rainwater and roof leakage. Technically, the tiles require special care and precaution, thus, causing difficult cleaning and treatment processes and complicated repair work procedures (Grimmer & Williams, 1993).

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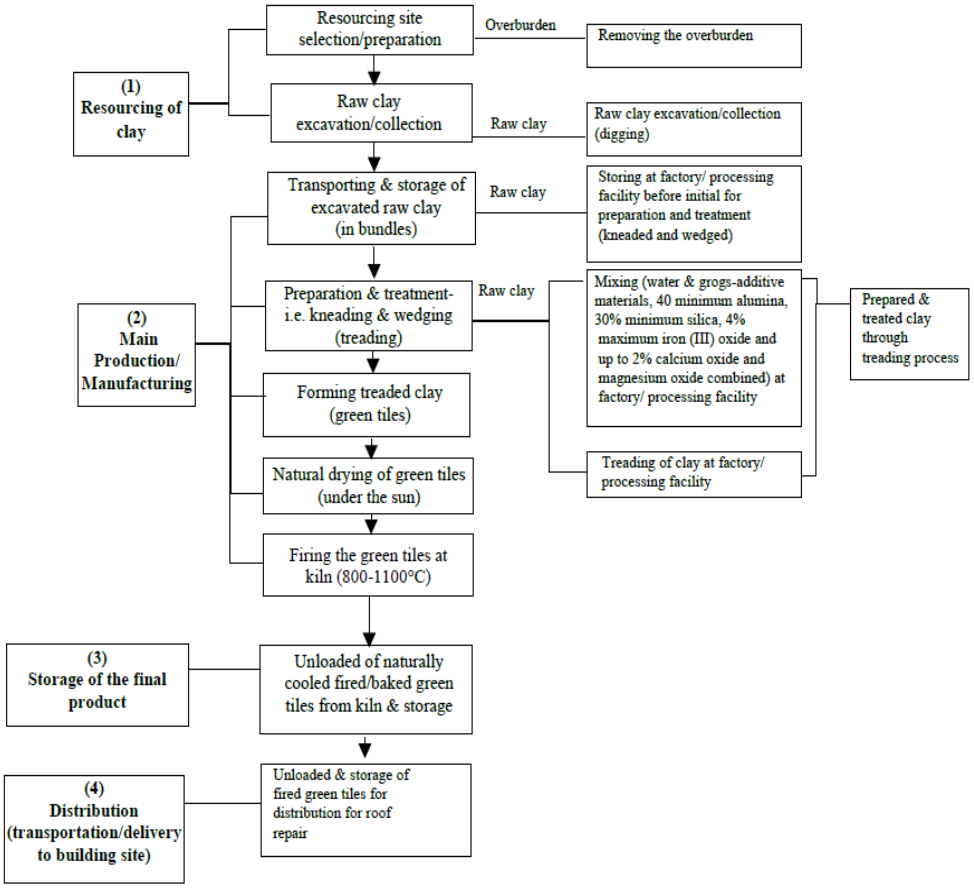


Figure 2: Traditional manufacturing processes of Marseille clay roof tiles
Source: Authors (2025)

Repair Impact on Embodied Carbon Expenditure and Sustainable Repair Approach

Roof repair options and their respective embodied carbon expenditure are usually determined by building design and forms, the repaired roof surface area, and the tiles used (Kayan & Ashraf, 2023). Considering the wide usage of Marseille clay roof tile in heritage buildings, the influences of repair in terms of the building's life-cycle environmental performances would be cumulatively significant. On the other hand, Marseille clay roof tiles are also known for their ability to sequester carbon, i.e., have better environmental credentials and performance compared to modern roof covering materials such as composites, concrete and zinc. Other roof repair approaches using modern tile materials that practitioners

might adopt are beyond the scope of this research's carbon LCA and EMI evaluation.

Recycling and Salvaging Options from A Low-Carbon Repair Perspective

Ideally, recycling or salvaging options may appear to be a good solution to the shortage of historic and traditional Marseille clay roof tiles, thus enabling low-carbon repair. However, the additional processes of sorting, cleaning and disposal of the tiles will cumulatively contribute to the additional embodied carbon expenditure.

RESEARCH METHODOLOGY

Case Study: Bangunan Sultan Abdul Samad

Bangunan Sultan Abdul Samad (Figure 3) inherited late 19th-century Indo-Saracenic, Neo-Mughal and Moorish styles, elaborated with pitched-Marseille clay roof tiles. The building was declared a National Heritage on 24 December 2008, under the National Heritage Act (Act 645) Malaysia, Section 67 (2)(a), i.e., a building with historical importance, association with or relationship to Malaysian history (Malaysia, 2006). The building's background and technical specifications for the Marseille roof tiles and common defects are described in Table 1. In 2019, a major repair was undertaken to the damaged roofing structure and covering materials using locally sourced Marseille-Monier clay roof tiles. In the case of this paper, the defective or damaged Marseille-Monier clay roof tiles are replaced with identical specification and similar materials to attain their authenticity based on repair work procedures by Jabatan Warisan Negara, Malaysia (JWN).

Repair Work Procedures

Due to the National Heritage status of Bangunan Sultan Abdul Samad, the repairing strategy and procedures for Marseille-Monier clay roof tiles are specified in Section 3.1 of the 2017 "Heritage Building Conservation Guidelines" issued by Jabatan Warisan Negara, Malaysia (JWN). The guidelines stated (i) adoption of approved methods of investigating and identifying the tile's profile such as originality and condition (including original finishes), (ii) rehabilitative and protective treatment (to avoid damage during repair), (iii) re-use of salvaged materials and similar materials in terms of type, appearance, colour, texture, etc., and (iv) usage of identical materials and original placement layout and technique. The repair work procedures of Marseille-Monier clay roof tiles for the case study building are further explained in Figure 4.

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Figure 3: Bangunan Sultan Abdul Samad (case study)
Source: Authors (2025)

Table 1: Case study's background, roof tiles specification and defects

Location	Year Built	Construction Method	Current Function	Building Data & Characteristics	Roof Tiles Technical Specifications	Roof Tiles Common Defects
Kuala Lumpur, Malaysia	1894 – 1897, 126 years old	Two storeys, red bricks, with a pitched tiled roof	Public institution	● Known as the 'Federal Secretariat' (1897) ● Named after Sultan Abdul Samad (1857-1898) ● Designed by A.C. Norman, assisted by R.A.J. Bidwell in a Classical Renaissance style ● Reworked by Bidwell, commissioned by C. E. Spooner ● Building fixtures by A.B. Hubback	● 19th-century Marseille Mornier brand/type ● Interlocking ● Variable gauge-great flexibility ● Exclusive "Bee" mark ● Natural colour ● Number of tiles per m^2: 13.5 ● Dimensions (cm): 42 x 26 ● Batten gauge/spacing (cm): 32 to 36 +/ 0.3 between each tile ● Weight (kg): ≈ 3.7 ● Laid with straight joints right to left ● Minimum roof pitch: 30% (16°70')	● Dirt-stained ● Fungus-infested ● Discoloured ● Faded/dulled ● Cracks ● Broken ● Holes ● Misalignment ● Displacement

Source: Authors (2025)

Carbon LCA and EMI Evaluation

The evaluation was undertaken to evaluate embodied carbon expenditure from the repair of Marseille clay roof tiles (in the form of CO_2 emissions) using the equation in Table 2 and a set of unit processes and workflows in Figure 4. Conceptually, Figure 4 demonstrates on how calculation procedures within cradle-to-site boundary of LCA in this paper were underpinned by EMI evaluation and correlated with the respective longevity, *l* and frequency of repair,

f_x (as in equation No. 3). Note that, f_x is frequency of Marseille clay roof tiles repair options within arbitrary period, while $\sum ECEcradle - to - site$ is overall total embodied carbon expenditure from cradle-to-site of LCA.

Table 2: Equation adopted in integrated carbon LCA and EMI

Equation	Output	Equation Formulae	Remarks
(1)	Overall total embodied carbon expenditure from cradle-to-site	$\sum ECEcradle - to - site = \sum ECEcradle - to - gate + \sum ECEgate - to - site$ where; $\sum ECEcradle - to - site$ = Overall total of Embodied Carbon Expenditure ($kgCO_2e/kg$)	● Within Cradle-to-site boundary of LCA
(2)	Total EMI	$\sum_{ti=1}^{n} EMIcradle - to - site_{tn} = EMIcradle - to - site_{t1} + \ldots EMIcradle - to - site_{tn}$ where; *tn* = longevity of Marseille clay roof tiles repair *EMIcradle-to-site* = total EMI within the cradle-to-site boundary of LCA [generated from Equation No. (1)]	● Within selected arbitrary years of maintenance profile periods, the value entered in Equation (2) will determine the overall total EMI
(3)	Frequency of Marseille clay roof tile repair	$f_x = \frac{x_{years}}{l}$ where; l = longevity of Marseille clay roof tiles repair x_{years}= arbitrary period (years) of Marseille clay roof tiles repair options f_x = frequency of Marseille clay roof tiles repair options within an arbitrary period	● The f_x can be calculated using an arbitrary period (in this paper is 100 years, divided by the estimated longevity of repair, l of 50 (supplier's data)
(4)	Overall total EMI within an arbitrary period	$\sum EMIyears = \sum ECEcradle - to - site \times f_x$	● The overall total EMI within the arbitrary period (in this paper is 100 years)

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Equation	Output	Equation Formulae	Remarks
		where; f_x = frequency of Marseille clay roof tile repair within an arbitrary period $\sum EMIyears$= Overall total EMI ($kgCO_2e$) within an arbitrary period	

Source: Authors (2025)

It should be noted that the topics and Green Maintenance concept and methodology adopted in this research have been applied in previous studies such as Kayan's 2017 "Green Maintenance for Heritage Buildings: Paint Repair Appraisal" (Kayan, 2017) and Kayan & Ashraf's 2023 "Evaluating the Environmental Maintenance Impact (EMI): A Carbon Life Cycle Assessment (LCA) of the Singgora Roof Tiles Repair in Heritage Buildings" (Kayan & Ashraf, 2023). Nevertheless, it has to be pointed out that this paper's study has established its significance and novelty. Even though both the previous studies were undertaken in the same tropical region, the selected Bangunan Sultan Abdul Samad and the investigated Marseille-Monier clay roof tiles in this research were different in terms of building orientation, exposure to local weathering agents, and rate of degradation. Comparatively, the earlier study by Kayan (2017) focuses on paint repair on the roof surface and its covering materials, while the work by Kayan & Ashraf (2023) researched Singgora roof tile repair.

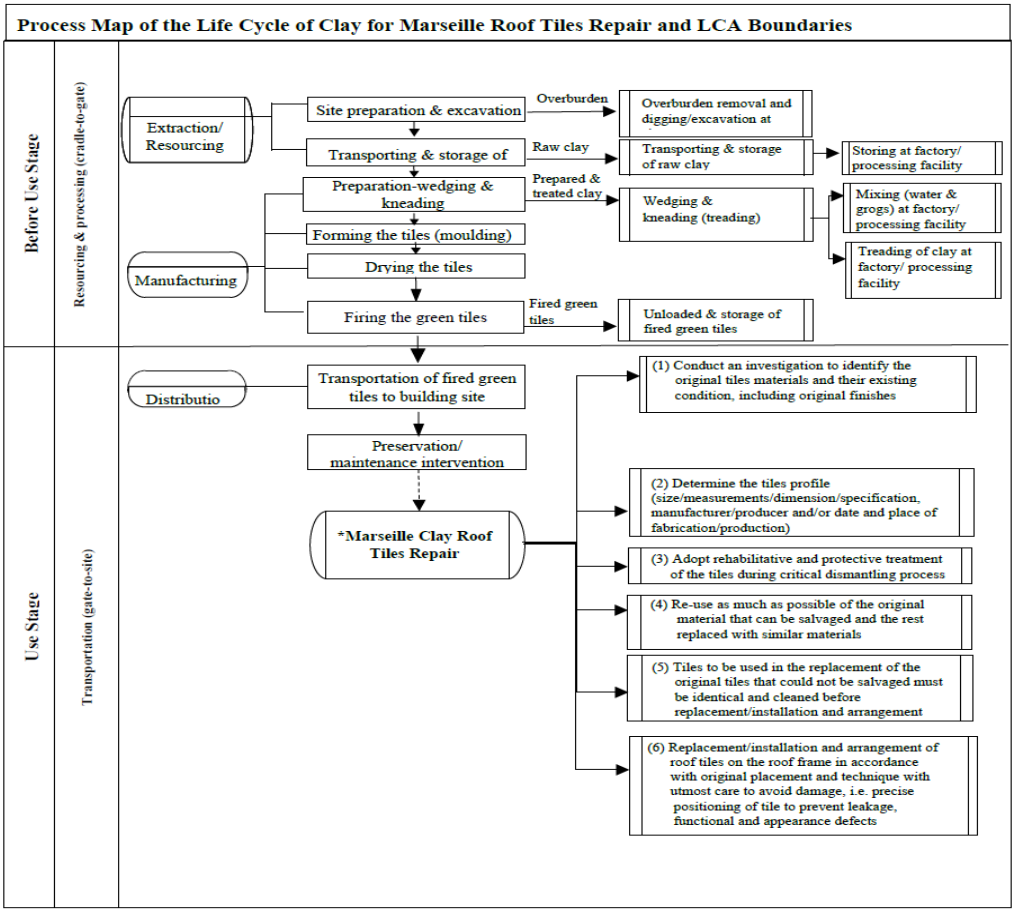


Figure 4: Process map of the life cycle of clay for Marseille clay roof tiles repair
Source: Authors (2025)

Moreover, the embodied carbon coefficient value $\frac{ecc_{kgCO2e}}{kgm^2}$) of 0.48 $kgCO_2e/kg$ of common clay materials of Marseille clay roof tiles generated in CIDB's Embodied Carbon Inventory Data for Construction Materials 2021 was adopted in this research as opposed to 0.24 $kgCO_2e/kg$ in earlier work by Kayan & Ashraf (2023). This is to better represent the embodied carbon coefficient value of common clay materials for Marseille clay roof tiles in the local context of Malaysia.

The adopted carbon LCA and EMI in this research utilised data from the United Kingdom (UK) and Malaysia (mainly due to similar power generation and modes of transportation used). Within the cradle-to-gate boundary of LCA, an embodied carbon coefficient value is derived from the Construction Industry

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Development Board (CIDB) Malaysia's Embodied Carbon Inventory Data for Construction Materials (2021) and UK Government GHG Conversion Factors for Company Reporting (Department for Energy Security & Net Zero & Department for Environment, Food & Rural Affairs, 2024).

ANALYSIS AND DISCUSSION

Total Mass Kg of Repair Materials and Approximate Repaired Roof Surface Area

Table 3 shows the mass, m_{kg} (kg), repaired roof area, A_{m2} (m^2) and mass kg/m^2 of Marseille clay roof tiles repair materials for Bangunan Sultan Abdul Samad. It can be established that the total mass kg of Marseille clay roof tiles repair materials for the building relied upon different numbers of replaced/re-installed tiles on the repaired roof surface area (in m^2).

Functional Units of Embodied Carbon Per m^2: Total $kgCO_2e/kg/m^2$

Table 4 shows functional units of embodied carbon per m^2 ($kgCO_2e/kg/m^2$), undertaken on 1 m^2 of Bangunan Sultan Abdul Samad's roof surface repaired area using Marseille clay roof tiles. It can be concluded that the functional units of this research generated within cradle-to-site carbon LCA are highly influenced by the total mass of tiles m_{kg} (kg) for repair, transportation distance to the building site, d_{km} (km), and embodied carbon coefficient, $ecc_{\frac{kgCO2e}{kg\ m2}}$ and carbon emission factors, $ef_{\frac{kgCO2e}{\frac{kg}{km}}}$.

Table 3: Total mass kg of Marseille clay roof tiles repair materials m_{kg} (kg) and total approximate repaired roof area A_{m2} (m^2) of Bangunan Sultan Abdul Samad

Tiles brand/ type	Mass (kg) /tile (a)	No. of tiles/m^2 (b)	Total mass (kg) tiles/ m^2 (c) = (a x b)	Total number of tiles for repair (d)	Total mass of tiles m_{kg} (kg) for repair (e)= (a x d)	Surface area (m^2)/ tiles (f)	Total Approx. Repaired Roof Area A_{m2} (g)= (d) x (f)
Marseille-Monier	3.70	13.5	49.95	13,000	48,100.00	0.42 x 0.26 = 0.1092	1,419.60

Source: Authors (2025)

Table 4: Functional Units of Embodied Carbon Per m^2 ($kgCO_2e/kg/m^2$) for Marseille roof tiles repair of Bangunan Sultan Abdul Samad

		Life Cycle Assessment (LCA) Boundary				
		Cradle-to-Gate		Gate-to-Site		Cradle-to-Site
Total mass of tiles m_{kg} (kg) for repair	Transportation distance to building site d_{km} (km)	Embodied carbon coefficient $ecc_{\frac{kgCO2e}{kg\ m2}}$	$kgCO_2e/kg/m^2$ (A)	Carbon emission factors $ef_{\frac{kgCO2e}{\frac{kg}{km}}}$	$kgCO_2e/kg/m^2$ (B)	Total $kgCO_2e/kg/m^2$ (A+B)
49.95	228.1	0.48	23.976	0.00054417	6.200	30.176

Source: Authors (2025)

Overall Total Embodied Carbon Expenditure ($kgCO_2e$)

Generated using Equation No. (1), the results in Table 5 show that the greater the number of replaced/ re-installed Marseille roof tiles during repair, the higher the overall total embodied carbon expenditure ($kgCO_2e$). It is discovered that a considerable 20.55% of the overall total embodied carbon expenditure for the transportation of Marseille clay roof tiles from Yong Peng, Johor, to the building site of Bangunan Sultan Abdul Samad in Kuala Lumpur.

Table 5. Overall Total Embodied Carbon Expenditure ($kgCO_2e$) within the cradle-to-site of Bangunan Sultan Abdul Samad

				Life Cycle Assessment (LCA) Boundary				
				Cradle-to-Gate		Gate-to-Site		Cradle-to-Site
Mass (kg)/ tile	**Total number of tiles for repair**	**Total mass of tiles m_{kg} (kg) for repair**	**Transportation distance to building site, d_{km} (km)**	**Embodied carbon coefficient** $ecc_{\frac{kgCO2e}{kg\ m2}}$	**Total embodied carbon expenditure ($kgCO_2e$) (A)**	**Carbon emission factors** $ef_{\frac{kgCO2e}{\frac{kg}{km}}}$	**Total embodied carbon expenditure ($kgCO_2e$) (B)**	**Overall total embodied carbon expenditure ($kgCO_2e$) (A+B)**
3.70	13,000	48,100.00	228.1	0.48	23,088.000	0.00054417	5,970. 421	29,058.421

Source: Authors (2025)

Overall Total EMI ($kgCO_2e$) Within Arbitrary Period

Overall total $\sum EMIyears$ EMI ($kgCO_2e$) of Marseille roof tiles repair of Bangunan Sultan Abdul Samad, within an arbitrary period and cradle-to-site of LCA is the multiplication of functional units with their respective frequency of repair, f_x. Generated from Equation (2) and Equation (3), this can be expressed in Equation (4) (see Table 2). The overall total EMI was calculated within the selected arbitrary period of this research (in this case f_x =100 years) and is shown in Table 7. For comparative purposes in this research, three different brands/types of tiles from the Marseille tiles family were selected. All of them were mainly

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made from clay materials and were nearly identical to each other. The slight differences among the tiles are in terms of their mass (kg) and surface (m^2). Results show that Mornier 12-GCI generated the highest overall total EMI, followed by Marseille-Monier, and the lowest is by Marseille-Terreal. The lowest EMI by Marseille-Terreal is mainly due to the lowest mass kg/tile (3.6) and mass (kg) tiles/m^2 (43.20), and total mass of tiles m*kg* (kg (46,800) (see Table 6). However, the heavier tiles will produce sturdier roofing material (ACAHUCH, 2025). Considering this, Marseille-Mornier and the Marseille-12 GCI should be more robust/durable materials as compared to Marseille-Terreal.

In the context of this research, the best Marseille clay roof tile brands/types for repair are not only viewed exclusively in terms of EMI. The most ideal tiles have to fulfil philosophical heritage conservation frameworks which include minimal intervention yet provide maximum preservation (Feilden & Jokilehto,1993), like-for-like material replacement (Nursaniah et al., 2023; Mari et al., 2024), and respect for traditional craft skills (Kayan & Shafigh, 2022). The ideal tiles also comply with conservation guidelines, e.g. "Heritage Building Conservation Guidelines" by Jabatan Warisan Negara, Malaysia (JWN) and are aligned with the aspiration of UNFCCC or COPs as well as SDGs. Considering this, Marseille-Mornier used for repair on Bangunan Sultan Abdul Samad is the most ideal, both in terms of EMI and philosophical frameworks. There are many examples of replaced/re-installed Marseille clay roof tiles still functioning satisfactorily in well-maintained Malaysia heritage buildings of different designs, forms, types and functions, some of which are more than 100 years old: 18th-century British Colonial Buildings in Fraser's Hill and Cameron Highlands in Pahang (over 200 years old) (Bahauddin et al., 2010; Ibrahim-Bell, 2019), Crag Hotel and Woodside Cottage in Penang Hill, Pulau Pinang (130 and 222 years old respectively) (Raub et al., 2015); Stamp Museum (over 200 years old, built in the 17th century during Dutch occupation) (Sari et al., 2023) and The Hong Kong and Shanghai Banking Corporation (HSBC) building (111 years old, built in 1912) in Melaka; St Mary's Cathedral in Kuala Lumpur (129 years old, built in 1894); and the Sanitary Board Building in Taiping, Perak (131 years old, built in 1892) (Kayan & Shafigh, 2022).

The results in Table 6 show that as high as one-fifth of the overall total embodied carbon expenditure $kgCO_2e$ for the transportation of Marseille clay roof tiles sourced from the Yong Peng, Johor, to the building site of Bangunan Sultan Abdul Samad in Kuala Lumpur. Comparative analysis for transportation of different brands/types of Marseille clay roof tiles from the same resourcing location, using a similar mode of transportation, demonstrates the same pattern of contribution upon the overall total embodied carbon expenditure. Thus, to lessen the transportation of material influence on the total embodied carbon expenditure in repair, it is practical to use locally sourced Marseille clay roof tiles.

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Table 6: Comparative analysis of overall Total Embodied Carbon Expenditure ($kgCO_2e$) within cradle-to-site of different brands/types of Marseille clay roof tiles

									Cradle-to-Gate		Gate-to-Site		Cradle-to-Site
	kg/ tile (a)	tiles /m^2 (b)	kg tiles/m^2 (c) = (a x b)	Total tiles (d)	Total m_{kg} (kg) for repair (e) = (a x d)	Surface area (m^2)/ tiles (f)	Total repaired roof area Am^2 (g) = (d) x (f)	d_{km} (h)	$ecc_{\frac{kgCO2e}{kg\ ti}}$ (i)	($kgCO_2$ e) (A)= e x i	$ef_{\frac{kgCO2e}{\frac{kg}{km}}}$ (j)	$kgCO_2e$ (B) = (e x h x j)	$kgCO_2e$ (A+B)
Monier	3.7	13.5	49.9	13,000	48,100.0	0.109	1,419.6	228.1	0.48	23,088.0	0.00054417	5,970.421	29,058.42
12 – GCI	4.1	11.9	48.8		53,300.00	0.119	1,544.4			25,584.0		6,615.872	32,199.87
Terreal	3.6	12.0	43.2		46,800.0	0.114	1,487.2			22,464.0		5,809.058	28, 273.05

Source: Authors (2025)

Table 7: Comparison of overall total EMI for Marseille clay roof tiles repair within the cradle-to-site of selected arbitrary period (100 years)

Brand/type	Overall total embodied carbon expenditure ($kgCO_2e$)	Frequency of roof tile repair within arbitrary periods, f_x (100 years)	Overall total EMI within cradle-to-site of selected arbitrary period (100 years) ($kgCO_2e$)
Monier	29,058.42	2	58, 116.84
12 – GCI	32,199.87		64,399.74
Terreal	28,273.05		56,546.10

Source: Authors (2025)

CONCLUSION

This research reveals that Marseille 12–GCI contributed to the highest overall total EMI of 64,399.74 $kgCO_2e$ as compared to the lowest of 56,546.10 $kgCO_2e$ for Marseille–Terreal. Marseille-Mornier tiles used in the case study of Bangunan Sultan Abdul Samad generated the second-highest EMI of 58,116.84 $kgCO_2e$. Marseille-Mornier tiles used to repair Bangunan Sultan Abdul Samad's roofing are the most ideal as they embrace low-carbon repair materials options and fulfil the environmental sustainability and heritage building conservation philosophical frameworks. The research demonstrates that the adoption of integrated carbon LCA and EMI of GM enable the quantification of embodied carbon expenditure in the repair of Marseille clay roof tiles. Additionally, the research supports environmentally focused conservation and is aligned with sustainable planning and development of heritage buildings and the historic environment as per the aspirations of UNFCCC or COPs and SDGs. More importantly, carbon LCA and EMI of this research could be appreciated as a resource in CO_2 emissions

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reduction and interdisciplinary heritage building conservation establishment, thus will be of value to both practitioners and researchers concerned with the low-carbon repair techniques and materials.

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DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

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EMBRACING CIRCULAR ECONOMY IN MALAYSIA'S CONSTRUCTION INDUSTRY: READINESS, CHALLENGES, AND STRATEGIC PATHWAYS

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Abstract

The construction sector in Malaysia is undergoing rapid urbanization, leading to increased resource consumption and environmental degradation. This paper aims to evaluate the readiness of Malaysia's construction industry to adopt Circular Economy (CE) principles, by examining existing regulatory frameworks, industry practices, and strategic barriers. This study offers grounded insights into how Circular Economy (CE) strategies can be operationalised in Malaysia's construction sector through a combination of stakeholder interviews, focus group discussions, and international benchmarking. The research investigates regulatory frameworks, industry practices, and existing barriers to CE adoption. A qualitative research approach, including policy analysis, local authority engagement, focus groups, and comparative framework analysis, was conducted. Findings contribute to policy recommendations and industry best practices, fostering a transition towards sustainability in Malaysia's built environment.

Keywords: Circular Economy, Sustainable Construction, Design Leadership, Malaysia, Built Environment

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INTRODUCTION

The construction industry in Malaysia is a key driver of the country's economic growth, contributing significantly to infrastructure development, job creation, and national GDP. However, it is also notably one of the largest consumers of raw materials and a major contributor to environmental issues such as resource depletion, waste generation, and carbon emissions. As urbanization and development pressures continue to rise, the built environment industry faces mounting challenges in balancing economic progress with environmental sustainability. Traditional linear construction practices—characterized by the "take, make, dispose" model—have led to excessive material wastage and inefficiencies, highlighting the urgent need for a more sustainable approach.

In response, the concept of a Circular Economy (CE) has gained traction worldwide as a transformative model that seeks to minimise waste and maximize resource efficiency through strategies such as material recycling, modular construction, and sustainable procurement. Countries with mature CE policies, such as the Germany and Japan, have demonstrated how integrating circular principles can enhance long-term resilience, reduce dependency on virgin resources, and lower carbon footprints. However, despite the growing global momentum, the Malaysian construction sector's readiness to embrace CE remains uncertain. The transition requires robust policy frameworks, industry-wide collaboration, and a fundamental shift in design leadership and project management strategies.

This paper seeks to evaluate the readiness of stakeholders within Malaysia's construction industry to integrate CE principles. It aims to identify key enablers, barriers, and strategic interventions necessary for a successful transition to a circular construction ecosystem. By examining regulatory frameworks, industry perceptions, and best practices from global benchmarks, this study aims to provide actionable insights that can drive Malaysia's construction sector toward a more sustainable and resource-efficient future.

CURRENT CIRCULAR ECONOMY PRACTICES AND CHALLENGES

Construction Waste Recycling Rates: Malaysia Vs. Other Countries

Recent data indicates that Malaysia's construction waste recycling rate was 30.67% in 2020, significantly lower than developed countries. Singapore achieves a recycling rate of 59%, while South Korea is at 49%, and Taiwan leads with 60% (MIDA, 2023). Germany and Japan implement rigorous recycling programs with material recovery rates exceeding 80%, largely due to Extended Producer Responsibility (EPR) policies and advanced waste separation systems (ASEAN Secretariat, 2022). Malaysia's construction waste recycling rate remains significantly lower than that of developed nations, largely due to structural and policy-related challenges. The country continues to rely heavily on landfilling, with 82.5% of solid waste disposed of in landfills as of 2021 (PwC,

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2024). As shown in in Figure 1, Malaysia still has a long way to go to achieve the targeted quota of 40% that is suggested in new solid waste blueprint plan.

Unlike countries such as Germany and Japan, where strict Extended Producer Responsibility (EPR) frameworks and industrial waste reuse policies ensure high recovery rates exceeding 80%, Malaysia lacks a comprehensive circular construction policy that mandates material tracking and sustainable waste management (European Commission, 2019). Additionally, government-backed financial incentives for recycling and sustainable building materials remain limited, deterring private sector investment (Benchmarking Report, 2025). Addressing these gaps will require a multi-faceted approach, integrating policy reforms, financial incentives, and industry engagement to improve Malaysia's alignment with global CE practices. Malaysia's recycling rate lags behind due to:

1. Heavy reliance on landfills – 82.5% of solid waste was disposed in landfills as of 2021 (PwC, 2024).
2. Limited financial incentives – Unlike developed countries, few government-backed schemes exist to promote recycling in the construction sector (Benchmarking Report, 2025).
3. Lack of mandatory circular construction policies – Countries like Germany and Japan enforce strict material tracking and industrial waste reuse regulations (European Commission, 2019)

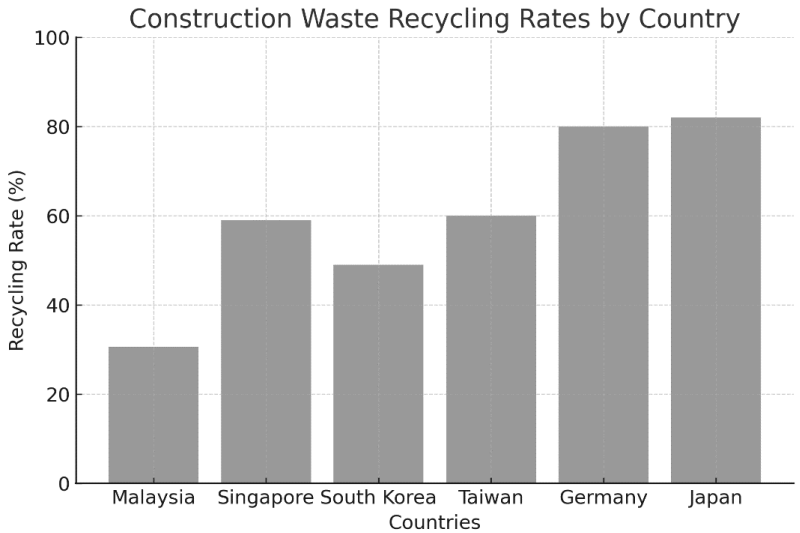


Figure 1: *Comparison for Construction Waste between selected countries*
Source: European Commission (2019), MIDA, (2023).

Adaptive Reuse in Circular Economy

Adaptive reuse is emerging as a vital strategy in Malaysia's shift toward a Circular Economy (CE), emphasizing the repurposing of existing buildings and materials to extend their lifecycle. This approach reduces demolition waste while decreasing reliance on virgin materials, aligning with the nation's sustainability goals. However, despite its potential, adaptive reuse in Malaysia remains underutilized, with limited incentives for retrofitting and repurposing older structures. The construction industry continues to favour new developments, often overlooking the environmental and economic benefits of reusing existing built assets (CIDB Malaysia, 2023). Studies indicate that Malaysia's building stock holds significant potential for adaptive reuse, yet the absence of clear regulatory frameworks and financial incentives has slowed its adoption (Malaysia Green Building Council, 2024). While awareness of adaptive reuse is growing, more structured policies and financial support are needed to encourage its widespread adoption.

The benefits of adaptive reuse within the Circular Economy framework are substantial. By repurposing existing structures, the need for new construction materials is reduced, helping to conserve natural resources and curb material extraction (UNEP, 2022). Likewise, this practice plays a crucial role in minimizing construction and demolition waste, easing the burden on Malaysia's landfills, which remain the dominant waste disposal method (PwC, 2024). Retrofitting also enhances the energy efficiency of buildings by improving insulation, ventilation, and overall operational performance, thereby lowering long-term carbon emissions (World Green Building Council, 2023). Beyond environmental gains, adaptive reuse supports the preservation of cultural and architectural heritage, ensuring that historical buildings can be revitalized while meeting modern sustainability standards (Think City, 2023). Heritage sites in Malaysia, particularly in cities like George Town and Kuala Lumpur, have demonstrated the economic and social value of adaptive reuse in strengthening community identity and tourism (National Heritage Department, 2024).

As Malaysia moves towards greater sustainability in its built environment, adaptive reuse must be reinforced through targeted policies and incentives. The introduction of financial benefits for retrofitting projects, such as tax rebates and green building grants, could significantly drive industry adoption (Malaysia Investment Development Authority, 2024). Moreover, mandated material audits and lifecycle assessments would ensure that repurposed buildings align with national sustainability objectives (Construction Industry Transformation Programme, 2025). Integrating adaptive reuse strategies into urban planning and green building frameworks would position it as a mainstream solution rather than an exception. Comparative benchmarking provides additional context for Malaysia's policy position. To situate Malaysia's adaptive reuse efforts within a broader policy context, it is useful to compare them with

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international approaches. Table 1 presents a benchmarking overview of selected countries, illustrating how regulatory frameworks, material recovery strategies, and industry participation have been structured to advance CE adoption.

Table 1: Different ways of adopting Circular Economy between selected benchmarking countries.

Country	Key Policies & Strategies	Material Recovery	Circular Design Adoption	Industry Participation
China	Circular Economy Promotion Law, Urban Mining, Prefabrication Mandates	High – 30% prefabrication target	Moderate – Green Building Rating System	Government-led incentives
Singapore	Zero Waste Masterplan, Built Environment Transformation, Waste-to-Energy System	Moderate – WTE system reduces landfill use	High – Circular material adoption	Industry collaboration in resource recovery
Japan	3R Framework, Circular Material Passports, Industrial Waste Tracking	High – Digital tracking of materials	High – Mandatory material reuse policies	Strict industry compliance
Germany	KrWG Act, Extended Producer Responsibility, Deposit Return System	Very High – 90% recycling rate	High – Extensive prefabrication and sustainable design	Strong producer responsibility enforcement

Source(s): Authors' synthesis based on data from European Commission (2019), ASEAN Secretariat (2022), PwC Japan Group (2024), CIDB Malaysia (2023), and national CE frameworks.

Existing Malaysian research underscores the need for practical CE interventions. For instance, Ali et al. (2024) identify infrastructure-related barriers to CE in project design and propose targeted countermeasures. Earlier, Salleh et al. (2022) developed guidance for CE in construction and demolition waste management, emphasizing actionable strategies relevant to local councils and industry players.

This comparative lens underscores that while Malaysia has taken initial steps, stronger integration of regulatory mandates, digital monitoring, and industry-driven compliance is needed to close existing gaps. Lessons from these frontrunner countries provide a roadmap for aligning adaptive reuse policies with wider Circular Economy goals.

Existing Guides and Blueprint Strategies

The Construction Industry Development Board (CIDB) Malaysia has introduced several guidelines to support the transition to Circular Economy (CE) practices in the construction sector. The CIDB Sustainable Construction Strategy emphasizes the adoption of low-carbon building materials, waste reduction strategies, and life cycle assessments. Additionally, the Construction Industry Transformation Programme (CITP) 2021–2025 highlights CE as a key component for achieving sustainable infrastructure goals. These efforts align with global best practices, yet challenges persist in policy enforcement, industry awareness, and financial incentives for sustainable material adoption. Globally,

CE practices have been widely implemented across various sectors, including construction. The European Union's Circular Economy Action Plan (2019) has led to the widespread adoption of recyclable materials, modular construction, and digital waste tracking. China has enforced urban mining policies to reclaim building materials, while Japan and Germany have introduced strict material recovery and waste segregation laws (European Commission, 2019). However, key challenges persist, including financial constraints, regulatory gaps, lack of industry awareness, and limited infrastructure (ASEAN Secretariat, 2022). Malaysia faces similar obstacles, requiring policy intervention, technological advancement, and industry engagement to support CE implementation.

METHODOLOGY

This study adopts a qualitative research design structured in four stages: (1) policy document analysis, (2) local authority engagement, (3) focus group discussions, and (4) international benchmarking. Interviews and focus groups were conducted with different tiers of municipal authorities, industry stakeholders such as manufacturers, professional consultants and building experts. Key questions were structured under three themes: (i) awareness and readiness, (ii) perceived barriers, and (iii) strategies for implementation. For the data analysis, several methods including descriptive analysis by using frequency are presented in this paper. Comparison between number of charts and description should be able to reflect the current state of the CE practice in Malaysia in comparison to the selected benchmarking countries. The methodology components include:

Policy Analysis

A comprehensive review of national policies was conducted to evaluate their effectiveness in facilitating CE adoption in the construction industry. Key policies analysed include the Green Technology Master Plan, National Policy on Climate Change, and Malaysia's Solid Waste Circular Economy Blueprint (2025–2035). The analysis focused on identifying policy gaps, regulatory barriers, and implementation challenges that affect the transition to CE-based construction practices.

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Local Authority Engagement

To explore the role of municipal governance in advancing Circular Economy (CE) practices, three local authorities (*Pihak Berkuasa Tempatan (PBTs))* — Johor Bahru City Council (MBJB), Shah Alam City Council (MBSA), and Hang Tuah Jaya Municipal Council (MPHTJ)) — were engaged between October 2024 and February 2025. These cities were strategically selected to reflect diverse urban typologies and institutional tiers within Malaysia's local governance system: Johor Bahru represents a dynamic southern growth corridor; Shah Alam, a mature industrial municipality in the Klang Valley; and MPHTJ represents an emergent administrative and institutional township with smart infrastructure ambitions.

The selection also aimed to capture insights across different tiers and capacities of local government *PBT*s at various administrative levels — including city councils, municipal councils, and planning officers — to reflect differing capacities in CE implementation and enforcement. Outreach efforts were also extended to other local authorities in Kuala Lumpur, Kota Bharu, Penang, Sabah, and Sarawak, but these entities were either unable to commit or did not respond within the study window.

Semi-structured interviews were conducted to examine each *PBT*'s policy orientation, enforcement approach, compliance mechanisms, and infrastructure support for CE initiatives. Thematic focus areas included regulatory alignment, organisational capacity, and practical pathways for mainstreaming CE at the local level.

Focus Groups

Structured discussions were conducted with selected industry stakeholders in construction sector including architect, green building specialists, members of construction agency and material suppliers. The focus group discussions was aimed to explore the awareness of CE at the basic level, and probe into industry readiness, as well as highlight practical implementation challenges. Key discussion points included knowledge, policy effectiveness, infrastructure gaps, and availability of cross-sector collaboration. Findings from the session provided a broader understanding of CE readiness beyond the construction industry, highlighting potential synergies between different economic sectors.

Comparative Framework Analysis

A benchmarking exercise was conducted from December 2024 to January 2025 to compare Malaysia's CE implementation with global best practices in sustainable construction. The analysis focused on China, Singapore, Japan, and Germany, examining key indicators such as:

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- **Policy Effectiveness**: Evaluating how government regulations facilitate CE adoption.
- **Material Recovery Rates**: Measuring the efficiency of waste recycling and reuse.
- **Adoption of Circular Design Principles**: Assessing the extent of integration of circular design methodologies in the construction sector.
- **Industry Participation**: Analysing the level of engagement from private sector stakeholders in CE practices.

LIMITATION OF STUDY

While this study offers valuable insights into Malaysia's readiness for Circular Economy (CE) adoption in construction, several limitations must be acknowledged. First, the analysis is based on literature, industry reports, and qualitative data from interviews and focus groups; as such, the themes presented reflect interpretive coding and may be influenced by researcher bias. Although triangulation with benchmarking mitigated this risk, a broader mixed-methods approach would strengthen validity (Braun & Clarke, 2006; Creswell & Plano Clark, 2018).

Second, the study emphasises perspectives from design and local authority actors, with limited engagement from suppliers, contractors, and end-users who also shape CE implementation. Broader stakeholder coverage would provide a more holistic view (Yin, 2018). Third, regulatory and economic conditions in Malaysia are evolving rapidly, which may render certain findings time-bound. The absence of comprehensive quantitative data on CE adoption rates, material recovery, and financial impacts further constrains generalisability (UNEP, 2023; Ellen MacArthur Foundation, 2020).

Despite these limitations, the study establishes a foundation for future research, which should include longitudinal surveys, broader stakeholder engagement, and comparative analysis across sectors and countries to identify best practices that can accelerate Malaysia's CE transition.

FINDINGS AND DISCUSSION

The findings are organised into thematic sections derived from the qualitative analysis of interview and focus group data, triangulated with policy benchmarking. Using a thematic coding approach, recurring ideas were grouped into higher-order themes that directly reflect the barriers, enablers, and pathways toward CE adoption. Four themes emerged from this process: (i) regulatory and policy gaps, (ii) industry readiness, (iii) local authority enforcement and capacity, and (iv) lessons from international benchmarking. These themes provide the structural headings that follow and allow the findings to be interpreted systematically against the study's aims.

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Regulatory Gaps and Policy Challenges

This theme emerges consistently across engagement with all stakeholders as well as the policy benchmarking phase. While Malaysia has introduced various green (and blue) policies to encourage Circular Economy (CE) adoption, but enforcement remains weak due to inconsistent regulatory frameworks, limited incentives, and a lack of compliance monitoring (ASEAN Secretariat, 2022). Interviews with local authorities in Johor, Shah Alam, and Melaka revealed that while policies like the Green Technology Master Plan provide guidelines, their implementation remains fragmented. A recurring theme identified from both local authority interviews and policy review was that the stakeholders emphasized the need for better coordination between federal and municipal agencies, as well as clearer CE compliance standards for construction projects (KPKT, 2024).

Resource Management Challenges

This coded theme derived from focus group discussions with developers and engineers highlighted recurring concerns how the construction industry in Malaysia remains heavily reliant on virgin materials, with limited adoption of recycled aggregates and modular components (PwC, 2024). Findings indicate significant concerns regarding material availability, inconsistent quality, and the absence of financial incentives for sustainable material adoption. In contrast, countries like Germany and Japan have effectively implemented Extended Producer Responsibility (EPR) frameworks, which promote material reuse and recycling through regulatory enforcement and industry collaboration (CE Benchmarking Report, 2025). Without structured incentives and government-backed green procurement policies, Malaysia risks lagging behind in the transition toward a circular economy.

Moreover, the lack of standardized regulations for construction waste management exacerbates inefficiencies in resource utilisation. Studies have shown that fragmented policies and weak enforcement mechanisms contribute to a lower recycling rate, leading to excessive landfill waste and environmental degradation (DOE Malaysia, 2023). While some Malaysian developers have piloted green building initiatives, the absence of mandatory waste diversion targets limits widespread adoption. Lessons from Singapore's Zero Waste Masterplan suggest that integrating digital tracking systems and mandatory recycling quotas could significantly enhance material circularity in construction projects (NEA Singapore, 2024).

A shift in industry mindset and stakeholder coyellaboration is crucial to overcoming these barriers. Policymakers must align construction waste regulations with broader national sustainability goals while providing financial incentives such as tax rebates for sustainable material use (UNEP, 2023). Additionally, industry players can benefit from public-private partnerships to

develop supply chain solutions that ensure consistent quality and availability of recycled materials. Strengthening awareness campaigns and capacity-building programs will further encourage developers to prioritize circular economy principles in project planning and execution.

Opportunities for Private Sector Involvement

Industry interviews and benchmarking with Germany and Singapore revealed a theme of opportunities for the private sector to play a vital role in accelerating circular economy (CE) innovations, particularly in the construction industry. Singapore's Zero Waste Masterplan serves as a prime example of how public-private partnerships can drive sustainable practices by investing in waste-to-resource technologies and closed-loop construction approaches (Benchmarking Report, 2025). By fostering collaborations between government agencies, businesses, and research institutions, Singapore has successfully implemented policies that encourage resource efficiency, material reuse, and waste reduction. Such initiatives have led to significant improvements in the adoption of green building materials, modular construction, and advanced recycling techniques. The seamless integration of these elements has not only contributed to environmental sustainability but has also enhanced economic competitiveness by reducing dependency on virgin materials and lowering construction costs in the long run.

However, in Malaysia, industry stakeholders face several challenges in implementing similar CE strategies. Interviews with local construction firms and sustainability consultants reveal that the primary barriers include a lack of financial incentives, technical expertise, and awareness regarding the long-term benefits of circular supply chains. Many firms perceive sustainable construction practices as costly and complex due to limited access to funding and a lack of standardized guidelines. To overcome these challenges, experts suggest the introduction of tax incentives, government-backed grant programs, and mandatory green building certifications to encourage CE adoption. Additionally, industry-wide education and capacity-building initiatives are needed to equip professionals with the necessary skills and knowledge to implement CE principles effectively. By fostering a supportive policy framework and incentivizing sustainable practices, Malaysia can gradually transition towards a more circular construction industry, aligning with global sustainability goals and enhancing its economic resilience.

Local Authority Role and Implementation Capacity

This theme emerged directly from interviews with Pihak Berkuasa Tempatan (PBTs) and triangulation with policy benchmarking. Johor Bahru, Shah Alam, and Hang Tuah Jaya were selected to represent diverse urban governance contexts, including high-growth southern corridors, industrialised Klang Valley

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municipalities, and planned township administrations. The interviews consistently revealed barriers in enforcing CE regulations, including budget constraints, limited trained personnel, and inadequate monitoring mechanisms (Kementerian Perumahan dan Kerajaan Tempatan, 2024).

Findings further suggest that fragmented policy landscapes hinder effective CE implementation at the local level. Many councils lack a cohesive framework that aligns national CE goals with municipal enforcement strategies. While studies from the European Union highlight the benefits of integrated regulatory frameworks with clear jurisdictional roles (European Environment Agency, 2023), this has yet to be translated into Malaysian practice. International examples such as Japan's Industrial Waste Tracking System illustrate how digital material passports could strengthen monitoring and compliance. Local authorities recommended pilot programmes that integrate such tools into Malaysian municipalities, enabling better reporting on material recovery rates and encouraging higher industry participation in CE practices.

Public Awareness and Industry Readiness

This coded theme emerged from focus group data across construction, manufacturing, and waste sectors in September 2024 and again reinforced in March 2025 highlighted low awareness of CE principles and their economic benefits (PwC, 2024). Many industry stakeholders viewed CE as a costly compliance requirement rather than an opportunity for long-term cost savings and business resilience. Countries like China and Germany have successfully embedded CE education into university curricula and professional training programs, ensuring a skilled workforce familiar with circular construction practices (Benchmarking Report, 2025). Malaysian stakeholders highlighted the need for structured CE training programs, industry workshops, and knowledge-sharing platforms to improve awareness and adoption rates.

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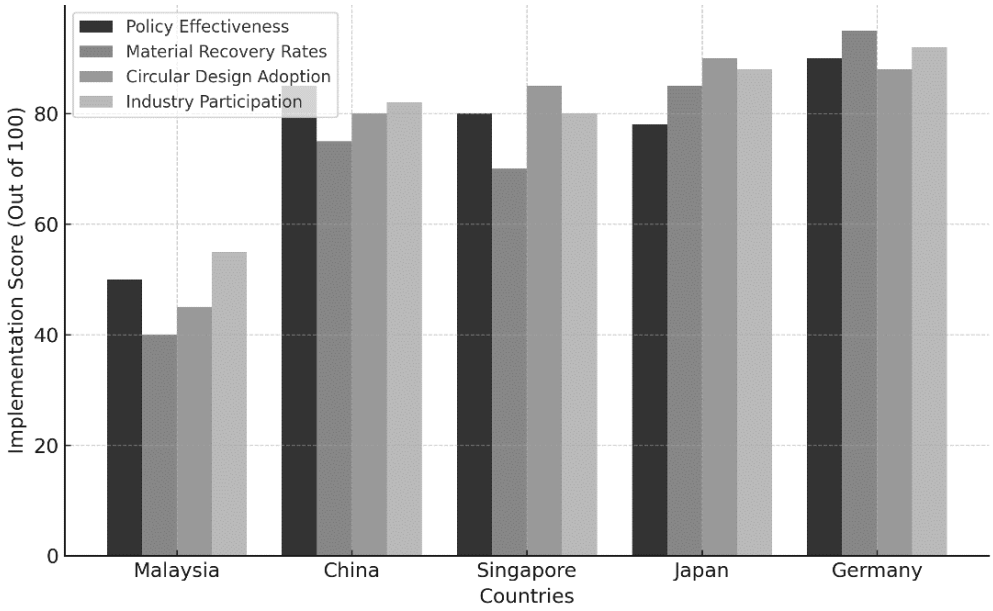


Figure 2: Percentage Distribution of Circular Economy (CE) Strategies Adopted in the Construction Sectors of Selected Countries (Germany, Japan, Singapore, China, and Malaysia).

Source: Percentage Distribution of Circular Economy (CE) Strategies Adopted in the Construction Sectors of Selected Countries (Germany, Japan, Singapore, China, and Malaysia).

Comparative Insights from China, Singapore, Japan, and Germany

This theme emerged from the benchmarking analysis, which was carried out between December 2024 and January 2025. Comparative findings highlighted key regulatory frameworks and practical implementations that have successfully integrated CE into the built environment in these countries. Table 1 shows Malaysia's position relative to advanced CE implementation, while Figure 2 illustrates the distribution of CE strategies adopted across the selected countries. Together, these comparative insights provide a reference point for evaluating Malaysia's readiness and identifying transferable lessons. In contrast, Germany and Japan demonstrate balanced advancement across policy, industry compliance, and digital monitoring

Key Lessons for Malaysia's Ce Readiness in Construction

The examination of Circular Economy (CE) implementation in established economies offers critical insights for enhancing sustainability within Malaysia's construction sector. A primary consideration is the necessity for robust regulatory frameworks and enforcement mechanisms. Countries such as Germany and Japan have effectively institutionalized stringent material recovery mandates and tracking systems to ensure widespread compliance across the construction

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industry (European Commission, 2019). These measures not only mitigate waste generation but also foster a culture of responsible resource management. In Malaysia, while regulatory efforts are in place, the enforcement of construction and demolition (C&D) waste management remains an area requiring further enhancement (CIDB Malaysia, 2023). Strengthening legislative frameworks and embedding mandatory compliance measures would serve as a vital step toward achieving greater CE integration.

An equally significant aspect is the adoption of digital innovations in material tracking and waste management. Japan's Industrial Waste Tracking System and Germany's Digital Material Passports exemplify how technology can be leveraged to enhance the efficiency of CE initiatives through real-time data monitoring and improved accountability (PwC, 2024). Malaysia's construction industry stands to benefit from the implementation of similar digital platforms, which would facilitate better oversight of material flows and streamline resource recovery processes. Encouraging industry-wide adoption of blockchain-enabled material passports and smart waste segregation technologies would further contribute to enhancing transparency and efficiency in resource utilization.

Furthermore, fostering collaborative partnerships between the public and private sectors has proven instrumental in countries that have successfully implemented CE frameworks. Singapore's Zero Waste Masterplan, for instance, underscores the benefits of synergistic engagements between governmental agencies and industry stakeholders in advancing sustainability goals (Singapore National Environment Agency, 2022). Establishing structured collaborations within Malaysia's construction sector—through incentives for firms that demonstrate excellence in material reuse and recycling, as well as through grants that support innovation in sustainable construction methodologies—can provide the necessary impetus for a broader transition to CE practices.

Findings strongly suggests that capacity building through education and workforce training plays an essential role in ensuring long-term CE readiness. In nations such as China and Germany, CE principles are systematically integrated into educational curricula, equipping future professionals with the requisite knowledge and skills to drive sustainability-oriented transformation within the construction industry (European Commission, 2019). In Malaysia, there remains significant potential to embed CE-oriented content into architectural and engineering programs, while also expanding vocational training opportunities tailored to builders, contractors, and other industry practitioners. Enhancing educational outreach in this manner would address existing knowledge gaps and encourage the widespread adoption of CE-aligned construction practices.

The Role of Government Agencies in Advancing CE in Construction

To effectively facilitate the transition toward a CE framework within Malaysia's construction industry, government agencies must adopt a proactive and

coordinated approach in shaping policy, fostering enforcement, and supporting capacity development. Several key ministries and regulatory bodies hold pivotal roles in this regard.

The Ministry of Housing and Local Government (KPKT) is well-positioned to spearhead efforts aimed at refining building regulations to incorporate CE principles. This may include the introduction of policies that encourage the use of recycled and repurposed materials in new developments, alongside enhanced guidelines for on-site waste segregation. Future strategies could focus on establishing a regulatory environment where sustainability-driven construction practices become a fundamental industry norm rather than an optional initiative.

The Construction Industry Development Board (CIDB), as the primary authority overseeing Malaysia's construction sector, has a critical role in promoting CE-centric building methodologies. By integrating CE principles into certification programs, CIDB can incentivize adaptive reuse, prefabrication, and modular construction, thereby reducing material waste and improving resource efficiency. Additionally, CIDB could introduce a dedicated CE performance rating system, akin to the Green Building Index (GBI), to assess and recognize projects that exemplify best practices in sustainable construction and material lifecycle management.

The Malaysian Investment Development Authority (MIDA) can play a strategic role in facilitating financial incentives and investment support for the adoption of circular construction practices. Offering tax incentives and targeted grants to companies that integrate CE methodologies—such as the production of low-carbon construction materials or advanced recycling technologies—would serve as a strong catalyst for industry-wide adoption. Furthermore, attracting foreign direct investment (FDI) in sustainable construction innovations could help accelerate Malaysia's progress toward achieving a more resource-efficient built environment.

The Ministry of Energy and Natural Resources (KeTSA) also has an important mandate in promoting resource conservation and energy-efficient practices within the construction industry. By advancing policies that support the incorporation of renewable energy systems, such as photovoltaic installations and energy-efficient building materials, KeTSA can contribute to reducing the environmental footprint of the built environment. Future strategies may also involve supporting research and development initiatives focused on alternative, sustainable construction materials and establishing a national database to monitor construction waste streams.

Moving forward, the establishment of an inter-ministerial task force dedicated to CE implementation in the construction sector would provide a structured approach to driving sustainable transformation. This task force could oversee the formulation of a comprehensive CE roadmap, integrating regulatory

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advancements, technological adoption strategies, public-private partnership models, and workforce training programs. Furthermore, conducting periodic progress assessments would ensure that Malaysia remains aligned with its sustainability objectives and global best practices.

Strategic Recommendations for Local Authorities (PBTs) in Advancing CE

Effective operationalisation of Circular Economy (CE) in Malaysia's construction sector hinges significantly on the role of local authorities (*Pihak Berkuasa Tempatan,* or PBTs). However, enforcement capacity across PBTs remains limited, with no designated CE focal officers or embedded circularity criteria within standard planning and development approval processes. To address this, CE monitoring responsibilities should be formally assigned within existing technical departments—such as planning, licensing, or environmental health—supported by structured CE indicators integrated into OSC workflows. Parallel to this, efforts must be made to harmonise fragmented federal mandates. Agencies such as KPKT, CIDB, DOE, and MGTC should align CE-related KPIs and develop a unified CE implementation toolkit that translates high-level policy into actionable local guidelines. These efforts would provide clearer institutional direction and enable municipalities to act decisively on CE.

Equally important are awareness, incentives, and infrastructure. CE remains poorly understood among industry actors and local officers alike, often reduced to recycling or waste segregation. To build local capacity, simpler and modular training approaches—such as short courses, peer-learning workshops, or online toolkits—could empower municipal teams without overburdening existing workflows. PBTs are well-positioned to co-develop such programmes in partnership with universities, NGOs, and professional bodies. On the financial front, development charge waivers and localised CE pilot grants could incentivise the uptake of adaptive reuse, prefabricated systems, or material recovery in construction projects. To ensure long-term enforcement, investment in digital tracking tools—such as QR-tagged waste documentation or material passports—should be prioritised, drawing from international models like Japan's industrial waste system. Together, these efforts would help institutionalise CE at the local level through targeted, practical interventions.

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CONCLUSION

Malaysia's construction sector stands at a pivotal juncture in its transition toward a more circular and resource-efficient model. This short study has shown that readiness for Circular Economy (CE) adoption is uneven but evolving, shaped by policy gaps, fragmented enforcement, and limited industry awareness. Through comparative benchmarking, local authority interviews, and industry focus groups, the research has highlighted key enablers—policy coherence, regulatory capacity, and CE literacy—while also surfacing persistent barriers such as weak incentives and the absence of robust monitoring systems. International examples reinforce that CE transitions are most effective when state-led mandates are matched by industry mobilisation and local implementation capacity.

Looking ahead, Malaysia's opportunity lies in translating policy ambition into measurable practice. National agencies such as KPKT, CIDB, KeTSA, and MIDA must work more closely with PBTs, professional bodies, and industry partners to embed CE into regulatory frameworks, procurement, and project delivery. Future research should evaluate the long-term outcomes of pilot initiatives, quantify embodied carbon reductions, and assess the scalability of innovations such as digital material passports. By combining coherent leadership with multi-stakeholder collaboration, Malaysia can accelerate its CE transition and position its construction sector as both a driver of sustainability and a model for regional resilience.

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AN EMPIRICAL STUDY IN PERCEIVING CAMPUS LEGIBILITY THROUGH COGNITIVE MAPPING

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Abstract

University campuses rely on imageability and legibility to support navigation and identity, yet complex layouts can undermine orientation and student experience. This study examines campus imageability at Universiti Malaya using a mixed-methods design: a questionnaire (n=50), cognitive mapping tasks grounded in Lynch's five elements, and semi-structured interviews (n=10). Descriptive and thematic analyses assessed wayfinding challenges, the salience of spatial elements, and perceived identity. Results show landmarks (e.g., Dewan Tunku Canselor, UM Library) and edges (notably Varsity Lake) dominate mental maps, while ambiguous intersections, inconsistent signage, and long, indirect pathways contribute to navigation friction. Pathways such as Jalan Lingkungan Budi anchor movement but nodes and districts are recalled less reliably. The findings indicate that a small set of highly imageable elements carries most of the cognitive load for wayfinding and belonging. We recommend (i) targeted signage and pathway reinforcement, (ii) coherent zoning into named "districts," and (iii) incremental adoption of digital/AR guides for first-time users. Enhancing legibility can strengthen campus identity and improve everyday student experience.

Keywords: Imageability, Mental mapping, Legibility, Campus Image and Identity

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INTRODUCTION

Imageability and legibility are crucial in a campus environment for effective navigation and creating a sense of ease. Imageability involves evoking clear mental images, making landmarks and spaces easily recognizable. Legibility involves organizing the environment intuitively, aiding orientation and movement. These elements make navigation more intuitive, reducing cognitive load on visitors and new students unfamiliar with the campus layout.

Complex campus layouts can lead to confusion, frustration, and negative experiences for students, especially newcomers. Overly complicated layouts discourage spontaneous exploration and limit engagement with campus resources. Imageability encompasses the elements that make the campus recognizable and memorable, influencing how people navigate and interact with space. This study focuses on legibility elements such as visibility of landmarks, organization of pathways and nodes, and overall aesthetics of the campus environment along the edge and characteristics of an area to form a signature district within the campus. Therefore, this research is seeking to find an answer to the question on what are the criteria in creating a legible campus that benefit students and enhances the image and identity of the campus environment? This question focuses on identifying the fundamental elements of campus design that make UM an accessible and cohesive environment, thereby strengthening its identity.

This research is a quest to explore the concept of campus legibility and its effect on students' experiences and the overall identity of the campus environment. It also aims to identify and analyse the factors that contribute to the campus's imageability using cognitive mapping techniques within the campus community. Based on these objectives:

i. to explore and analyse students' perceptions of their image and identity within the campus environment and
ii. to assess the legibility of the campus from the students' cognitive perspectives, focusing on how spatial design, signage, and the overall campus layout influence their navigation, sense of belonging, and identification with the institution.

The study collects qualitative and quantitative data via cognitive maps to understand students' campus layout experiences and perceptions. It aims to identify patterns in how students identify campus features and spaces, and their emotional connections to university areas, thereby developing a comprehensive approach to perceived campus image and cognitive navigation.

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LITERATURE REVIEW

A campus's performance is determined by its ability to meet the biological, psychological, social, and cultural needs of its communities (Lynch,1960). A well-functioning campus ensures basic biological requirements like clean air, safe drinking water, and housing, while also nurturing residents' psychological wellbeing through relaxation, reflection, and community interaction (Ding et.al, 2024). Active transportation infrastructure positively impacts students' physical activity, while natural environments like perceived naturalness, blue space, and greenness support mental health and quality of life. Mental mapping has been widely applied in Malaysian urban contexts to identify legible elements and spatial cognition, particularly in historical districts (Lai & Ujang, 2012), demonstrating its reliability for capturing user perceptions of place.

Theoretical Foundations of Campus Image and Identity

In his seminal work for *The Image of the City (1960*), Kevin Lynch explores how individuals mentally organize and interpret urban environments, focusing on the alignment of physical layout with human perception and cognitive mapping. Lynch argues that an effective urban environment meets cultural and social needs while ensuring accessibility to transportation and amenities. Gordon Cullen's The Concise Townscape (1961) emphasizes Lynch's concept of environmental imageability, detailing five key elements that contribute to a city's legibility: paths, edges, landmarks, nodes, and districts. Christian Norberg-Schulz's Genius Loci (1980) emphasizes the importance of architecture in shaping a sense of place and the identity and spirit of a location. These theories enhance our understanding of urban legibility by illustrating how humans experience and interpret their physical surroundings. Lynch's mappable elements, Cullen's pedestrian perspectives, and Norberg Schulz's architectural considerations emphasize the importance of creating navigable and meaningful environments, particularly in campus environments where spatial clarity, identity, and accessibility significantly impact users' experiences, shaping research on orientation and place attachment.

Understanding the Concept of Genius Loci and the Essence of a Place

The concept of genius loci, or the "spirit of place," suggests that a location's atmosphere and character are shaped by its inhabitants, who are considered its "geniuses" or caretakers. These individuals, through their presence, interactions, memories, and personal connections, create a unique identity for the place.

This influence extends beyond physical presence, encompassing shared experiences, emotions, and collective perceptions which contribute to essence or "spirit" that defines place (Vecco,2020). Campus attachment, on the other hand, is the emotional bond individuals form with specific places, expressed through emotions, beliefs, knowledge, and actions (Hidalgo & Hernandez, 2001). This

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attachment is not only emotional but also functional, enhancing a sense of belonging, familiarity, and the creation of great leaders (Stokols & Shumaker 1981). The study emphasizes the need to understand the psychological sense of place in campus and advocate for identifying place attachment dimensions to better understand the relationship between attachment, perception, and the identity of places.

Genius loci, or the "spirit of place," is a concept that helps identify both tangible and intangible values that are crucial for fostering a human-centred approach in sustainable development, particularly in a campus environment (Vecco, 2020). Tangible values, such as architecture, landscape, and spatial organization, form the visible foundation of a campus's identity. This aligns with findings on place attachment within Malaysian urban environments, where the value of place significantly shapes users' lived experiences and sense of belonging (Tan & Ujang, 2014). Intangible values, such as lived experiences, traditions, memories, and social interactions, give a campus its unique personality and emotional resonance. Understanding genius loci is essential for creating functional, meaningful, and supportive spaces for a strong campus community. Institutions can foster a sense of belonging and identity among students, faculty, and staff by recognizing both tangible and intangible elements. This approach to campus design promotes a sustainable, vibrant community that values both physical and experiential qualities, enhancing the educational experience and nurturing personal growth and wellbeing.

Exploring Campus Legibility through Mental Mapping

Mental maps are a person's perception of their surroundings, created by the brain subconsciously to understand their environment and interact with elements (Guelton, 2023). Lynch's Theory of Legibility identifies five legible elements that influence citizens' mental maps: paths, edges, districts, nodes, and landmarks as shown in Figure 1. Mental maps can be interpreted in various ways, including cognitive maps and concept maps, also known as heuristic or mind maps each representing distinct contexts within the mental mapping framework (Guelton, 2023). This study focuses on how individuals navigate physical spaces and how these routes contribute to memory formation and internal spatial representations. Mental mapping and cognitive mapping share similar functions and outcomes.

Tan and Ujang (2012) emphasize the significance of perceived image in shaping a place's reputation. Their study on Kuala Lumpur's historical district suggests mental mapping as a reliable technique for understanding people's cognition of an area. Irfan's research highlights the role of student satisfaction in mediating the relationship between perceived university image and reputation, creating a genius loci that enhances student experience on campus. Deniz and Topcu (2012) criticized undefined and vacant areas between faculty buildings and unstructured spaces on the Selcuk University campus that lack a clear

purpose. Research shows that up to 90% of individuals receive environmental information through visual perception (Latypova et al., (2021).

Examining architectural structures is crucial for understanding how cityscapes influence perception and spatial cognition. Cognitive mapping, through visual, cognitive, and perception-based studies, is often used to define campus environments. Understanding community perception of campus open spaces informs current campus design trends, aiming for liveable environments that prioritize usability and quality of life.

A study in Turkey employing cognitive mapping and photo projective methods found that students associated cafes, green spaces, and panoramic views with a strong sense of belonging. In contrast, Universiti Malaya students emphasized the calming presence of roadside trees as key elements supporting orientation. Together, these findings illustrate how cognitive mapping consistently highlights the influence of natural and social features in reinforcing campus legibility and identity.

Advancements in Digital Campus Wayfinding:

While Lynch's (1960) framework remains foundational, recent studies highlight the role of digital tools in enhancing campus legibility. AI-assisted navigation systems, such as augmented reality (AR) campus guides and smart signage systems, have been implemented in universities like MIT and NTU Singapore, improving real-time orientation for students (Zhang et al., 2024). Studies indicate that students increasingly rely on mobile mapping apps rather than traditional landmarks for navigation, shifting the way cognitive maps are formed (Turk et al., 2015). Integrating these digital systems into future research on campus wayfinding could offer a more precise analysis of spatial cognition. The study highlights the significance of spatial-cognitive features in urban and architectural navigation. It introduces a new experimental technique using 3D isovists to measure spatial distinctiveness and evaluate architectural designs' effectiveness in wayfinding. (Bhatia et al., 2013). Principal component analysis differentiates between monotonous and structurally distinct regions, providing a quantitative method for assessing architectural saliency.

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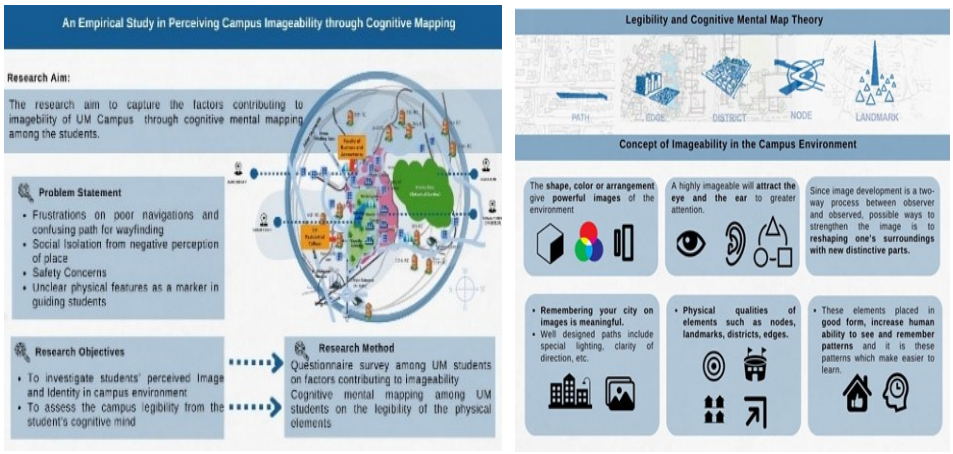


Figure 1: Diagram of Research Conceptual Framework
Source: Authors (2025)

RESEARCH METHODOLOGY

This study employed a multi-method approach combining quantitative surveys, qualitative interviews, and cognitive mapping techniques to analyse campus legibility at Universiti Malaya. The integration of these methods reflects a pragmatic paradigm, which values the use of multiple perspectives to comprehensively address the research problem.

Multi- Method of Data Collections

The study approached data collection through both objective and subjective lenses as below:

i) **Quantitative Approach: Objective Data Collection** - A questionnaire was given to 50 students from different faculties to collect data on spatial layout and accessibility. The survey examined students' perceptions of campus layout and accessibility, the frequency and types of wayfinding challenges they encountered, and their attitudes toward campus identity and imageability, with responses analysed using descriptive statistics to identify common patterns and highlight navigation trends across the student population.

ii) **Quantitative Approach: Objective Data Collection Cognitive Mapping –** 50 participants created mental maps of a campus using Lynch's (1960) framework to explore their spatial experiences. Thematic analysis of these maps identified common spatial patterns and individual perceptions. The maps gave valuable insight into how students perceive and priorities campus spaces. Participants were free to sketch in their own way, without strict instructions, so their drawings reflected genuine impressions rather than guided answers. Students who were very familiar with the campus and those

who were less experienced were both included, ensuring a range of perspectives. From this, the study was able to see not only the strengths and weaknesses of UM's spatial design but also how students mentally organise and make sense of a complex environment.

iii) **Qualitative Approach: Semi-Structured Interviews -** Interviews with 10 students revealed recurring themes on how navigation challenges shape their sense of belonging and engagement on campus. The interviews focused on how difficulties in navigation affected their daily lives, their sense of safety, and even how connected they felt to the university. Students were asked open questions but encouraged to share their own stories.

Overall, merging spatial analysis with experiential insights provides a comprehensive understanding of the campus, addressing both its physical layout and its impact on students' sense of place and navigation.

Universiti Malaya as a Case study

Universiti Malaya (UM) faces spatial challenges on its Kuala Lumpur campus due to architectural inconsistencies and poor legibility, impacting safety. Mental mapping, an individual's spatial understanding, aids navigation and develops over time. Cognitive maps, internal environmental representations, use geometric features to organize data. While mental maps show familiarity, cognitive maps detail environmental information. UM's diverse spatial environment offers a suitable context for studying how design affects campus legibility and student navigation.



Figure 2: UM Campus Map |& Urban Campus
Source: Photos taken during fieldwork by the Authors. (2023, Oct 21)

Selection of Participants

Data were gathered through surveys, semi-structured interviews, and cognitive mapping tasks. A total of 50 students, balanced by gender and drawn from diverse faculties were selected. to participate in the study. The use of structured interview

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protocols and standardised cognitive mapping exercises ensured response consistency, minimised bias and strengthened the validity of perceptions captured.

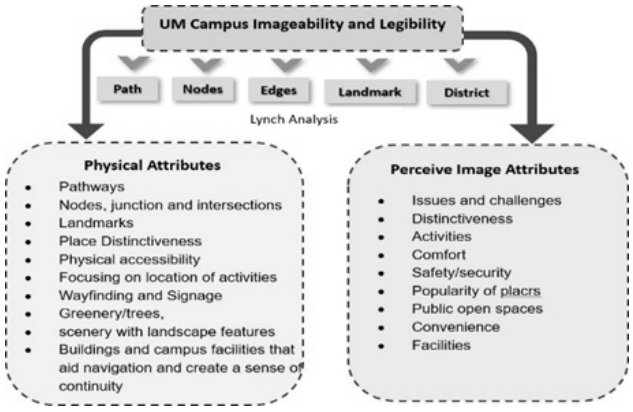


Figure 3: Physical and perceived image attributes
Source: Authors (2025)

Research Instruments

This study investigated campus legibility and identity using mental mapping and architectural theory with Lynch's five elements (1960) illustrated in Figure 3 is used to enhance spatial perception and cognition within the UM campus, drawing on Deniz and Topcu (2012). Interactive and free-hand mapping tools are utilised to capture students' subjective spatial knowledge and perceptions of campus environments, their experiences, and suggestions for improvement.

This study analysed campus physical and image attributes using primary data from mental mapping and surveys, supplemented by secondary data, to improve design and experiential outcomes. Cognitive maps were assessed using Lynch's (1960) urban legibility elements, considering landmark recall frequency, spatial distortion, and navigational significance. Statistical analysis correlated survey results with cognitive maps to confirm the reliability of mental representations for campus wayfinding.

RESULTS AND FINDINGS

The study employed a mixed-methods approach in analysing the collected data. Quantitative survey responses were examined using descriptive statistics to identify trends in wayfinding challenges, while qualitative data from interviews and cognitive mapping were thematically analysed to capture patterns of perception and spatial representation. This dual approach provided a

comprehensive assessment of campus legibility and identity, allowing both objective measures and experiential insights to be systematically integrated.

Questionnaire Survey Analysis

The Universiti Malaya (UM) campus faces challenges in navigation due to ambiguous intersections and a lack of clear signage. 50% of respondents find these intersections confusing and inefficient, while 75% express frustration with the lack of clear pathways, as shown in Figure 4. This feedback highlights the need for improved campus wayfinding strategies, such as better signage, distinct landmarks, and improved pathway layouts, to create a more navigable and student-friendly environment. Based on Figure 4, Students face lengthy walking distances to key locations, leading to shortcuts and reduced legibility. The lack of clear signage and extended pathways contributes to students seeking shortcuts, making the educational and residential zones less navigable and harder to interpret, ultimately affecting the overall campus experiences.

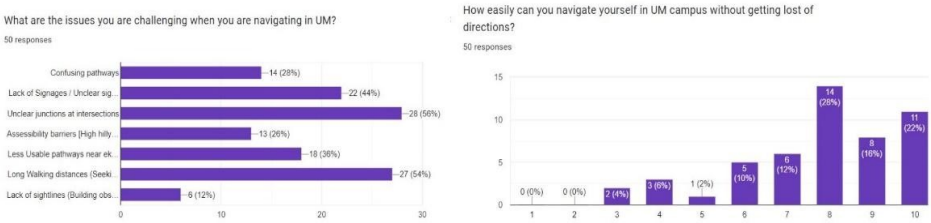


Figure 4a and 4b: Legibility Issue & Challenges and Level of ease in Navigation in UM Campus.
Source: Authors (2025)

Based on Figure 4, Majority of students (80%) found the UM campus pathways to be somewhat easy to navigate, with some having minor difficulties in locating specific destinations. New or infrequent visitors may struggle more in certain areas. The study suggests that adding clearer signs or improving pathway designs could make navigation more straightforward.

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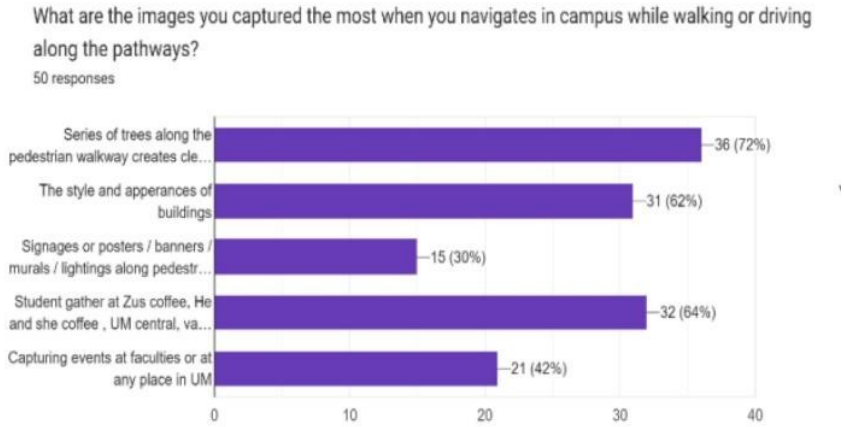


Figure 5: Perceived Image and Identity of UM Campus
Source: Authors (2025)

The survey results show Varsity Lake is a prominent campus feature, with a strong visual image captured in their perceptions (Figure 5). Students found it a focal point for social gatherings and leisure, with fewer green and hardscape elements. The lake's role in campus legibility is significant, as it functions as an edge and landmark, aiding in orientation and enhancing the overall navigability of the campus.

Table 1: Survey findings on campus legibility and wayfinding at Universiti Malaya (n = 50)

Category	Item	%
Legibility Challenges	Number of roads/paths	29.7
	Ambiguous intersections	50.0
	Pathway clarity	75.0
	Number of facilities	13.9
	Location clarity	31.0
	Nodes & districts clarity	16.7
	Other	2.7
Legibility Issues	Missing/unclear signage	75.0
	Ambiguous intersections	50.0
	Long/indirect pathways	47.2
	Unclear district definition	44.4
	Insufficient social hubs	30.6
	Lack of lighting/visibility	19.4
	Other	5.6
Overall Experience	Yes (legible)	80.6
	No (not legible)	5.6
	Somewhat	13.9

Note: Results summarize student-reported challenges and issues affecting campus legibility, as well as their overall experience of wayfinding. Percentages reflect proportion of responses per category.

The study shows that students at UM feel a strong sense of belonging to key areas, such as Varsity Lake, UM Central, and Dewan Tunku Canselor (DTC). These iconic spaces, with their distinctive architecture and symbolic importance, act as a point of orientation and connection for students. Engaging in campus life within these spaces positively influences students' sense of connection and belonging to UM, highlighting the role of these spaces in enhancing campus identity and student experience.

Cognitive Mapping Analysis

A study of 50 hand-drawn sketches identified the most frequently noted legible elements on campus. Landmarks, such as Dewan Tunku Canselor, Kolej Pengajian Sains, UM Library, and Chancellery, accounted for 90% of the identified features. Edges, particularly Varsity Lake, were identified as key elements with a 100% recognition rate. Main pathways, such as Jalan Lingkungan Budi from KL Gate and PJ Gate, accounted for 80% of the sketches, indicating their significant role in subjective legibility. Nodes and districts were the least frequently represented elements in respondents' cognitive maps. Further analysis will focus on the specific attributes of identified landmark typologies to understand their influence on campus experience and identity.

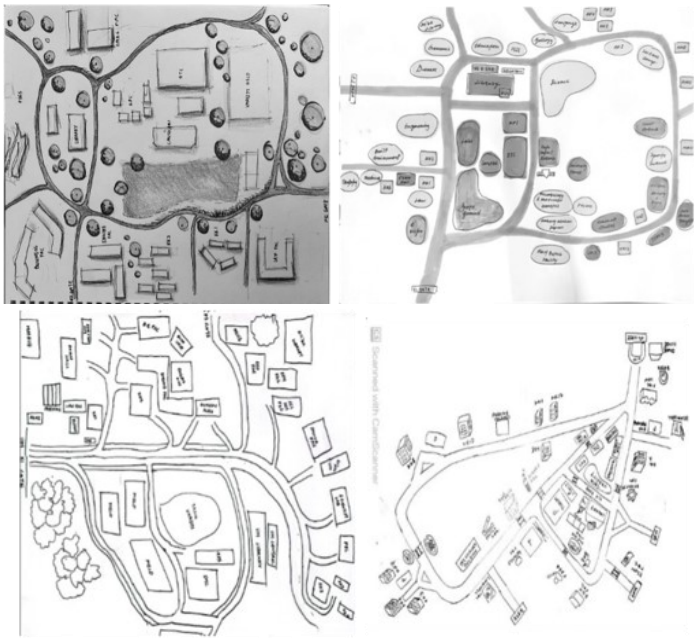


Figure 6: Sample of cognitive mental maps from the respondents
Source: Data collected during fieldwork, Authors (2023)

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The study of hand-drawn cognitive mental maps reveals that landmarks, edges, pathways, nodes, and districts significantly influence students' perceptions of campus legibility. These maps, based on cognitive mapping theories, are created based on experiences and interactions, encoding elements like these. Landmarks like Dewan Tunku Canselor and UM Library serve as reference points, while edges define spaces and guide movement. Main pathways like Jalan Lingkungan Budi connect key locations, while nodes and districts are less frequently mentioned. The frequency of these elements in the maps highlights their importance in shaping students' understanding of campus layout, potentially improving campus design and making it more navigable and connected.

The cognitive sketch map shows 42 to 47 legible elements, including pathways, greeneries, faculties, and residential colleges. Pathways were shown with dotted lines, while images of Varsity Lake and UM Campus were captured. Green transitional nodes were identified, and landmarks were identified with red color boxes. Legibility was higher from a student's perspective, and more bus stops were drawn for more transportation nodes.

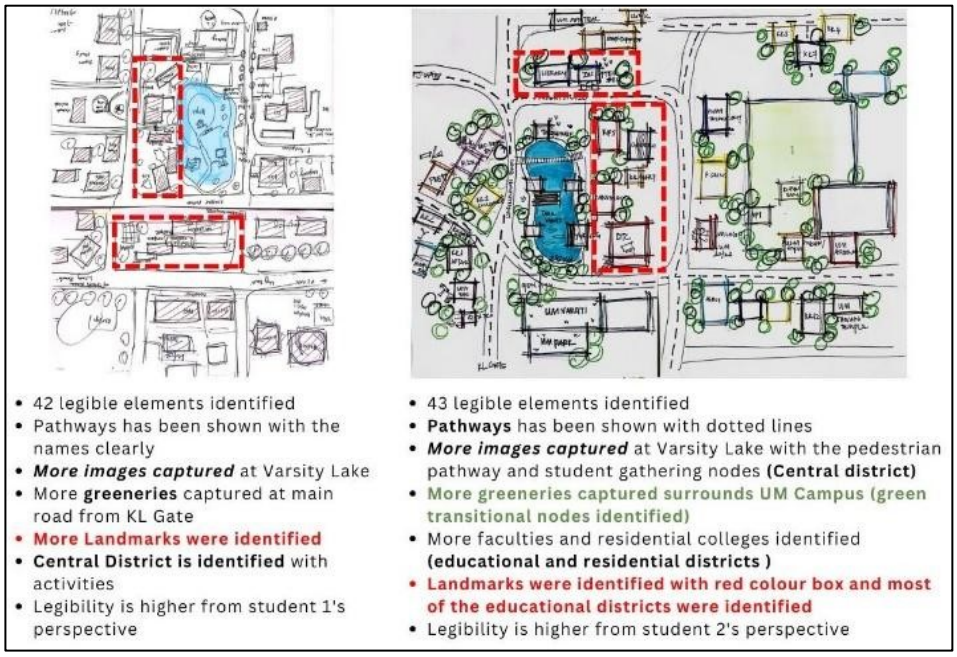


Figure 7: Cognitive Mental Maps Analysis
Source: Data collected during fieldwork, Authors (2023)

The study identifies four **key landmarks** in the study area**: DTC, KPS, UM Library, and Chancellery. DTC and Varsity Lake** are the most frequently mentioned landmarks, indicating their significance in the mental mapping of the

area. The central district, including UM Library, UM Central, and popular eateries, serves as a transitional node for student gathering. 72% of participants noted this area as a social hub, and 54% agreed it has the potential to become a designated "student district" in the future. The main road, Jalan Lingkungan Budi, is consistently represented on maps. The path leading to the student plaza is seen as an influential route, enhancing student life and fostering a sense of belonging.

ANALYSIS AND DISCUSSION

Data analysis from hand-drawn sketches from participants was used to visually represent elements from mental mapping. This method is to communicate individual spatial perception and organization. Data from findings indicated that landmarks and edges are crucial for campus navigation, with Varsity Lake, Dewan Tunku Canselor, and the UM Library being the most recalled features, consistent with Lynch's theory on landmark recognition reducing cognitive load. However, while main pathways were consistently mapped, nodes and districts were less represented, suggesting a reliance on a few prominent features for wayfinding, which may pose challenges for new visitors. These findings parallel Esfandfard's (2018) conclusions that wayfinding elements such as signage and directional maps are essential for enhancing urban navigability and mental map accuracy.

Understanding the contribution of the Present Study

Individuals engage with place through cognitive, affective, and behavioural dimensions (Erfani, 2022). Lynch's framework identifies physical elements such as landmarks, paths, edges, districts, and nodes as central to spatial legibility; however, subsequent scholarship has critiqued this approach for insufficiently addressing the relational dynamics among these elements (Lynch, 1960).

Lynch's urban design approach, though foundational, neglects the significance of relational qualities like proximity and visual connectivity in shaping cognitive maps and spatial understanding. This oversight limits its utility in complex urban settings (Zacharias,1997; Appleyard,1970). Unlike campuses with robust wayfinding infrastructure, UM's campus lacks consistent signage and clearly defined spatial districts. Studies, such as one on Selcuk University (Deniz & Topcu,2012) indicate that undefined spaces hinder navigation efficiency, a problem also present in UM's open areas.

Urban legibility depends on both landmarks and the integration of spatial elements. Cognitive maps provide useful insights but are limited by memory distortions (Lopez & Bosco, 2022), as seen in the more coherent maps of long-tenured UM students. Future studies could use GPS or AI validation, while user-centered tools like mobile apps and tactile maps highlight inclusive wayfinding solutions (Swobodzinski, 2021).

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CONCLUSION

The study highlighted how imageability and cognitive mapping is crucial for campus navigation at Universiti Malaya. Designed landmarks and pathways are proven to essential as spatial aids. Navigation challenges such as poor signage, indistinct zones, and inconsistent wayfinding were identified. Cognitive mapping assists students in understanding campus layouts and fostering belonging. Future longitudinal research could examine how extended exposure affects spatial perception and mental campus representations, assessing changes in perceivability, imageability, and legibility. Enhancing campus legibility requires improving navigation and spatial clarity, alongside aesthetic experience and place attachment, to create a more engaging student environment.

This research studied on campus legibility which offers several key recommendations:

1. Implementation of Smart Navigation Systems – Universities should integrate AR-based campus guides and real-time digital maps to assist navigation, particularly for first-year students and visitors.
2. Redesign of Campus Pathways & Signage – Pathways should be visually reinforced with distinct paving, lighting, and signage to enhance clarity and spatial recognition.
3. Creation of Themed Campus Districts – Introducing zoning strategies (e.g., "Academic District," "Cultural Hub," "Recreational Green Zone") can help students develop a stronger mental association with specific campus areas.

Future research has high potential to focus on integrating AI-driven wayfinding tools to analyse real-time student navigation patterns as well as conducting comparative studies across multiple campuses to establish a universal framework for university spatial design.

ACKNOWLEDGEMENTS

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DISCLOSURE STATEMENT

The authors declare that there are no potential conflicts that could have influenced the outcomes of this research. The study was conducted independently and exclusively for academic purposes as part of the *Architecture Academic Report (BIA 3022)*.

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THE ROLE OF MOSQUES IN SUSTAINABLE COMMUNITIES: BOSNIA AND MALAYSIA COMPARED

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Abstract

Mosques play a vital role in Muslim communities, extending beyond places of worship to function as social, educational, and cultural hubs fostering identity and sustainability. Despite their significance, many modern Mosque struggle with inefficient spatial utilization and high energy demands, undermining their roles. This study conducts a comparative analysis of two iconic Mosques, the Federal Territory Mosque in Malaysia and the Gazi Husrev-Beg Mosque in Bosnia. By employing a qualitative case study approach. This paper proposes specific contributions to the field of sustainable religious architecture, (1) comparative assessment framework in occupancy ratio, energy consumption, sustainability, and urban planning integration. (2) Demonstrating Mosque typology significant impact on its performance. (3) Synthesizing energy audit data to identify design interventions to balance religious and cultural authenticity with energy goals. The findings highlight key architectural issues, the Federal Territory Mosque reflects a grand-scale design, resulting in underutilization and high energy dependency, while the Gazi Husrev-Beg Mosque exemplifies a community-centered approach with efficient space use and passive environmental strategies. The study emphasizes the necessity of adopting adaptive architectural solutions that align with cultural and religious significance while incorporating modern sustainability practices. This research provides actionable design recommendations to regulate sustainable religious architecture.

Keywords: Religious Architecture, Sustainable Architecture, Mosque Utility Efficiency, Community Engagement, Energy Consumption, Bosnia, Malaysia

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INTRODUCTION

Mosques have historically served as more than places of worship; they act as social and cultural urban anchors reflecting the region's cultural heritage and fostering social cohesion. Each Mosque have a distinguished characteristics that is driven to flourish the cultural identity and region's history *"Historical architectural sites have demonstrated that spatial and decorative design elements are key to maintaining cultural identity while also ensuring functional and aesthetic integration* (Baydoun et al.,2024). In both Bosnia and Malaysia, Mosque architecture embodies distinct historical trajectories. In Malaysia, Mosque architecture has evolved from modest timber and village based "*surau"* into monumental post-independence landmark such as the Federal Territory Mosque (2000), which blend Malay, Middle Eastern, and modern stylistic influences. These large-scale grandeur designs symbolize national Muslim identity and Islamic heritage (Afridi, 2011). In Bosnia, Ottoman rule introduced a rich legacy of Islamic architecture, where Mosques such as the Gazi Husrev-Beg Mosque (1530s) became enduring symbols of faith, and cultural resilience. Their compact forms, integration within urban fabric, and emphasis on passive environmental strategies illustrate how traditional design supported both spiritual and social life (Dervisevic, 2020). While this cultural richness is significant, however, modern Mosque designs often prioritize grand aesthetics over functional sustainability, leading to sustainable challenges such as inefficient spatial utilization, high energy consumption, and limited community engagement (Ismail et al., 2015). The Federal Territory Mosque in Malaysia is built to accommodate massive congregations, however, they often suffer from underutilization and significant energy wastage (Al-Hafith et al., 2021). In contrast, smaller Mosques like the Gazi Husrev-Beg Mosque in Bosnia emphasize compact, community driven designs that promotes sustainability. This study aims to explore the role of Mosques in achieving sustainable communities by comparing two distinct architectural approaches. The research is examining how spatial planning, energy efficiency, and urban integration influence their long-term viability. A qualitative case study analysis is employed to assess four key factors: **(i) occupancy patterns, (ii) energy consumption, (iii) sustainability aspects,** and **(iv) urban planning integration.** These factors provide insight into how Mosques can optimize their functionality while minimizing their environmental footprint. By analyzing two Mosques from different socio-cultural and climatic contexts, this study contributes to the discourse on sustainable religious architecture. It highlights the need for adaptive design strategies that align with Islamic values while embracing modern sustainability practices. The findings will offer practical recommendations for enhancing Mosque architecture, ensuring to remain environmentally responsible, socially engaging, and culturally significant in contemporary urban landscapes.

LITERATURE REVIEW

The Concept of Sustainability and Energy Efficiency in Mosques

Sustainability in architecture is creating structures that minimize environmental impact while ensuring long-term efficiency and resource conservation (M. Yilmaz, 2006). The term "Sustainability" is often overused without concern for long-term consequences. The focus should shift from "Architecture about Sustainability" to "Architecture for Sustainability. Therefore, sustainability should be seen as a core architectural design principle rather than an optional feature (Azmi et al., 2019). Within Mosques, utility systems encompass space utilization efficiency, lighting, ventilation, and facility management. Effective spatial planning ensures that Mosque structures align with community needs while minimizing environmental impact (Budaiwi et al., 2005).

Energy Usage in Mosques

Mosques have unusual energy consumption patterns due to their intermittent use throughout the day for prayer rituals. Typically, they operate daily five times for brief durations, with peak attendance during religious events. Despite this infrequent use, many Mosques, particularly in Malaysia, rely significantly on artificial lighting and mechanical air conditioning systems to maintain thermal comfort (Ismail et al., 2015). Studies reveal that passive energy-saving methods, such as natural ventilation and daylight optimization, can reduce Mosque energy use by 30-50% while maintaining adequate thermal comfort (Azmi et al., 2019).

Occupancy Patterns in Mosques

"Effective spatial distribution in historical structures has long been recognized as a key factor in enhancing both visual harmony and functional sustainability" (Baydoun et al., 2024). The efficiency of a Mosque's utility system is greatly impacted by its occupancy pattern. In Malaysia, the Mosque construction trends favor large-scale structures with expensive facilities, the Federal Territory Mosque in Kuala Lumpur spans 47,000 square meters and can accommodate 17,000 worshippers. However, outside peak prayer times, it remains largely unoccupied, resulting in substantial energy wastage (Nayeem et al., 2019). In contrast, Bosnian Mosques, such as the 400 square meter Gazi Husrev-Beg Mosque, with its compact scale home-like design fosters stronger community engagement and efficient space utilization. Illustrating the importance of aligning architectural design with cultural and social dynamics (Dervisevic, 2020)

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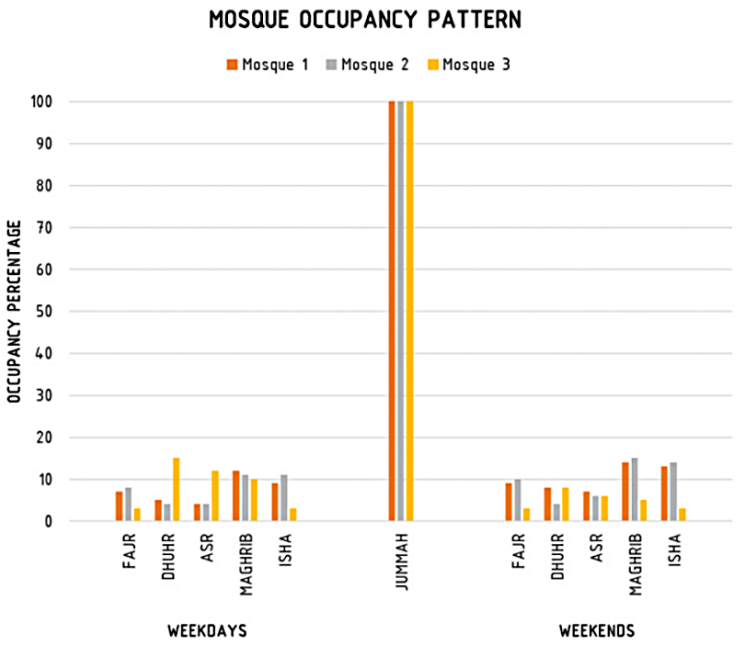


Figure 1: Chart based on the occupancy pattern in 3 Mosques in Malaysia
Source: Published research by Azmi & Kandar,2019

Bosnian Mosques Features

Bosnian Mosques embody a distinct architectural philosophy that prioritizes community-centered planning. It was argued by (Baydoun et al., 2024). That *"Architectural designs that integrate historical elements while adapting to modern needs have proven to be more sustainable and culturally resilient over time"*. The Gazi Husrev-Beg Mosque adheres to traditional Ottoman design principles, incorporating functional spaces within the Mosque complex (Hercegovini, 2016). Bosnian Mosques are more sustainable due to their lower size and planned spatial design, which optimizes natural ventilation and daylight (Gekić et al., 2020).

Malaysian Mosques Features

Malaysian Mosque architecture is distinguished by its grand scales, drawing inspiration from Ottoman, Persian, and Moghul influences. The Federal Territory Mosque integrate elements from the Blue Mosque in Turkey, the Shah Mosque in Iran, and the Taj Mahal in India (Afridi, 2011).

"Islamic architectural designs are inspired by diverse influences, including Ottoman, Safavid, Central Asian, Persian, and Mughal styles, resulting in an eclectic yet distinctly Islamic city identity." Adding to that "*Islamic artistic traditions rely heavily on the utilization of geometric, floral, and calligraphy patterns, which are essential in defining architectural identity while also contributing to environmental sustainability through shading and ventilation elements."* Argued by (Baydoun et al. 2023*).*

Importance of Mosques in Muslim Communities
Placemaking and Community Attachment to Mosque
Placemaking involves fostering an emotional and cultural bond between individuals and physical spaces. According to research, Mosque architecture has a significant impact on community attachment and involvement, it can achieve the sustainable meaning for a community. The inclusion of communal facilities, accessible spaces, and cultural relevance enhances the Mosque's role as an inclusive urban space (Altman et al., 1992).

The Islamic perspective on Sustainability in Mosque Architecture
Islamic teachings emphasize resource conservation and environmental stewardship. The Quran explicitly cautions against wastefulness: "*But do not waste: verily, He does not love the wasteful*" *(Al-Araf: 31)*. In Islam, wastefulness is "*Tabdir*" while extravagance is known as "*Israf*". Both are "*Haram*" or forbidden (prohibited). In the Quranic verse, the word "*Israf*" refers to the use in a wasteful manner. It is defended by (Baydoun et al., 2024) that *"Sustainable architecture in Islamic history was deeply rooted in resource-conscious design, where structures were planned to minimize excess and maximize functional longevity".* Islamic architectural philosophy encompasses sustainability across economic, environmental, and social dimensions. Analyzing this verse to be a guideline within an Islamic concept frame would add a religious dimension to this research.

RESEARCH METHODOLOGY

1- **Approach and Case Selection Justification**
This study adopts a qualitative case study approach to analyze how Mosque architecture impacts sustainability, focusing on spatial utilization, energy efficiency, and community engagement. The selection of the Federal Territory Mosque in Malaysia and the Gazi Husrev-Beg Mosque in Bosnia is justified by their contrasting architectural scales, energy reliance, and integration within their respective urban contexts.

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2- Data Collection & Analysis Methods

To ensure a comprehensive analysis, this study utilizes three primary data sources. The first source, energy performance analysis, relies on previous energy audits, direct field observations, and ventilation assessments to evaluate cooling systems, lighting consumption, and natural ventilation efficiency. These assessments are supported by studies such as (Azmi et al., 2019). The second data source focuses on occupancy and spatial utilization, employing ***direct observational surveys.*** The third source involves an ***investigation*** of sustainability strategies and architectural elements through archival research. By integrating these methods, the study provides a structured and transparent approach to evaluating Mosque sustainability.

3- Benchmark Comparison for Mosque Sustainability

To enhance the validity of the findings, this article compares the energy performances and sustainability strategies of the selected Mosques with documented best practices in Mosque sustainability. Existing research on energy-efficient Mosques, including studies on passive cooling, daylight optimization, and the integration of renewable energy sources, serves as a reference framework for evaluating the case studies. Additionally, comparative studies on occupancy patterns and spatial utilization provides insight into how Mosque design can enhance community engagement while minimizing environmental impact.

ANALYSIS AND DISCUSSION

"*Mosques are to be ingeniously and skillfully planned, designed, and built to satisfy the religious, social, educational, and welfare requirements of the people*" (Spahic, 2013). A place is formed by the people's emotional relationship with its physical environment, identifying it as "Place identity, Place attachment, Sense of Place, or Space Utility" (Altman et al., 1992).

Here, a newly encouraged approach for Mosques brought back into the light *"Urban Mosque refers to the representative religious edifice constructed by Muslims who reside primarily within urban locales, it is where the faithful gather to engage in communal worship, spiritual retreat, matrimony, education, and other significant socio-cultural activities"* (Kahera et al., 2007).

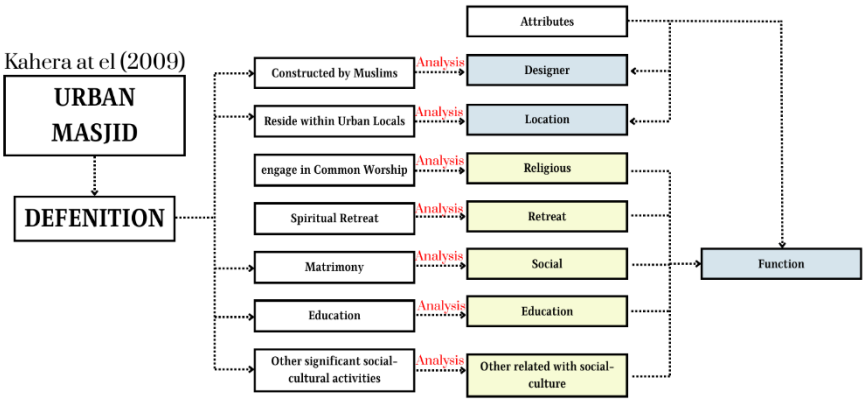


Figure 2: Definition of Urban Mosque
Source: Published research by Kahera et al. 2007

The Federal Territory Mosque "Wilayah" is classified as an urban Mosque, but an issue remains: no expected attendance, as with all other grand Mosques in Malaysia. So, for comparative seeking, a view of the Malaysian Mosque's history should be taken. Malaysia has a Muslim-majority nation from back at the time, the earlier typological construction of a Mosque was purely a timber product based on a timber frame, small in size, with the usual characteristics of two tiers pyramidal roof with a long gable house type, it was a repetitive picture of the typical Malay house mentioned by (Utaberta et al., 2012) The villages were smaller and surrounding the Mosques, they were treated as an actual community centers regardless of the size. Nowadays, many influences attributed to the Mosque architecture design, creating a trace of all historical events that significantly changed Malaysia, argued by (Nayeem el al., 2019). Over the decades, Malaysia faced the Portuguese and Colonial periods, which extensively influenced the presentation and construction of the architecture in the region (Nayeem el al., 2019). So, the Mosques became a historical language of the Malay community. Now, Malaysia has huge states with huge Muslim populations, so they adopted the idea of having bigger Mosques, creating a display of Malaysian cultural and historical events more than a community-bonding structure as the "Kampong Masjid" was once (Ahmad, 1999).

A scope of the study was defined under the title *"Public Attachment to Religious Places: a Study of Place Attachment to Mosques in Malaysia"* by (Najafi et al., 2011). The survey in the study was conducted targeting locals only, questioning three statements:

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- *Mean values of the components of functional attachment*
- *Mean values of the components of place identity*
- *Mean values of the people's emotional component attached to the selected Mosques*

Table 1: Mean values of the components of functional attachment.

Components		Statements	Mean Value				
			Negara	Putra	Wilayah	Sembilan	Al-Azim
Emotional Attachment N=288	01	I am very attached to this mosque	3.53	3.69	3.86	3.78	3.77
	02	I have positive impression about this place	4.04	4.18	4.23	4.12	4.24
	03	Coming here is one of the most satisfying things to do	4.14	4.16	4.26	4.24	4.57
	04	I enjoy being here more than being in any other mosque	3.32	3.72	3.50	3.86	3.67
	05	I would prefer to spend more time here if I could	3.64	3.67	3.74	3.94	4.03
	06	I feel I am closer to Allah when I am here	4.03	4.14	3.77	4.34	4.41
	07	Here I can concentrate on my religious activities more than any other mosque	2.99	3.39	3.03	3.13	3.57
	08	The quality of the environment influences my concentration while praying	3.77	3.98	4.05	3.88	4.19
	09	I feel secure being in this mosque	3.27	3.59	3.58	3.24	3.56
Total			3.64	3.84	3.78	3.84	4.00

Table 2: Mean values of the components of place identity.

	Component	Mosque				
		Negara	Putra	Wilayah	Sembilan	Al-Azim
01	This mosque is convenient, comfortable and tranquil	3.96	3.95	3.98	4.04	3.97
02	This mosque has appropriate facilities and equipment	3.78	3.79	3.92	3.78	3.82
03	This mosque has a very good maintenance and management system	3.53	4.79	3.63	3.56	3.64
04	No other place can compare to this place	3.15	3.32	3.22	2.71	3.12
05	The access of this mosque is more and better	3.57	3.31	3.63	3.69	3.58
06	A lot of social activities are done in this mosque	3.31	3.03	3.29	3.50	3.30
07	The good facilities and equipment of this mosque influence my better concentration while doing religious activities	3.85	3.97	4.03	3.90	3.97

Table 3: Mean values of the meanings associated with the selected Mosque.

Components		Statements	Mean Value				
			Negara	Putra	Wilayah	Sembilan	Al-Azim
Place Identity N=288	01	This place says a lot about who I am	3.60	3.65	3.78	3.78	3.78
	02	I feel most most in this place	3.99	4.16	4.25	4.12	4.27
	03	Everything in this place in a reflection of me	4.13	4.11	4.25	4.24	4.57
	04	This place reflects the type of person I am	3.73	3.84	3.84	3.94	3.84
	05	This place is part of me	3.63	3.67	3.75	3.94	4.03
Total			3.72	4.16	4.25	3.83	3.79

Source: Published research by Najafi, 2011

Survey results indicate strong attachment toward the Federal Territory Mosque, comparable to other Mosques. Respondents acknowledged its significance as an urban Mosque for the Malay Muslim community. However, the survey was conducted after *Juma'a* prayer, primarily among the elderly, limiting its scope to broader community engagement. Highlighting the need for further study on weekday attendance and diverse demographic participation. On the other side of the comparative study, the Mosques in Bosnia were partly based on a Christian Church upon the Constantinople conquest; it aimed to show that culture and religion don't exist in isolation. Notwithstanding, the Bosnian Muslim community was always under the pressure of the Christian world, wars barely ended. Bosnian history has been written through religious architecture since the 15th century. Bosnia coexistence is reflected in their insistence constructing their identity through the lens of rebuilt and newly built Mosques following the same architectural style as the first-ever Mosques in the region (Aksamija et al., 2011)

The research related to environmental sustainability, specifically energy consumption, is limited, but it has been observed that Mosques consume a significant amount of energy, unfortunately, in an unsustainable manner (Sobri et al., 2021). Malaysian Mosques experience extreme heat due to their equatorial location, making high humidity and temperature significant challenges in ensuring occupant comfort (Fauziah et al., 2016). Poor ventilation and insulation further exacerbate discomfort, necessitating green sustainable design approaches to improve indoor air quality, however, most Malaysian Mosques rely heavily on air conditioning and artificial lighting, leading to high energy consumption (Sobri et al., 2021). Large-scale Mosque designs, such as the Federal Territory "Wilayah" Mosque, amplify these challenges. As it is built with a sense of grandeur, it requires significant thermal regulation, often resulting in excessive energy waste (Suhono et al., 2020). Conducting energy audits is essential to quantify energy costs and promote sustainable solutions. Ensuring adequate indoor air quality in urban Mosques is crucial, as factors like airflow behavior, temperature distribution, humidity, and carbon dioxide levels directly affect the high-occupancy environment (Sobri et al., 2021).

This issue manifests in two key scenarios: first, running air conditioning continuously throughout the day, despite low occupancy, leading to excessive energy waste; second, activating air conditioning only during prayers, which does not allow sufficient time for effective cooling. A more efficient solution is pre-cooling, where the space is cooled beforehand, and allowing air conditioning to remain off during prayer times. Thus, balancing thermal comfort with reduced energy consumption (Atmaca et al., 2020). Adopting this method can significantly enhance Mosque sustainability while maintaining a comfortable worship environment.

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Both the Federal Territory "Wilayah" Mosque and Gazi Husrev-Beg Mosque have an increased height of prayer hall; the difference is in the overall size of both Mosques, "Wilayah" Mosque is bigger and depends on the air conditioning system for its huge prayer hall, Gazi Husrev-Beg is making use of the prayer hall design for passive natural ventilation which permitted the praying hall to stay relatively cool while overhead sun-heated air is closer to the ceiling (Gekić et al., 2020).Overall, it is proved that natural ventilation achieves better indoor air quality than air conditioning.



Figure 3: Gazi Husrev-Beg Medresesi, drawing by the author
Source: Original Drawings by Dr. Tuna Alp, 1983

Another aspect is related for achieving a sustainable urban Mosque, efficient lighting. In simple words, the energy used in lightning can be reduced by replacing it with daylight in the daytime. A suggested solution is using solar VP on the Mosque's rooftop. It is an experienced practice in Malaysia in a few Mosques before, including Sultan Ismail Mosque, in which the solar system reduced UTM's electricity bill by 33,000 RM annually by around 47% of reduction (Rashid et al. 2011).

Table 4: Suggested sustainable design strategies for Urban Mosque in Malaysia

Sustainable Design Principles	Sustainable Design Strategies for Mosque
Energy Efficient	Solar PV Wind Turbine Water Treatment
Climate Condition	Daylighting Natural Ventilation Thermal Comfort
Sustainable Materials	Local Materials
Indoor Air Quality	Natural Ventilation Daylighting

Source: Journal of Islamic Architecture, 2021

Religious institution should be planned according to sustainable factors in terms of form, spaces or activities. Mosque design gives a significant impact on enriching the quality of life. For the reason that the religious institution is faithfully related to the presence of a Muslim believer (Jaffar et al., 2020*)*. Sustainable urban Mosque building methods are not a recent new idea in Islam. "*Authentic Islamic architecture is sustainable, not only in terms of environmental and economic aspects but also in terms of social, educational, and spiritual development. Similarly, a truly sustainable architecture is rightly called 'Islamic', rather than those architectural traditions that endorse literal symbolism, shallow formalism and blind following."* (Spahic, 2013).

CONCLUSION

This study demonstrates that Mosque typology and spatial scale significantly influence sustainability outcomes. Oversized Mosque complexes with limited daily use tend to embed high operational energy demands, whereas compact, community-embedded models are better positioned to harness passive strategies and achieve continuous functional use. The comparative analysis highlights how the Federal Territory Mosque reflects the risks of over-dimensioning and mechanical reliance, while the Gazi Husrev-Beg Mosque illustrates the enduring value of courtyards and ventilation pathways, in balancing environmental performance with cultural continuity. The findings underscore broader implications for sustainable religious architecture. Firstly, Mosque design must prioritize right-sizing in relation to actual patterns of occupancy, ensuring that prayer halls and ancillary spaces are adaptable to community activities beyond ritual use. Secondly, environmental performance should privilege passive systems by demanding responsive technologies to minimize reliance on mechanical conditioning. Thirdly, urban siting and integrations are critical, enabling Mosques to function as accessible civic anchors rather than episodic religious destinations.

To advance this discourse, further research is required to establish Mosque specific sustainability benchmarks. Recommended directions: (1) development of standardized performance indicators (e.g., energy use per worshipper, space-use intensity); (2) longitudinal monitoring of energy consumption, thermal comfort, and occupancy patterns; and (3) systematic investigation of social and cultural dimensions, including place attachment and their relationship to environmental performance. To advance sustainability in Mosque architecture, policy frameworks and architectural strategies must align with evidence-based research and contextual considerations. Architectural solutions must integrate proven sustainable strategies. Mosques should function to enhance community participation. By incorporating learning facilities, social activity spaces, and environmental awareness initiatives, they can reinforce their

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role in sustainable urban planning. Still, it is noticed that there are modern sustainable Mosque examples in Malaysia, it was stated by (Dariyadi et al., 2022) that Putra Mosque in Putrajaya exemplifies modern sustainable mosque design by integrating geometric patterns for shading, passive cooling, and natural lighting. Its porous arches enhance ventilation, reducing energy use while maintaining cultural authenticity.

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IMPLEMENTATION OF VERTICAL GREENERY SYSTEMS IN BUILDING PROJECTS IN MALAYSIA

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Abstract

Rapid real estate development in Malaysia has led to the depletion of green areas, resulting in various environmental issues, some of which may have irreversible consequences. To address and mitigate these negative impacts, sustainable development practices that prioritize environmental concerns are essential. Vertical Greenery System (VGS) has emerged as a promising solution to enhance the environmental quality of dense urban areas in a sustainable manner. However, despite its potential benefits, VGS implementation remains limited in Malaysia due to system-related challenges and low public awareness. This paper aims to evaluate the application of VGS in Malaysian buildings and identify the primary obstacles to its widespread adoption. To gather insights, a comprehensive survey was distributed to 118 construction professionals and tenants of VGS-equipped buildings, examining multiple aspects of VGS such as energy consumption, indoor air quality, cost-effectiveness, property value enhancement, noise reduction, fire safety, architectural features, and their overall effects on occupant health and well-being. The data was analysed using descriptive statistics and Factor Analysis and revealed key VGS attributes, challenges to implementation in Malaysia, potential solutions and critical barriers to wider adoption. The findings offer valuable insights for policymakers, planners, and building professionals in devising strategies to effectively integrate VGS into Malaysian cities.

Keywords: Vertical Greenery System (VGS), Sustainable Development, Environmental Quality, Energy Consumption, Indoor Air Quality, Architectural Features

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INTRODUCTION

Increasing urbanisation worldwide can reduce green spaces, raise pollution, and waste energy. Vegetated facades, also known as Vertical Greenery Systems (VGS), represent an effective approach to restoring green areas on urban building exteriors, particularly where ground-level planting space is limited. VGS encompasses a range of applications, including vertical gardens, green walls, and bio-walls. By strategically integrating plants into building facades, VGS contributes to reducing ambient temperatures in metropolitan areas. This system further mitigates heat transfer through the building envelope, thereby enhancing thermal comfort for occupants and improving overall energy efficiency.

Owing to limited awareness and certain disadvantages, the adoption of Vertical Greenery Systems (VGS) in Malaysia remains at an early stage. Rapid urbanisation, driven by the country's dense population, where 77% of Malaysians now reside in urban areas has resulted in significant loss of open green spaces. This percentage is likely to have increased, highlighting the severe impact of urbanisation on Kuala Lumpur's green spaces and the resulting environmental challenges. The city experiences a pronounced urban heat island (UHI) effect, with nighttime UHI intensity reaching 6.0 °C and daytime urban cool island (UCI) intensity measuring 4.0 °C because urban commercial areas are hotter than green regions.

The hypothesis of this study is to determine whether installing VGS in Malaysian buildings can improve their sustainability and liveability by resolving the stated difficulties and raising public awareness. Policymakers, urban planners, and building experts will be able to create efficient strategies for the promotion and integration of VGS, resulting in a greener and more sustainable future for Malaysian cities, by comprehending and resolving the challenges to its implementation.

LITERATURE REVIEW

The practise of adding flora to vertical building surfaces, such as walls, facades, balconies, or roofs, is known as a vertical greenery system (VGS). A vertical garden or living wall is created by carefully placing plants, climbing vines, and other greenery (Wang et. al., 2019). To make up for the loss of green spaces brought on by growing urbanisation, the VGS idea seeks to reintroduce nature back into urban settings (Hanna, G. and Jerzy, S., 2019). VGS offers a variety of advantages for both the built environment and its occupants by integrating vegetation vertically.

The vegetation in VGS serves as a natural air filter, absorbing pollutants and particulates from the air and enhancing air quality in general (Heindri et. al., 2024). By providing shade, lowering solar heat absorption, and releasing moisture through evapotranspiration, they also aid in minimising the urban heat island

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effect. Besides, VGS contributes significantly to improving energy efficiency. The plant layer serves as an insulating barrier, lowering the amount of heat transmission through building walls and lowering the demand for excessive air conditioning (Heindri et. al., 2024). This can therefore result in less energy being used and fewer greenhouse gas emissions.

In addition, by absorbing and holding onto rainwater, VGS helps to manage stormwater flow by easing the burden on urban drainage systems and lowering the risk of flooding. In addition to supporting habitat and biodiversity, the plants in VGS can aid in ecological preservation in urban settings (Moravej et. al., 2025). VGS has aesthetic and psychological benefits in addition to environmental ones. Greenery in the built environment benefits human wellbeing by lowering stress levels, elevating mood, and encouraging a sense of connection with nature (Salleh et. al., 2022, Lipczyńska et. al., 2024). By converting dull concrete walls into vivid green spaces, VGS can design visually appealing landscapes.

Careful planning and design considerations are required for the VGS implementation. To ensure the long-term viability of the green projects, factors including plant selection, irrigation systems, structural support, and maintenance requirements must be taken into consideration. Overall, VGS offers a creative and sustainable method for greening metropolitan areas. It provides a means of reintegrating nature into the constructed environment, resulting in cities that are healthier and more habitable (Manouchehri et. al., 2024). Wong, et al. (2010b) revealed that VGS does not improve rainfall retention or façade longevity. If neglected, aggressive vegetation on the façade can harm the building wall (Kontoleon & Eumorfopoulou, 2010).

RESEARCH METHODOLOGY

A questionnaire survey was adopted to understand the overall detailed needs and demands of VGS customers (end users who are those living or working in the buildings which have implemented VGS) and particularly construction professionals (landscape architects, engineers, contractors) who are more familiar and have related knowledge on VGS. 200 questionnaire surveys were sent to construction professionals from a non-probability sampling method. Whereas, the case studies of Vertical Greenery Systems (VGS) include Digi Technology Operation Centre, Platinum Sentral, and Jamnah View Condominium inhabitants were surveyed, and these buildings were described in Table 2. The case studies were selected due to several factors as in Table 1.

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Table 1: Key Factors for Selecting the Case Studies.

Key Factors	Explanation
Location	Case studies should be chosen from areas that are like the research's target area or context. Regional aspects including temperature, building codes, and cultural preferences should be considered to get insights that are more relevant to the desired study area
Project Scale	It is crucial to include case studies that address a variety of project scales, from modest installations in private residences to sizable ones in public or commercial structures. This guarantees a thorough comprehension of the potential applications and difficulties across various project sizes
Project Type	A wider understanding of how VGS can be incorporated into various architectural typologies can be gained by including several project kinds. Residential complexes, office buildings, healthcare facilities, educational institutions, and public areas are a few examples. Every project type may have different factors to consider and requirements to implement VGS
Design Innovation	Choosing case studies that show cutting-edge design strategies or distinctive VGS implementation aspects might provide helpful insights into original solutions and best practises. Projects with excellent aesthetic integration, inventive plant species use, or new structural systems are a few examples.
Performance Metrics	Consider case studies that include performance metrics that have been measured and recorded in relation to the desired study objectives. Data on energy savings, improvements to air quality, thermal comfort, stormwater management, or tenant satisfaction may be included. The benefits of VGS can be supported by facts in projects with thorough performance evaluations
Success and Durability	Look for case studies that have been in use for long enough to have their long-term effectiveness assessed. Projects that have successfully established and maintained the VGS throughout time might offer insightful information on the robustness and efficacy of the system.
Diversity	Make sure that the case studies you choose to use reflect the various architects, designers, developers, and project teams. This aids in capturing a variety of viewpoints, strategies, and lessons discovered from different stakeholders participating in the implementation of VGS
Lessons Discovered	Case studies can offer insightful advice for overcoming obstacles and maximising the success of VGS initiatives by documenting problems, lessons learned, and recommendations for future implementations

Table 2: Profile of Selected Buildings with VGS Features

Building Name	**Digi Technology Operation Centre**	**Platinum Sentral**	**Jamnah View Condominium**
Perspective			
Building Type	Office	Commercial	Residential
Location	Subang High Tech Park, Shah Alam, Selangor	Lot E, Kuala Lumpur Sentral Park,	Damansara Height
Number of Storey	4-storey (23.5m high)	7-storey	23-storey
Green Building Index	GBI Gold rating	N.A.	N.A.
Plant Type	Climber plants	Climber plants	Bougainvillea

Building Name	Digi Technology Operation Centre	Platinum Sentral	Jamnah View Condominium
Plant Age	7 years	5 years	22 years
Plant Condition	Healthily grown with +/-20 cm thickness	Healthily grown with +/-10 cm thickness	Well grown in planter boxes
Orientation of VGS	All directions	Surrounding building	Northwest
Façade Materials	Plaster and paint with groove line	Plaster and paint	Plaster and paint

Structure of Questionnaire

The questionnaire survey was divided into three sections. The first section gathered respondents' demographic information, the second section contained the degree of importance & degree of satisfaction of demanded qualities of VGS and the third section assessed challenges/constraincts encountered in VGS implementation. VGS's lacking features are shown by the disparity between importance and satisfaction in second section and the the third section covered VGS implementation issues and requested responders for solutions. At the end of the last part, construction professionals can answer three optional questions to learn more about project client requirements for VGS, key technical considerations for VGS implementation, and any thoughts on VGS implementation in Malaysia.

Second section and third section of the questionnaire survey were measured using a 4-point Likert scale, to avoid mid-points like "neutral". The data is collected through online platform and is self-administrated. Data is verified for readability and completeness before being coded and loaded into SPSS for analysis. 52 construction professionals and 66 building tenants completed the surveys. The response rate is 59% which is good. Reliability is assessed using Cronbach's Alpha before analysis (Nunnally, 1978). Table 2 shows good instrument reliability, i.e., above 0.7.

Table 3: Reliability of the measurement instrument

Section	Cronbach's Alpha	Number of Items
Demanded qualities of VGS	0.878	24
Challenges encountered in VGS implementation	0.829	16

Results and Discussion

Implementation and Benefits of VGS

VGS was considered moderately implemented by 57 respondents (48%) and lowly implemented by 61 respondents (52%). The most perceived benefits are energy savings (45 respondents), environmental benefits (38 respondents), aesthetic benefits (31 respondents), economic advantages (2 respondents), acoustic benefit (1 respondents), and others (1 respondents).

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Degree of Importance and Satisfaction of Demanded Qualities

Table 3 shows the discrepancy between VGS mandated attributes' importance and satisfaction. This displays the desired attributes; however, respondents are unsatisfied with their performance. The total mean value for importance is 3.39 and satisfaction is 2.93, indicating that VGS implementation has to be improved. For the following items, importance and satisfaction differ most: VGS requires regular maintenance to maintain good condition and avoid damages, careful selection of vegetation to provide high durability and long lifespan, low life cycle cost (operation and maintenance cost) and low installation cost. VGS maintenance and cost must be improved. The mean ranking of desired attributes from responders from different backgrounds is also shown.

VGS's most desired traits are architecturally appealing VGS, VGS cools and comforts occupants (Taib et. al., 2018), VGS restores urban greenspaces, VGS filters dust and harmful gases, improving indoor air quality and VGS harmonises nature in cities. ANOVA reveals the significance of respondents' viewpoints from varied backgrounds (i.e. construction professionals and building occupants). Significance is 0.05 or less. All respondents agreed on the importance and satisfaction of these qualities, except for "VGS helps in reducing the temperature and provides thermal comfort to occupants," which had a significant level of 0.013, indicating that respondents from different backgrounds did not agree on this item. So, this study's top VGS features are architectural attractiveness and practicality in improving air quality, recovering green areas, and attaining urban sustainability.

VGS represents a novel green infrastructure idea combining vertical walls and living plants. VGS can improve a building's architectural design and produce a greener skyline to relieve the urban environment. Rapid urban development is replacing ground-level green spaces with concrete roads and pavement. Yusof and Johari (2012) found that Kuala Lumpur's green areas decreased by 59.4% from 24,222 to 14,386 hectares. Since most land is used for development, there is less land for planting vegetation to increase green areas. Hence, instead of planting on the ground, VGS allows vertical planting on building walls, which maximises space.

VGS is an alternative way to restore and increase green spaces in urban areas by planting vegetation vertically on building walls or facades. Vegetation is limited in modern cities due to the usage of land and space for construction. VGS also filters dust and hazardous gases. It inhibits dust (Johnson & Newton, 1993). According to Koyama et al. (2013), VGS traps airborne pollutants and filters indoor toxins emitted from the ventilation system. This is crucial in polluted cities. VGS are gigantic green lungs that filter airborne pollutants and improve air quality. Hence, VGS's dust and gas filtering is a sought-after feature. Respondents rate "bringing nature harmony" fifth. Flowers and greenery attract

birds, butterflies, and bees, creating a sense of natural harmony and a brighter, more relaxing environment. Building occupants may enjoy birds chirping in vegetated areas. Harmony in nature can refresh the mind and boost well-being. According to a landscape architect, Wong et al. (2010b) found that VGS can invigorate inhabitants in contact with vegetation. VGS can bring nature to towns lacking greenery.

Table 3 shows that construction professionals regard "VGS as one of the fire protection mediums," "raise the land price," and "decrease noise reflectivity" as the three least important attributes. As buildings have fire-fighting equipment and systems, VGS is not needed as a fire prevention medium. Most building professionals don't value VGS's ability to raise land prices. Most building experts don't prioritise VGS's sound reflectivity reduction. Not all VGS absorbs noise well. Wong et al., (2010a) found that VGS is a costly way to reduce noise. In the next step, Factor Analysis was used to gain greater insight into the desired attributes and main components.

Factor Analysis Results

Factor analysis was used to limit the many demanded features to certain factors (components) based on importance and reveals the most desired VGS attributes for future deployment. Data was pre-tested before factor analysis. Kaiser-Meyer-Olkin (KMO) sampling adequacy is 0.824, and Bartlett's Test of Sphericity has a Chi-Square of 1429.959, 276 degrees of freedom, and 0.000 significance level. This suggests factor analysis is possible with the data (Hair et al., 2010). Factor analysis using Principal Component Analysis extraction and Varimax with Kaiser Normalization rotation demonstrates that the twenty-four needed attributes can be grouped into six components. Table 4 shows that the components represent the set of items because the cumulative eigenvalue is > 67%. (Hair et al., 2010). The entries in Table 5 can be used to name each component. Hence, the six components expressing the desired attributes are energy and indoor air quality, VGS cost, VGS and property value, noise and fire danger reduction, VGS architectural characteristics and occupant health and well-being. Factor analysis

Barriers of VGS Application

Table 6 ranks barriers by highest mean value and the barriers hinder VGS implementation. Apart for "Vegetation might attract undesired insects and animals," all respondents ranked the barriers similarly. The majority of respondents believe VGS cost, including installation and life cycle cost, is the biggest obstacle to its adoption. Pérez et al. (2014) found that VGS usually has significant capital and life cycle costs for installation and operation and maintenance. Project size, VGS type, design complexity, local material availability, labour prices, and others affect VGS installation and life cycle costs

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(Šuklje et al., 2013). VGS uses imported plants to enhance the building's aesthetics, which raises the expense of installation and maintenance. To maximises VGS cost while maintaining system quality, these parameters should be examined together.

Regular maintenance is one of the main challenges hindering the installation of Vertical Greenery Systems (VGS), as building management must ensure the durability and performance of the plantations. Respondents also noted that the lack of technical information is a significant barrier, as VGS remains a relatively new technology in Malaysia. The absence of clear design and installation guidelines further complicates adoption. Overall, insufficient technical knowledge, plant dependency on weather, and the need for strict regulation of design variables are the most significant hurdles in implementing VGS.

Ways to Overcome the Challenges in VGS

Respondents identified several enablers to overcome challenges in VGS implementation, including selecting suitable growing media, reducing costs through design, installation, and maintenance efficiency, and choosing the right plant types. They also suggested locating VGS where sunlight exposure is optimal, developing self-sustaining and low-maintenance systems, and creating a standardized database for design and performance. Cost was highlighted as the most pressing issue, as high capital and maintenance expenses hinder adoption. Plant selection and growth medium were also viewed as critical since inappropriate choices could reduce durability and waste investment. Overall, lowering costs and ensuring proper plant growth conditions were seen as essential to improving VGS feasibility.

In addition, respondents emphasized that VGS placement should balance sunlight access and aesthetic appeal, noting that improper orientation could hinder plant health. Self-sustaining VGS designs were recommended to reduce maintenance costs, though they require higher technical expertise and resources. A standards database was seen as vital for guiding architects, engineers, and landscape designers in ensuring quality and consistency. Raising awareness among developers, professionals, and the public was also identified as crucial, as limited knowledge continues to slow adoption. Finally, government support and incentives, alongside these technical strategies, were considered key to promoting wider implementation of VGS in Malaysia.

CONCLUSION

Construction professionals and end-users value Vertical Greenery Systems (VGS) for their aesthetics, cost efficiency, thermal comfort, energy savings, and contribution to restoring urban green spaces, though their priorities differ in

emphasis. Despite its potential, VGS adoption in Malaysia is constrained by high costs, intensive maintenance, limited technical knowledge, and plant suitability challenges. Respondents suggested solutions such as lowering costs, selecting appropriate vegetation, optimising placement for sunlight, developing low-maintenance systems, and creating standardised guidelines. Overall, VGS can enhance sustainability, environmental quality, and occupant well-being, but greater public awareness, technical support, and stakeholder collaboration are essential to accelerate widespread adoption in Malaysian cities.

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Table 6: Barriers of the implementation of VGS in Malaysia

Barriers	Mean	S.E. of Mean	ANOVA (Between Groups, df = 1)	
			F	Sig
High life cycle cost i.e., operation and maintenance cost	3.74	0.042	0.018	0.892
High installation cost	3.73	0.044	1.239	0.268
Requires regular maintenance of the vegetation throughout its lifetime	3.67	0.050	0.386	0.536
Lack of technical information (e.g., watering system, support structure)	3.58	0.052	0.101	0.751
Lack of knowledge on the suitability of plants used	3.58	0.053	0.000	0.991
Plant growth is largely influenced by weather condition	3.55	0.057	0.037	0.849
Architects and engineers have to consider the regular control of all design variables as it involves plants which are living life form	3.55	0.053	0.276	0.601
Lack of public awareness on VGS	3.50	0.055	2.453	0.120
Vegetation can attract unwanted insects and animals	3.50	0.052	5.457	0.021*
Poor workmanship	3.41	0.059	2.883	0.092
Complex design	3.39	0.069	0.845	0.360
Complex construction method	3.39	0.066	0.497	0.482
Possibility of damaging the building due to aggressively growing vegetation	3.29	0.070	2.923	0.090
Lack of incentives for implementing VGS	3.10	0.070	1.982	0.162
Overgrowing of plants makes VGS looks wild and unattractive	3.03	0.075	0.005	0.942
No established standardization of VGS	2.89	0.079	2.853	0.094

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Table 3: Degree of importance and satisfaction of VGS demanded qualities.

Items of Demanded Qualities	Degree of Importance of Demanded Qualities		ANOVA (Between Groups, df = 1)		Degree of Satisfaction of Demanded Qualities		ANOVA (Between Groups, df = 1)		Absolute Difference Between Means	Grand Mean	Ranking (based on Grand Mean)
	Mean	S.E. of Mean	F	Sig.	Mean	S.E. of Mean	F	Sig.			
1. VGS helps in reducing the temperature and provides thermal comfort to occupants.	3.695	0.044	0.191	0.663	3.492	0.052	6.415	0.013*	0.203	3.593	2
2. VGS helps to improve air ventilation of the building.	3.441	0.063	0.085	0.771	3.085	0.068	1.240	0.268	0.356	3.263	12
3. VGS reduces energy consumption for air-conditioning.	3.636	0.055	0.407	0.525	3.178	0.061	0.123	0.727	0.458	3.407	7
4. VGS helps mitigating urban heat island (UHI) effects by reducing heat caused by UHI effects.	3.525	0.048	4.241	0.042*	3.297	0.054	0.033	0.857	0.229	3.411	6
5. VGS is able to absorb and filter dust and toxic gases, which helps to improve indoor air quality.	3.669	0.050	0.933	0.336	3.322	0.056	3.089	0.081	0.347	3.496	4
6. VGS helps to mitigate air pollution.	3.551	0.056	4.224	0.042*	3.017	0.066	0.555	0.458	0.534	3.284	11
7. VGS as a building's attractive architectural feature.	3.729	0.049	0.433	0.512	3.669	0.050	0.933	0.336	0.059	3.699	1
8. VGS hides displeasing building features (e.g. unevenly painted building wall).	3.398	0.066	5.249	0.024*	3.322	0.068	20.665	0.000**	0.076	3.360	8
9. VGS helps to hide service areas, mechanical equipment and storage access.	3.254	0.067	0.039	0.844	3.059	0.074	2.674	0.105	0.195	3.157	14
10. VGS absorbs and reduces noise disturbances.	3.102	0.061	2.239	0.137	2.644	0.062	0.475	0.492	0.458	2.873	21
11. 11. VGS is able to reduce sound reflectivity.	3.059	0.064	1.851	0.176	2.610	0.063	0.382	0.538	0.449	2.835	22

Items of Demanded Qualities	Degree of Importance of Demanded Qualities		ANOVA (Between Groups, df = 1)		Degree of Satisfaction of Demanded Qualities		ANOVA (Between Groups, df = 1)		Absolute Difference Between Means	Grand Mean	Ranking (based on Grand Mean)
	Mean	S.E. of Mean	F	Sig.	Mean	S.E. of Mean	F	Sig.			
12. VGS acts as fire prevention.	1.890	0.073	3.331	0.071	1.915	0.086	0.501	0.480	0.025	1.903	24
13. VGS enhances urban environmental conditions by bringing nature harmony.	3.517	0.055	1.655	0.201	3.415	0.057	2.863	0.093	0.102	3.466	5
14. VGS helps to improve human health and well-being.	3.085	0.075	3.059	0.083	2.881	0.068	0.499	0.481	0.203	2.983	18
15. VGS helps to reduce human stress level by providing sense of nature in urban area.	3.432	0.056	0.021	0.885	3.229	0.056	2.279	0.134	0.203	3.331	9
16. VGS helps to restore green areas particularly in urban areas.	3.678	0.048	0.008	0.928	3.475	0.057	0.633	0.428	0.203	3.576	3
17. VGS as habitats for flora and fauna within urban areas.	3.297	0.063	10.382	0.002*	3.119	0.070	9.339	0.003*	0.178	3.208	13
18. VGS helps in increasing property value due to environmental benefits provided.	3.203	0.071	1.221	0.271	2.949	0.072	2.292	0.133	0.254	3.076	15
19. VGS helps in increasing the land price as a result of improvement of greenery quality levels.	2.924	0.073	0.880	0.350	2.576	0.084	7.366	0.008*	0.347	2.750	23
20. VGS contributes to sustainability features of a building.	3.449	0.068	7.188	0.008*	3.212	0.061	12.323	0.001**	0.237	3.331	10
21. Installation cost of VGS has to be lowered.	3.695	0.049	0.421	0.518	2.398	0.079	5.108	0.026*	1.297	3.047	16
22. Life cycle cost i.e. operation and maintenance cost of VGS has to be lowered.	3.754	0.047	0.081	0.776	2.271	0.087	4.679	0.033*	1.483	3.013	17
23. VGS requires regular maintenance to preserve good condition and avoid damages.	3.754	0.047	0.081	0.776	2.161	0.091	3.338	0.070	1.593	2.958	19
24. Vegetation used for VGS requires careful selection to ensure high durability i.e. long lifespan.	3.686	0.051	0.325	0.570	2.110	0.095	5.978	0.016*	1.576	2.898	20
Overall Mean	**3.393**				**2.934**				**0.459**	**3.593**	

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Table 4: Cumulative eigenvalues and loadings

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.413	30.886	30.886	7.413	30.886	30.886	3.841	16.004	16.004
2	2.631	10.964	41.850	2.631	10.964	41.850	3.486	14.524	30.528
3	1.880	7.834	49.684	1.880	7.834	49.684	2.803	11.678	42.206
4	1.707	7.112	56.796	1.707	7.112	56.796	2.164	9.015	51.221
5	1.325	5.519	62.315	1.325	5.519	62.315	1.922	8.008	59.230
6	1.131	4.710	67.026	1.131	4.710	67.026	1.871	7.796	67.026
7	0.899	3.746	70.771						
8	0.819	3.411	74.182						
9	0.766	3.192	77.374						
10	0.689	2.872	80.246						
11	0.609	2.536	82.783						
12	0.565	2.352	85.135						
13	0.490	2.044	87.179						
14	0.460	1.918	89.096						
15	0.418	1.743	90.839						
16	0.399	1.663	92.502						
17	0.361	1.506	94.008						
18	0.301	1.256	95.263						
19	0.263	1.096	96.360						
20	0.227	0.947	97.306						
21	0.204	0.851	98.158						
22	0.198	0.827	98.985						
23	0.138	0.577	99.562						
24	0.105	0.438	100.000						

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Table 5: Rotated components of demanded qualities of VGS

Items of Demanded Qualities	Component					
	1	2	3	4	5	6
2. VGS helps to improve air ventilation of the building.	0.763					
1. VGS helps in reducing the temperature and provides thermal comfort to occupants.	0.760					
3. VGS reduces energy consumption for air-conditioning.	0.756					
4. VGS helps mitigating urban heat island (UHI) effects by reducing heat caused by UHI effects.	0.686					
5. VGS is able to absorb and filter dust and toxic gases, which helps to improve indoor air quality.	0.664					
6. VGS helps to mitigate air pollution.	0.566					
22. Life cycle cost i.e. operation and maintenance cost of VGS has to be lower.		0.867				
21. Installation cost of VGS has to be lower.		0.863				
23. VGS requires regular maintenance to preserve good condition and avoid damages.		0.780				
24. Vegetation used for VGS requires careful selection to ensure high durability i.e. long lifespan.		0.623				
13. VGS enhances urban environmental conditions by bringing nature harmony.		0.450				
18. VGS helps in increasing property value due to environmental benefits provided.			0.830			
19. VGS helps in increasing the land price as a result of the improvement of greenery quality levels.			0.800			
20. VGS contributes to sustainability features of a building.			0.662			
17. VGS as habitats for flora and fauna within urban areas.			0.623			
16. VGS helps to restore green areas particularly in urban areas.			0.447			
11. VGS is able to reduce sound reflectivity.				0.889		
10. VGS absorbs and reduces noise disturbances.				0.874		
12. VGS acts as fire prevention.				0.525		
9. VGS helps to hide service areas, mechanical equipment, and storage access.					0.808	
8. VGS hides displeasing building features (e.g. unevenly painted building wall).					0.773	
7. VGS as a building's attractive architectural feature.					0.547	
14. VGS helps to improve human health and well-being.						0.769
15. VGS helps to reduce human stress levels by providing a sense of nature in the urban area.						0.751

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INTEGRATING URBAN DESIGN PRINCIPLES FOR SUSTAINABLE URBAN PARKS: INSIGHTS FROM USER EXPERIENCE IN GURNEY BAY AND PENANG MUNICIPAL PARK, MALAYSIA

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Abstract

Sustainable urban parks are vital components of resilient and liveable cities, providing environmental, social, and economic benefits. Ensuring their long-term relevance requires design principles that prioritise usability, inclusivity, and ecological sustainability. This study examines urban design principles that contribute to sustainable urban parks, with specific reference to Gurney Bay Park and Penang Municipal Park in Penang, Malaysia. Applying a quantitative approach, a questionnaire survey of 102 respondents was conducted to investigate the relationship between urban design principles and sustainability outcomes. The results reveal six key principles that shape sustainable park development: accessibility, safety, social interaction, aesthetic quality, resilience, and economic viability. Despite these guiding principles, the findings highlight persistent challenges in accessibility, including inadequate transportation connections and limited user satisfaction with available amenities. These shortcomings undermine the parks' potential to serve as inclusive and multifunctional community spaces. The study contributes empirical evidence from the Malaysian context to the discourse on sustainable urban design, offering practical insights for urban planners and policymakers. By embedding sustainability principles into park design and management, cities can enhance user experiences, promote healthier lifestyles, and advance broader urban resilience goals in line with the Penang2030 vision.

Keywords: Urban design principles, sustainable urban parks, accessibility, community engagement, resilient city, Penang 2030

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INTRODUCTION

Urban parks are integral to the development of healthy and sustainable urban environments with studies showing that well-designed parks contribute significantly to physical, mental, and social health (Adibhesami, 2024). These parks act as vital sanctuaries within cities, offering aesthetic value, recreational opportunities, and environmental benefits such as cleaner air, while also fostering social interaction and enhancing community well-being (Pukowiec, 2022; Zhao, Aziz & Ujang, 2024). Despite their many benefits, urban parks risk underutilization as social media and online entertainment draw people indoors. With increasing screen time and busy daily routines, opportunities for community engagement and mental health benefits from nature are reduced (Handoyotomo et al., 2018). Hence, finding ways to revitalize interest in these urban parks is critical for fostering community bonds and enhancing the overall quality of urban life.

While numerous studies have highlighted the benefits of urban parks (Zhang & Li, 2024; Zhang et al., 2024), most studies addressing Malaysian parks have concentrated on issues of provision, safety, or accessibility (Zhao, Aziz, & Ujang, 2024). Few have examined the synergistic relationship between urban design principles and sustainability outcomes in the context of local development visions such as Penang 2030. To address this gap, this study pursues two core objectives: (i) to identify essential urban design principles, and (ii) to explore their effective integration in the creation of sustainable urban parks. Gurney Bay and Penang Municipal Park are examined as case studies, providing insights into how urban park design can be optimized to meet community needs and enhance environmental resilience in support of Penang's green development aspirations.

LITERATURE REVIEW

Urban parks are essential communal space that significantly enhance quality of life by providing inclusive recreational spaces while strengthening community identity and contributing to environmental balance. Recent studies highlight their multifaceted value: Zhang et al. (2024) and Yang (2024) emphasize the role of urban parks in fostering social interactions, offering diverse recreational opportunities, maintaining urban sustainability and enhancing citizen wellbeing. Nevertheless, their effectiveness is often constrained by challenges such as safety concerns, social exclusion, inequities in access, and inadequate planning or provision of open spaces (Zhao, Aziz, & Ujang, 2024; Zhang et al., 2024).

To be effective, the urban park design must respond to contextual factors such as population density, demographic diversity, and equitable accessibility, ensuring spaces are inclusive and responsive to user needs. In Malaysia, the Department of Town and Country Planning (2005) articulate guiding principles for urban parks under the *Total Planning and Development*

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Doctrine, which stresses the interconnected relationship between people, the Creator, one another, and the environment. These principles prioritize accessibility, safety, aesthetics, and sustainability which complemented Richard Rogers' *Towards an Urban Renaissance* (1999) that identifies three critical forces shaping urban parks—technological innovation, ecological pressures, and social transformation—underscoring the importance of adaptive, resilient, and sustainable approaches in contemporary park planning and design.

Key Urban Design Principles in Urban Park

Connectivity and Accessibility

Parks should be easy to reach and navigate by walking, cycling, and public transport to maximize use and equity. Kevin Lynch (1960) emphasized that clear, legible urban form — particularly well-defined paths, edges, nodes and landmarks — is essential for seamless integration of open spaces into the city. ADA-compliant features ensure inclusivity for all users. Walking- and cycling-friendly connections and high-quality transit access strongly improve park accessibility and use (Zhang et al., 2022), while park networks that are physically and perceptually connected encourage broader patterns of use across communities (Li, Dali & Nordin, 2023). While, inaccessible or poorly designed paths and entrances create real exclusionary effects for people with disabilities, reducing independence and quality of life (Kapsalis, Jaeger & Hale, 2024). Thus, designing clear pathways, protected bike lanes, frequent transit stops near park entrances, and ADA-compliant entrances, surfaces, signage, and facilities support both connectivity and social inclusion, helping parks to serve diverse populations equitably (De la Barrera et al., 2023).

Social Interaction and Inclusivity

As urban parks function as social catalysts that foster engagement across diverse communities, it is crucial to design spaces that encourage interaction (Gehl, 1987). Physical, social, and environmental elements of parks—such as seating areas, community gardens, and inclusive facilities create welcoming environments for all, including marginalized groups (Cui, Maliki, & Wang, 2024). Parks that are designed with involvement from people with disabilities, universal access features (ramps, accessible walkways), and varied amenities are crucial so that all users feel able to interact and belong (Selanon, Puggioni & Dejnirattisai, 2024).

Safety and Comfort

A safe and comfortable park enhances the overall user experience. Well-lit pathways, clear sightlines, and natural surveillance improve perceived security. Gehl (1987) emphasized the importance of human-centered design, incorporating

shaded areas, ample seating, and weather protection to create an inviting and inclusive space for all. Recent studies reinforce these principles, showing that lighting designs that promote legibility and perceived safety improve how people feel in parks at night (Lis et al., 2023), while maintenance, planting design, and scenic vistas are significant in fostering perceived safety in neighbourhood parks (Kurzi et al., 2024). Comfort, especially thermal comfort (shade, water features, visible environmental amenities) also strongly influences how long users stay and how frequently they visit (Chan, Chau, & Leung, 2017; Niu et al., 2022).

Aesthetic Quality

Visually appealing parks enhance urban landscapes. Landry (2000) advocated for inspiring designs that stimulate creativity and cultural vibrancy. Thoughtful landscaping, art, water features, and natural materials create harmony, attracting visitors and encouraging cultural activities. Chen, Marzbali and Abdullah (2024) emphasized that landscape attractiveness in urban parks significantly strengthens place identity and fosters social interaction, reinforcing the importance of aesthetic and inspiring park designs.

Resilience and Adaptability

Parks must continuously adapt to environmental and social changes to remain relevant. Geddes (1915) emphasized the importance of sustainable and flexible design in urban spaces, highlighting the need for green infrastructure that supports both ecological processes and human well-being. Recent studies further validate these ideas: Sabri and Ponrahono (2024) demonstrated that small urban parks can play a crucial role in enhancing urban resilience to climate change when assessed against clear sustainability criteria and indicators. Abdul Latip et al. (2023) indicate that visitor awareness and satisfaction are closely tied to the presence of sustainable design features, underscoring the importance of adaptability in urban park management. Well-designed urban green spaces not only support environmental sustainability but also promote social cohesion and economic vibrancy (Mohd Nor & Sahrir, 2024).

Sustainability of Urban Park

The sustainability of an urban park can be assessed by evaluating user satisfaction with activities that foster social interaction—activities that are themselves underpinned by high-quality design elements such as accessible pathways, visual enclosure, seating, and maintenance. Zyed et al. (2025) found that inadequate sidewalk conditions, poor lighting, and limited social surveillance during elementary school commutes in Fukuoka heightened children's perceptions of environmental risk, underscoring how design deficiencies can undermine safety and well-being—even within routine travel activities. This suggests that in urban

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park contexts, the absence of well-designed elements may similarly impede safe, social engagement and long-term sustainability of the space. Achieving sustainability requires a multi-faceted approach that integrates strategies such as green design, resource efficiency, and inclusive community engagement. By aligning park design with sustainability goals, cities can create spaces that are both functional and resilient, contributing to the broader vision of a sustainable urban future.

Economic sustainability of urban parks lies in their ability to generate long-term value while minimizing costs. Parks contribute to local economies by attracting tourism, supporting businesses, and hosting events such as markets and festivals. They also increase property values and municipal revenues, while small-scale commercial activities like cafés or kiosks contribute to the park upkeep. Sustainable practices—such as native planting and energy-efficient infrastructure—reduce maintenance costs, making parks more financially resilient (Mohd Nor & Sahrir, 2024; Sabri & Ponrahono, 2024).

Social sustainability in urban parks emphasizes inclusivity, equity, and community engagement. Parks should be accessible to all, with amenities that cater to diverse groups, including children, the elderly, people with disabilities, and various cultural communities. Public participation in park design and management ensures spaces reflect community needs, fostering ownership and pride. By offering recreational opportunities, cultural events, educational programs, and inclusive playgrounds, parks strengthen social bonds, support physical and mental well-being, and enhance social cohesion. Zhang et al. (2025) suggest that equitable access across different travel modes, coupled with streetscape quality, is key to ensuring park use among marginalized and mobility-limited populations.

Environmental sustainability is central to urban park design, as parks help counter the negative impacts of urbanization. Green infrastructure such as permeable surfaces, stormwater systems, and floodable parks reduces runoff, prevents flooding, and improves water quality (Martín Muñoz et al., 2024). Using native plants not only is cost effective, but also supports biodiversity, lowers irrigation needs, and increases carbon storage, strengthening climate resilience (Rehman et al., 2025). By integrating these features, sustainable parks enhance ecological health, support resilience, and deliver lasting environmental benefits to cities.

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RESEARCH METHODOLOGY

This study examines the sustainability of Penang Municipal Park and Gurney Bay Park by evaluating the integration of urban design principles through user experience. The assessment focuses on two key dimensions: **accessibility** and **social engagement**. Accessibility, reflects how easily the parks can be reached and navigated by diverse groups, ensuring equity and encouraging sustainable modes of transport. Social engagement, on the other hand, reflects the parks' capacity to foster community interaction, inclusivity, and vibrant social activities, positioning them as hubs for leisure and cultural exchange. Together, these dimensions provide a holistic measure of how urban parks contribute to social, environmental, and economic sustainability. Situated merely 4.4 kilometres apart, these parks serve a critical function for Penang's urban population of 722,384, providing vital green spaces for recreation, exercise, and social interaction.

Quantitative technique is adopted to evaluate the integration of urban design principles in the selected urban parks. A structured questionnaire survey was distributed via Google Forms to the public, specifically targeting park users of the selected case study, as park user constitute the most knowledgeable and directly affected group, thereby ensuring that the data reflects informed perspectives grounded in actual experiences. This sampling strategy is adopted as depth and relevance of responses are prioritised over statistical generalisation which is particularly valuable for this exploratory and context-specific research. Although pose certain limitations—such as the exclusion of individuals with limited internet access or digital proficiency, the use of online distribution through Google Forms further enhanced efficiency, cost-effectiveness, and accessibility, enabling the study to reach a diverse pool of respondents within a relatively short time frame. To enhance representativeness, the survey is disseminated through local community groups, social media platforms, and university networks, capturing diverse user perspectives, including families, youth, elderly individuals, and special needs users. Data collection was conducted over a one-month period, yielding 102 valid responses. This final sample is considered sufficient for correlation analysis; based on conventional power estimates ($\alpha = 0.05$, power = 0.80), it provides adequate sensitivity to detect medium effect sizes ($r \approx 0.30$) (Cohen, 1988; Field, 2018).

ANALYSIS AND FINDINGS

Respondents Profile

Majority of the park users (respondents) are young adults aged 18 to 34, aligning with Erik Erikson's stage of young adulthood, which emphasizes social engagement and physical activity (Erikson, 2003). Most youth are frequent park users, engaging primarily in relaxation and nature-seeking behaviours, with

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substantial segments visiting parks once or twice per week (Yao, Yun, Zhang, Meng & Mu, 2022). At Gurney Bay Park, 96.6% of visitors fall within this age group, while Penang Municipal Park records 79.5%. This highlights the appeal of both parks to young adults. Additionally, more females frequent both parks, underscoring the need for safe, inclusive, and well-equipped urban spaces.

Accessibility

Accessibility is a key element of urban design emphasized in this study, particularly in relation to transportation modes used by park visitors. **Table 1** reveals that only 1.7% of respondents use public transportation, such as buses, to access Gurney Bay Park, while the other 98.3% relied on private vehicles, that include cars and motorcycles. Similarly, respondents visiting Penang Municipal Park also predominantly uses private vehicles due to the limited public transport options in the area.

Table 1: Modes of Transport used by Respondents

Mode of Transport	Gurney Bay Park		Penang Municipal Park	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Public Bus	1	1.7%	0	0.0%
Motorcycle	9	15.5%	10	22.7%
Taxi	0	0.0%	0	0.0%
E-Hailing	0	0.0%	0	0.0%
Own Car	48	82.8%	34	77.3%
Total	**58**	**100.0%**	**44**	**100.0%**

Source: Author, 2025

This strong dependency on private-owned transportation highlights a significant challenge in making these parks sustainable, as poor transit connectivity limits accessibility, increases carbon emissions, and restricts inclusivity. Enhancing public transport links, such as integrating public transportation routes or providing a variety of last-mile connectivity solutions, could encourage broader community access, reduce environmental impact, and contribute to the long-term sustainability of these urban parks.

Social Engagement

Respondents of this study generally find the social and physical activities available at Gurney Bay Park enjoyable, unique, and motivating, though they express lower agreement regarding the challenge level of activities, with safety receiving a mean score of only 3.7, indicating a need for improvement. Similarly, respondents at Penang Municipal Park rate their activity satisfaction highly, with a mean value of 5.02 for enjoyment and a higher score of 3.84 for challenging

activities, likely due to the presence of hiking trails. Based on overall satisfaction ratings, the sustainability of both parks is moderate, with respondents rating their satisfaction between 2 and 6. However, the higher mean values at Penang Municipal Park suggest that it demonstrates a more substantial level of sustainability than Gurney Bay Park, highlighting the importance of diverse and engaging activities in promoting long-term park usage and sustainability. The sustainability of an urban park can be evaluated by looking at user satisfaction with activities that encourage social interaction, which are supported by high-quality design elements. The Spearman's rho correlation analysis in **Table 2** and **Table 3** highlights significant relationships between design elements and user satisfaction factors, including uniqueness, challenge, safety, motivation, and enjoyment.

In Gurney Bay Park (Table 2), pathways and entrances demonstrate a moderate positive correlation with both perceived safety and user motivation, underscoring the importance of connectivity and ease of access in shaping visitor confidence and engagement. Open spaces and seating areas also show positive but weaker associations with experience uniqueness and enjoyment, indicating that while physical amenities contribute to comfort and leisure, they alone are insufficient to significantly elevate the overall park experience. By comparison, the strongest influences on user perception stem from the provision of green infrastructure in the park and the park's integration with surrounding urban form. Spatial integration shows the highest overall associations, particularly with uniqueness ($\rho = 0.521$, $p < 0.001$) and motivation ($\rho = 0.486$, $p < 0.001$). These findings highlight that dynamic qualities such as sustainability and contextual integration exert a far greater impact on user satisfaction and engagement than static amenities, reinforcing the idea that urban parks must be designed as integrated, sustainable spaces to achieve long-term social and environmental value.

Table 2: Correlation Between the Activity's Satisfaction and Urban Design Principles at Gurney Bay

	Urban Design Principles		Activity's Satisfaction				
			Experience Uniqueness	**Challenging**	**Safety**	**Motivated**	**Fun**
Spearman's r	Pathways and entrances connecting park to nearby areas	Correlation Coefficient	0.304	0.152	0.442	0.404	0.284
		Sig. (2-tailed)	0.021	0.256	<0.001	0.002	0.031
		N	58	58	58	58	58
	Adequate open spaces and seating areas	Correlation Coefficient	0.278	0.057	0.217	0.084	0.261
		Sig. (2-tailed)	0.037	0.674	0.105	0.536	0.050
		N	57	57	57	57	57
	Landscaping and public art reflect	Correlation Coefficient	0.253	0.156	0.308	0.382	0.216
		Sig. (2-tailed)	0.055	0.242	0.019	0.003	0.103

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	Urban Design Principles		Activity's Satisfaction				
			Experience Uniqueness	Challenging	Safety	Motivated	Fun
ho	local history and culture	N	58	58	58	58	58
	Cafe spaces, market areas, and local vendor within the park	Correlation Coefficient	0.288	0.357	0.479	0.346	0.321
		Sig. (2-tailed)	0.028	0.006	<0.001	0.008	0.014
		N	58	58	58	58	58
	Provision of green infrastructure in the park	Correlation Coefficient	0.343	0.446	0.484	0.470	0.493
		Sig. (2-tailed)	0.008	<0.001	<0.001	<0.001	<0.001
		N	58	58	58	58	58
	Integration of the park and surrounding buildings and spaces	Correlation Coefficient	0.521	0.431	0.496	0.486	0.510
		Sig. (2-tailed)	<0.001	<0.001	<0.001	<0.001	<0.001
		N	58	58	58	58	58

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Source: Author, 2025

While user satisfaction at Penang Municipal Park, is strongly linked to elements that enhance cultural identity, safety, and social vibrancy, as shown in Table 3. Landscaping and public art reflecting local history and culture show strong correlations with multiple dimensions of experience—uniqueness, motivation, and fun—highlighting the importance of cultural expression in fostering meaningful engagement. Similarly, café spaces, market areas, and local vendors demonstrate high associations with safety and motivation, indicating that vibrant social and commercial activities strengthen the park's role as a safe and lively community hub. Pathways and entrances also significantly contribute to safety and motivation, underlining the importance of accessibility. In addition, safety perceptions themselves are positively associated with, emphasizing that secure environments are crucial for active park use. While green infrastructure in the park shows moderate correlations with uniqueness and fun, its impact is less pronounced compared to cultural and social features. Overall, the findings suggest that Penang Municipal Park's sustainability is most strongly driven by cultural identity, safety, and socially engaging amenities rather than static physical features alone.

Table 3: Correlation Between the Activity's Satisfaction and Urban Design Principles at Penang Municipal Parks

	Urban Design Principles		Activity's Satisfaction				
			Experience Uniqueness	**Challenging**	**Safety**	**Motivated**	**Fun**
Spearman's rho	Pathways and entrances connecting park to nearby areas	Correlation Coefficient	0.342	0.083	0.458	0.361	0.352
		Sig. (2-tailed)	0.023	0.594	0.002	0.016	0.019
		N	44	44	44	44	44
	Adequate open spaces and seating areas	Correlation Coefficient	0.188	0.244	0.404	0.341	0.126
		Sig. (2-tailed)	0.222	0.111	0.007	0.023	0.417
		N	44	44	44	44	44
	Landscaping and public art reflect local history and culture	Correlation Coefficient	0.393	0.296	0.600	0.585	0.510
		Sig. (2-tailed)	0.008	0.051	<0.001	<0.001	<0.001
		N	44	44	44	44	44
	Cafe spaces, market areas, and local vendor within the park	Correlation Coefficient	0.417	0.383	0.575	0.472	0.390
		Sig. (2-tailed)	0.005	0.010	<0.001	0.001	0.009
		N	44	44	44	44	44
	Provision of green infrastructure in the park	Correlation Coefficient	0.312	0.261	0.573	0.351	0.352
		Sig. (2-tailed)	0.040	0.087	<0.001	0.020	0.019
		N	44	44	44	44	44
	Integration of the park and surrounding buildings and spaces	Correlation Coefficient	0.188	0.225	0.403	0.407	0.239
		Sig. (2-tailed)	0.223	0.143	0.007	0.006	0.118
		N	44	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Source: Author, 2025

Accessibility, social interaction, and safety are critical components of sustainability, as illustrated by the well-connected spaces of Penang Municipal Park and the aesthetic appeal of Gurney Bay Park. Correlation analysis indicates that pathways, café areas, and landscaping are vital for user satisfaction. To improve sustainability, both parks need better public transport access, enhanced safety measures, and versatile multifunctional spaces. The comparative analysis between these two parks reveals distinct factors shaping user satisfaction between Gurney Bay Park and Penang Municipal Park.

At Gurney Bay, accessibility features such as pathways and entrances exhibit moderate correlations with safety ($\rho = 0.442$, $p < 0.001$) and motivation ($\rho = 0.404$, $p = 0.002$), while open spaces and seating areas enhance perceptions of uniqueness ($\rho = 0.278$, $p = 0.037$) and enjoyment ($\rho = 0.261$, $p = 0.050$).

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These findings underscore the importance of physical design in establishing baseline usability and comfort. Conversely, Penang Municipal Park demonstrates stronger associations with cultural and social dimensions, where landscaping and public art significantly influence uniqueness ($\rho = 0.393$, $p = 0.008$), motivation ($\rho = 0.585$, $p < 0.001$), and fun ($\rho = 0.510$, $p < 0.001$). Similarly, café spaces and local vendors correlate with safety ($\rho = 0.575$, $p < 0.001$) and motivation ($\rho = 0.472$, $p = 0.001$), highlighting the role of social vibrancy and local identity in driving satisfaction. Overall, safety consistently emerges as a determinant of motivation across both parks, aligning with studies that emphasize security as a prerequisite for active and prolonged park use (Zhang et al., 2024). However, while Gurney Bay's appeal is largely functional, rooted in accessibility and spatial openness, Penang Municipal Park demonstrates how socio-cultural features transform parks into vibrant community destinations. This contrast suggests that sustainable urban park design should balance physical accessibility with cultural and social activation to maximize user engagement and long-term urban resilience.

DISCUSSION

This study highlights the importance of integrating urban design principles to enhance the sustainability of urban parks. By analysing user experiences at Gurney Bay Park and Penang Municipal Park, the findings provide valuable insights into how well-designed parks can serve as inclusive, multifunctional spaces that foster community engagement. While both parks serve important recreational roles, their differing physical designs and layouts critically influence user experiences, revealing strengths in accessibility and aesthetics but also weaknesses in cultural representation and functional sustainability. Penang Municipal Park is characterized by its expansive green spaces and extensive pathway networks, which support accessibility, daily recreation, and integration with surrounding neighbourhoods. While Gurney Bay Park emphasizes waterfront aesthetics, vibrant event spaces, and leisure-oriented design, attracting social gatherings and tourists but revealing gaps in cultural heritage integration and long-term sustainability. These variations demonstrate how physical layout influences user preferences, usage patterns, and overall park performance.

Situating these findings within international contexts, urban parks in cities such as Singapore, Seoul, and Copenhagen exemplify best practices by integrating multifunctionality, cultural identity, and ecological resilience (Angelia et al., 2023; Kim & Jung, 2019). Likewise, European models underscore inclusive design, accessibility through public transport, and diverse amenities that cater to varied demographic groups, reinforcing the centrality of user-centred planning (Kabisch et al., 2022). In comparison, Penang's parks could benefit from embedding stronger cultural narratives, incorporating climate-adaptive

infrastructure, and strengthening integration with urban mobility systems. These lessons highlight the need for Penang to move beyond aesthetic enhancements toward holistic design strategies that align with global sustainability agendas while retaining local identity. Penang Municipal Park benefits from well-connected pathways and open spaces, while Gurney Bay Park excels in aesthetics and social interaction but falls short in historical and cultural integration. Correlation analysis further indicates that factors such as pathway accessibility and café spaces positively influence user satisfaction, pointing to the importance of carefully planned amenities in sustaining long-term engagement. From a policy and planning perspective, the study emphasizes the importance of community engagement, safety, and essential amenities in creating attractive and functional urban parks. Recommendations include hosting regular community events, integrating cafés and local vendors, and improving shaded seating areas to enhance comfort and usability. Conversely, the neglect of urban design principles—such as inadequate maintenance, limited accessibility, and uninspiring design—risks creating underutilized and unsustainable spaces. Finally, while this study provides valuable insights for urban planners and policymakers in Penang, certain limitations must be acknowledged. The contextual challenges during data collection constrain generalizability. Future research should build on these findings through larger-scale studies and advanced analytical approaches to better capture causal relationships and multidimensional park dynamics. Nonetheless, the research contributes to the broader agenda of achieving sustainable, inclusive urban parks in alignment with the Penang 2030 vision.

CONCLUSION

In conclusion, this study emphasizes the significance of integrating comprehensive urban design principles to ensure the sustainability of urban parks, with specific insights drawn from Gurney Bay Park and Penang Municipal Park. Findings demonstrate that ***Connectivity and Accessibility***, ***Social Interaction and Inclusivity,*** and ***Safety and Comfort***—as pivotal to park sustainability. Addressing identified gaps—such as the need for shaded seating, café spaces, and improved connectivity—can transform these parks into multifunctional hubs that respond to diverse community needs while advancing the vision of Penang 2030: *"A family-focused green and smart city that inspires the nation."* Beyond practical recommendations, this study contributes to the academic field of urban design and planning by empirically linking user experience with design attributes, offering evidence-based insights into how specific spatial elements influence social interaction, accessibility, and long-term sustainability. Methodologically, the use of correlation analysis provides a valuable starting point for examining these relationships, while also highlighting

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the necessity of adopting more advanced analytical tools, such as regression or structural equation modelling (SEM), to capture causality and multidimensional dynamics. By situating local findings within broader global discourses on sustainable urbanism, this study enriches ongoing debates on how parks can function as key instruments of urban resilience, social equity, and cultural expression, ultimately positioning Penang's parks as potential models for sustainable urban development in Southeast Asia.

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ETHICAL STATEMENT

This study was carried out in compliance with the research ethics regulations of Universiti Malaya. Prior to participation, all respondents were fully briefed on the purpose of the study and provided voluntary informed consent. Strict measures were observed to ensure anonymity and confidentiality throughout the research process.

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INVESTMENT IN SUSTAINABILITY UNIVERSITY GREEN CAMPUS PROJECTS: THE CASE OF UNIVERSITI MALAYA, MALAYSIA

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Abstract

Sustainability has become a central priority in higher education, with universities worldwide investing in initiatives to reduce environmental impact and promote long-term responsibility. Despite this trend, there remains limited comparative research on Universiti Malaya's (UM) sustainability practices concerning established green campuses. This study addresses this gap by examining UM's sustainability investments and identifying areas for improvement. A quantitative approach was adopted, involving a questionnaire survey of 361 UM employees. Data were analysed using the Relative Importance Index (RII) to rank the significance of sustainability initiatives. The findings reveal waste management and external stakeholder collaborations are the most prominent investment areas. At the same time, other initiatives are perceived at medium to high levels of importance, indicating a solid foundation for UM's sustainability efforts. The study recommends strengthening institutional strategies by benchmarking UM's practices against international green campus models. The results contribute to advancing UM's environmental responsibility and aligning its efforts with broader sustainability goals.

Keywords: Sustainable investment, Universiti Malaya, university green campuses

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INTRODUCTION

Sustainability has evolved into a paramount pillar of global discourse, advocating for the seamless integration of economic progress, societal equity, and environmental stewardship (Al-Sakkaf et al., 2021; Fallah Shayan et al., 2022; Mohd Muhiddin et al., 2023). One of the cornerstones in the global movement toward sustainability is the proliferation of award-winning green campuses worldwide. These campuses represent the pinnacle of environmental consciousness and exemplary sustainable practices. Renowned institutions such as Arizona State University, University of California, Irvine, and the University of Nottingham have been recognised for their exceptional efforts in creating sustainable campuses. These campuses serve as global benchmarks, showcasing innovative approaches to sustainability by integrating renewable energy sources, implementing green technologies, and adopting eco-friendly practices across their operations (Alhazemi, 2024Mohd-Rahim et al., 2018).

This surge in interest in sustainability aligns with Universiti Malaya's (UM) proactive steps toward fostering sustainability within its academic community. UM has been increasingly focused on integrating sustainable practices into its educational programmes, campus operations, and research initiatives (Universiti Malaya, 2021, 2024). However, while UM's dedication to sustainability is commendable, a noticeable disparity remains concerning routine maintenance considerations. While UM has placed considerable emphasis on external landscape initiatives, such as green spaces and energy-efficient buildings (Yuvarani & Nurulaini, 2019), the focus on internal factors vital for long-term sustainability may have inadvertently taken a back seat. In contrast to globally recognised green campuses, where sustainability is a part of daily operations and standard maintenance practices, UM appears to lack the same level of comprehensive integration of sustainability principles into its routine operational practices. UM also lacks innovative and varied investing techniques.

Within the broader spectrum of sustainability initiatives, investment financial management holds a pivotal position, intricately woven into the fabric of responsible practices (Boffo & Patalano, 2020). Its incorporation into sustainability initiatives signifies a shift towards comprehensive and conscientious approaches. Going beyond monetary concerns, this facet of investment within sustainability endeavours involves strategic resource allocation, ensuring economic feasibility and synchronisation with environmental stewardship and societal welfare (Mensah, 2019). Globally recognised higher education institutions have established a precedent by adeptly integrating financial management into their sustainability endeavours, highlighting the significance of structured investment initiatives that bolster sustainability goals. This amalgamation of investment within sustainability signifies the necessity for an integrated approach, intertwining financial considerations with environmental

impact, societal well-being, and governance paradigms, aiming for astute resource allocation to secure economic returns (Onuselogu & Shahzad, 2023; Salleh et al., 2022).

Disappointingly, despite notable strides in sustainability initiatives, the effective integration of investment within UM's sustainability efforts remains challenging. A substantial research gap regarding aligning UM's investment with its sustainability goals needs specific attention and investigation. Therefore, this research compares the sustainability investment of green university campuses and UM. The study involves an extensive review of the university's sustainable investment initiatives, an evaluation of UM's current initiatives, and the creation of cohesive initiatives aligning UM's investment decisions with sustainability objectives. The ultimate goal is to strengthen UM's commitment to sustainability and to pioneer the harmonisation of financial prudence with environmental stewardship, fostering a thriving and enduringly sustainable campus (Qi et al., 2023).

INVESTMENT INITIATIVES FOR SUSTAINABILITY AT REPRESENTATIVE UNIVERSITY

Investment initiatives for green campuses involve financial strategies that support sustainability projects within educational institutions. These include funding environmentally beneficial initiatives, waste management, renewable energy, and technologies to reduce environmental impact. The goal is to make financial decisions that promote sustainability while protecting the environment and generating profits (Bhattacharyya, 2020; Khoshbakht et al., 2019).

A global review of green campuses shows universities implementing various investment initiatives to achieve sustainability. These initiatives cover renewable energy investments, partnerships and collaborations, socially responsible investments, energy efficiency improvements, green infrastructure development, waste management initiatives, sustainable transportation, and continuous monitoring and improvement. Table 1 summarises the investment initiatives for sustainability at a representative university green campus. Based on the results in Table 1, this study provides a reference for optimising the investment in green campuses at UM.

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Table 1: Investment initiatives for sustainability implemented by university green campuses

Initiative	Representative Universities	Key Outcomes	Citations
Renewable Energy	Nottingham, Toronto, California, Imperial, Emory, Bryant, Lancaster	Up to 40% carbon reduction; solar, wind, geothermal adoption; PV-leaf tech (+10% efficiency); electricity savings >USD 80,000; 50% reduction in heating emissions.	University of Nottingham (2024); University of Toronto (2024); University of California (2024); Bryony (2023); Gana (2020); Kimmell et al. (2020); Ian (2022)
Energy Efficiency	California, British Columbia, MIT, Washington	LEED-certified buildings (31 Gold+); USD 50M utility grants; high-efficiency retrofits; CO_2 reduction >2,300 tonnes; multi-million-dollar savings.	University of California (2023); University of British Columbia (2019); MIT (2024); University of Washington (2024)
Green Infrastructure	Arizona State, Stanford, MIT, Pennsylvania, Nottingham	Rain gardens, permeable pavements, stormwater systems; reduced flood risk; water conservation; BREEAM Excellent/LEED ratings.	Arizona State University (2020); Bea et al. (2019); MIT (2023); Penn (2024); University of Nottingham (2024)
Waste Management	Arizona State, Auckland, Massey, Sheffield	72% recycling rate; >2,000 tonnes diverted; composting/reuse; landfill waste reduced by 10%; annual savings >£125,000.	Arizona State University (2013); Moezzi & Janda (2014); University of Auckland (2024); Kelly et al. (2006); Zhang et al. (2011)
Sustainable Transportation	UC Davis, Stanford	EV and low-carbon transport research; hybrid/electric buses; >2.7M rides; cycling/ride-sharing culture.	University of California (2021); Stanford University (2023)

Based on this literature, renewable energy adoption has become a significant focus, with institutions such as Nottingham, Toronto, and California achieving up to 40% reductions in carbon emissions through solar, wind, and geothermal projects (University of Nottingham, 2024; University of Toronto,

2024; University of California, 2024). Energy efficiency improvements are another critical area, as seen at MIT, UBC, and Washington, where large-scale retrofitting, LEED-certified buildings, and utility savings have substantially reduced energy consumption (University of British Columbia, 2019; MIT, 2024; University of Washington, 2024). In terms of green infrastructure, campuses such as Arizona State, Stanford, and Nottingham have invested in rain gardens, permeable pavements, and stormwater systems to reduce flood risks and enhance resource conservation (Arizona State University, 2020; Bea et al., 2019; University of Nottingham, 2024). Waste management initiatives, including composting, recycling, and circular economy practices, have diverted thousands of tonnes of waste annually, as demonstrated by Auckland, Sheffield, and ASU (Arizona State University, 2013; University of Auckland, 2024; Zhang et al., 2011). Sustainable transportation is another priority, with UC Davis and Stanford promoting electric vehicles, hybrid buses, and cycling, reducing reliance on fossil-fuel transport (University of California, 2021; Stanford University, 2023). Beyond infrastructure, universities such as Edinburgh, UCL, and Vermont have embraced socially responsible investments, divesting fossil fuels and integrating ESG principles into financial management (UCL, 2018; University of Edinburgh, 2020; University of Vermont, 2024). Partnerships and collaborations, such as those between UBC and the City of Vancouver, demonstrate how long-term cooperation enhances sustainable outcomes (Plaut et al., 2013; Pauer et al., 2020). Finally, as practised at Nottingham and Lancaster Universities, continuous monitoring and reporting systems ensure that sustainability remains a dynamic and accountable process (University of Nottingham, 2021; Ian, 2022). In conclusion, these examples highlight universities' diverse but complementary approaches to advance campus sustainability. They also provide a strong benchmark for evaluating and improving UM's sustainability initiatives.

RESEARCH METHODOLOGY

This study adopted a quantitative research approach using a questionnaire survey as the primary research method to examine Universiti Malaya's (UM) sustainability investment initiatives. The data collection instrument was structured into four sections: demographics, familiarity with sustainability initiatives, current UM practices, and areas for improvement, using a 5-point Likert scale with an open-ended option for additional input. The target population comprised UM employees (academic, operations, and executive staff), chosen because of their longer tenure and familiarity with institutional procedures compared to students. The sample size was determined using Krejcie and Morgan's (1970) formula, with the UM Fact Sheet (2025) reporting 5,629 employees, yielding a required sample of 360. A simple random sampling technique was applied to ensure that every employee had an equal chance of

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selection. The survey was administered via Google Forms and distributed through official email, Telegram, and WhatsApp, with reminders to enhance participation. In total, 361 valid responses (n = 361) were received. Data were analysed using SPSS for descriptive statistics (to profile demographic distribution and respondent characteristics, with total numbers and percentages stated in tables and charts) and the Relative Importance Index (RII) to prioritise sustainability initiatives. The Relative Importance Index (RII) was applied, calculated using the following formula:

$$RII = \frac{\sum w}{A \times N} RII=A×N∑w$$

Where w = weight given by each respondent (1–5), A = highest possible weight (5), and N = total number of respondents. RII values were then ranked into five levels of importance (Mustafa et al., 2021).

The RII values were categorised into five importance levels, allowing systematic ranking of initiatives. The findings provide evidence-based insights that directly inform UM's sustainability strategy, highlighting key areas such as waste management, stakeholder collaboration, and continuous monitoring that can advance UM's environmental responsibility and long-term sustainability goals.

RESULT AND DISCUSSION

The 361 respondents to the questionnaire survey at UM represent diverse age groups, job categories, roles, educational backgrounds, and work experiences, as shown in Table 2. Most respondents are 36 to 45 (32.5%), and local academic staff (36.67%). A significant portion holds advanced degrees, with 36.67% possessing a PhD. Most participants have over ten years of work experience, providing a strong foundation of institutional knowledge. Administrative staff and senior lecturers were most represented, focusing on the university's investment strategy and sustainability efforts. The respondents' varied backgrounds offer comprehensive insights into UM's sustainability practices, highlighting strengths and areas for improvement in its initiatives. This diversity ensures a thorough understanding of the university's sustainability policies and offers multiple perspectives for future developments.

Table 2: Pie Chart Distribution

Roles	Nos	Percentage %
Administration	17	14.17%
Assistant Architect	1	0.83%
Assistant Project Officer	2	1.67%
Assistant Quantity Survey	1	0.83%
Assistant Registrar	3	2.50%
Assistant Science Officer	3	2.50%
Associate Professor	7	5.83%
Development & Property	8	6.67%
Engineer	5	4.17%
IT Officer	4	3.33%
Lecturer	12	10.00%
Librarian	4	3.33%
Post-Doctoral Research	7	5.83%
Producer	1	0.83%
Professional & Management	13	10.83%
Professor	8	6.67%
Research Officer	6	5.00%
Senior Lecturer	16	13.33%
Skill Assistant	2	1.67%
Total	120	100%

Familiarity with Investment Initiatives for Sustainability implemented by University Green Campuses

According to Table 3, data analysis revealed that UM employees' familiarity with sustainability initiatives falls between medium and high levels, with sustainable transportation being the most recognised initiative (RII: 0.645), reflecting UM's proactive efforts in promoting sustainable transportation (Universiti Malaya, 2024). Other initiatives, such as waste management, partnerships, and continuous improvement, also show significant recognition (RII: 0.642–0.633). However, familiarity with renewable energy investments is lower among UM employees, possibly due to the lower visibility of such projects on campus and the technical complexity of renewable energy (Gajdzik et al., 2023). The analysis categorised the initiatives into high-medium and medium relevance levels, highlighting well-established areas such as sustainable transportation and waste management while suggesting that renewable energy may require more promotion and investment. These findings provide valuable insights into the recognition and significance of sustainable investment decisions in university green campuses.

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Table 3: Ranking of Familiarity of Investment Initiatives for Sustainability implemented by University Green Campuses

ID	Familiarity with Investment Initiatives for Sustainability implemented by University Green Campuses	RII	Overall Ranking
F5	Sustainable Transportation	0.645	1
F7	Partnerships and Collaborations	0.642	2
F4	Waste Management Initiatives	0.633	3
F8	Continuous Improvement and Monitoring	0.632	4
F3	Green Infrastructure Development	0.612	5
F2	Energy Efficiency Improvements	0.593	6
F6	Socially Responsible Investments	0.593	7
F1	Renewable Energy Investments	0.587	8

Source: compiled from data analysis results

Current Investment in Sustainability Implemented by Universiti Malaya

According to Table 4, findings show that all initiatives are of high-medium importance, with waste management ranking highest, emphasising recycling and circular economy concepts. This reflects UM's commitment to sustainability and environmental leadership, with programs like the Zero Waste Campaign and water conservation efforts (Universiti Malaya, 2022, 2024). Collaborations with external stakeholders, such as NGOs, further enhance UM's impact on Sustainable Development Goals (SDGs). However, renewable energy initiatives rank lower, suggesting areas for future development, likely due to high initial costs and limited visibility (Lorente et al., 2023). In summary, UM's sustainability investments align with long-term goals and potential improvements in clean energy efforts.

Table 4: Ranking of Current Investment in Sustainability Implemented by UM

ID	Current Investment in Sustainability Implemented by Universiti Malaya	RII	Overall Ranking
C3	Implement waste reduction strategies	0.732	1
C5	Collaborate with external stakeholders	0.725	2
C4	Emphasise economic viability	0.707	3
C2	Eco-friendly behaviours	0.705	4
C6	Monitoring and continuous improvement	0.697	5
C1	Integrate clean energy initiatives	0.693	6

Areas of Improvement in UM's Investment for Sustainability

This section analyses the areas in UM sustainability investment that require improvement, as shown in Table 5. The RII and mean values highlight key regions, with continuous improvement and monitoring ranked first. This suggests that UM needs better systems for assessing and improving sustainability activities, such as road maintenance and cycling facilities (Kamarudin et al., 2023). Sustainable transportation follows closely, indicating a need to improve infrastructure to reduce environmental impact due to campus traffic congestion. Green infrastructure, waste management, and energy efficiency improvements also rank high, focusing on reducing environmental impact and promoting sustainability (Hajam et al., 2023; Selamat et al., 2017). Partnerships and socially responsible investments (SRI) are also prioritised but face challenges in implementation (Martini, 2021). Lastly, renewable energy investments are ranked the lowest, likely due to high initial costs and technical complexities (Gajdzik et al., 2023). These findings suggest areas for future development in UM's sustainability strategy.

Table 5: Ranking of Areas of Improvement in UM's Investment for Sustainability

ID	Areas of Improvement in UM's Investment for Sustainability	RII	Overall Ranking
A8	A Continuous Improvement and Monitoring	0.788	1
A5	A Sustainable Transportation	0.770	2
A3	A Green Infrastructure Development	0.768	3
A4	A Waste Management Initiative	0.767	4
A2	Energy Efficiency Improvements	0.765	5
A7	Partnerships and Collaborations	0.763	6
A6	A Socially Responsible Investment	0.762	7
A1	A Renewable Energy Investment	0.747	8

Source: compiled from data analysis results

These findings demonstrate how targeted improvements in waste management, stakeholder engagement, and continuous monitoring can enhance UM's institutional responsibility toward environmental stewardship.

CONCLUSION

This study examined Universiti Malaya's (UM) investment initiatives for sustainability, focusing on employees' perceptions of current practices, familiarity with green campus strategies, and areas for improvement. Using a questionnaire survey of 361 respondents and applying the Relative Importance Index (RII), the findings highlight waste management, stakeholder

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collaborations, and continuous monitoring as the most significant priorities. These results suggest that while UM has a solid foundation in sustainability, greater attention is needed for renewable energy and socially responsible investments, which remain relatively underdeveloped. However, the research encountered several limitations, including imbalanced responses, time constraints, and restricted access to some literature, which may have influenced the comprehensiveness of the analysis.

Future studies are encouraged to target more balanced respondent groups, adopt qualitative or mixed-method approaches, extend data collection periods, and conduct comparative analyses across green campuses. Despite these limitations, the study contributes meaningfully to advancing UM's environmental responsibility by identifying clear and actionable areas for improvement. Strengthening waste reduction strategies, expanding collaborations, and embedding continuous monitoring systems can enhance UM's capacity to manage sustainability more effectively. Moreover, aligning these improvements with international best practices and the United Nations Sustainable Development Goals (SDGs) will help position UM as a leading sustainable university in the region, reinforcing its long-term commitment to environmental stewardship and institutional sustainability.

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EXPLORING THE CHALLENGES IN IMPLEMENTING BLOCKCHAIN TECHNOLOGY IN CONTRACT MANAGEMENT FOR QUANTITY SURVEYING PROFESSION IN MALAYSIAN CONSTRUCTION INDUSTRY

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Abstract

The increasing complexity of construction projects in Malaysia has amplified the need for transparent, efficient, and secure contract management systems, particularly within the quantity surveying profession. Blockchain technology, with its decentralised ledger and smart contract capabilities, presents a potential solution to long-standing issues such as data manipulation, inefficiencies, and a lack of accountability in contract administration. This study explores the challenges associated with implementing blockchain technology in construction contract management and propose effective strategies for its integration into quantity surveying. A quantitative research method was employed through the distribution of 600 questionnaires to registered quantity surveyors. Data collected from the survey of 142 respondents were analysed using descriptive statistical techniques. The results of this study reveal the ranking of key barriers to blockchain adoption by the quantity surveying profession, including the immaturity of the technology, high implementation costs, privacy concerns, resistance to change, and security risks. This paper provides recommendations for addressing these challenges to facilitate the digital transformation of contract management in the industry. This study concludes that while blockchain holds significant potential to contract management efficiency, strategic efforts in education, policy, and industry collaboration are essential to support its successful adoption by the Malaysian quantity surveying profession.

Keywords: blockchain technology, construction, contract management, quantity surveying, challenges, adoption

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INTRODUCTION

The increasing demand for transparency, efficiency, and accountability in the Malaysian construction industry has further encouraged the exploration of emerging technologies such as blockchain. One profession that plays a vital role in cost control and contract administration is quantity surveying. Despite the industry's significant contribution to the national economy, employing 1.2 million individuals and accounting for 9.5% of the total workforce (Aziz & Hamid, 2020), it continues to face persistent challenges such as low productivity, slow technological adoption, and vulnerability to unethical practices. These challenges are exacerbated by the limited use of digital innovations, particularly in contract management practices.

Several studies have argued and concluded that the construction industry's slow integration of advanced digital technologies, including blockchain, artificial intelligence, and big data, has hindered improvements in project performance and ethical standards (Jasimin et al, 2023; Ghaffarpasand et al., 2020; Li et al., 2020). The lack of awareness, understanding, and readiness among construction professionals, especially quantity surveyors, has contributed to the limited implementation of such transformative technologies (Farid et al., 2019). Blockchain, known for its decentralised, transparent, and tamper-proof nature, has been identified as a promising solution to these issues. Through its smart contract features and secure data-sharing capabilities, blockchain technology offers potential benefits such as improved traceability, automated compliance, enhanced data integrity, and reduced transaction costs in contract management (Muneeb et al., 2022).

The objective of this paper is to explore the challenges faced by quantity surveying professionals when adopting blockchain technology for contract management in the Malaysian construction industry. The outcome of this study will identify the key barriers to blockchain implementation within the local quantity surveying profession, specifically in its transition towards digital transformation in contract management through blockchain adoption.

LITERATURE REVIEW

Construction Contract Management

Construction contract management is a crucial aspect of ensuring the effectiveness and efficiency of construction projects. This involves various activities, including the administration of contracts, risk management, compliance oversight and, the continuous evaluation of performance to meet the goals outlined in the contracts. Okereke et al., (2023) asserted that the expertise of a quantity surveyor is crucial throughout the construction process, particularly in managing claims and ensuring adherence to contract terms. This comprehensive involvement equips QSs to address complexities and potentially

mitigate risks associated with contract execution, which is vital for maintaining project performance.

One significant challenge in construction contract management is the reliance on traditional legal frameworks and documentation practices, which are often cumbersome and difficult to navigate. Gurgun and Koc (2021) emphasis that participants in construction projects express concerns about the legal processes tied to traditional contract management, which often leads to operational and enforcement difficulties. The adoption of smart contracts has emerged as a potential solution, although it introduces additional challenges, such as the need for legal professionals to acquire programming skills to manage and develop these contracts effectively (Gurgun & Koc, 2021). However, Mwaiseje et al., (2024) indicated that the lack of an adequate dispute resolution mechanism remains a prominent risk in these new frameworks, underscoring the complexities faced by construction managers in navigating concurrent legal obligations and technological innovations.

Blockchain in Construction Contract Management

Blockchain technology is increasingly recognised as a transformative force in the construction industry, particularly in contract management. The application of blockchain and smart contracts has shown significant potential to streamline various processes, enhance transparency, and improve trust among stakeholders involved in construction projects. By facilitating automated compliance with contractual conditions, blockchain can mitigate common issues, such as payment delays, disputes, and inefficiencies (Celik et al., 2024; Muneeb, 2022).

One of the primary benefits of blockchain technology in contract management is its ability to create secure and transparent layers of information that can be accessed by all stakeholders involved in a construction project. This capacity serves to enhance accountability and reduce disputes arising from ambiguities in contract terms. Celik et al., (2024) asserted that blockchain can significantly improve various construction processes, including contract management, by ensuring that every change or transaction is accurately documented and traceable. Their review emphasis the technology's role in increasing efficiency and effectiveness across the construction supply chain. Similarly, Muneeb et al., (2022) highlighted how blockchain-based smart contracts can automate and streamline business processes, thereby significantly optimising workflows in multiparty arrangements, which is especially pertinent to quantity surveying projects involving several stakeholders.

Moreover, the use of smart contract that utilises automated scripts running on blockchain that execute predefined condition offers the potential to transform how quantity surveying manages contracts. Yigit and Dag (2024) emphasis that implementing smart contracts on blockchain platforms can foster

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transparency and accountability, leading to increased contract execution processing speeds and improved construction resources management. This is critical in quantity surveying, where tracking and verifying compliance with contract specifications is paramount. Additionally, Pan et al., (2023) explored a framework for integrating smart contracts with Building Information Modelling (BIM), asserting that this combination can enhance the material supply chain management aspect of construction projects, reducing risks associated with traditional contract execution.

Considering the broader implications of integrating blockchain for supply chain management, Malik et al., (2021) detailed how blockchain technology can address critical issues related to transparency and traceability in global supply chains, a significant aspect of construction contract management that quantity surveyors must navigate. Their findings resonate with those of Syamsuddin et al., (2023), who argued that this technology promises to increase operational efficiency and significantly reduce costs related to contract management across various sectors, including construction.

The implications for project risk management are also substantial. Jasimin et al., (2023) and Demirkesen et al., (2024) note that blockchain's unique properties enable improved data management practices, which can significantly enhance project risk management strategies in construction. By employing a structural equation model, this study demonstrated how blockchain ensures more reliable risk management frameworks, enhancing trust among parties involved in contract agreements through transparent data-sharing mechanisms.

In short, the potential integration of blockchain technology and smart contracts into contract management within the quantity surveying profession represents a noteworthy advancement towards improving efficiency, reducing disputes, and fostering accountability in construction processes. Collective insights from the discussed literature affirm that blockchain not only facilitates better contractual arrangements but also enhances overall project effectiveness within the construction sector.

Challenges in Implementing Blockchain in Construction Professional Practice

The integration of blockchain technology into construction contract management has substantial potential, particularly in the field of quantity surveying. However, several key challenges continue to hinder its adoption, ranging from organisational barriers to technological and regulatory limitations. Among the key challenges that can be identified from existing the literatures are, but not limited to the following:

Lack of Management Support and Technical Knowledge

One of the most pressing barriers to blockchain adoption in construction is the lack of internal management support and technical expertise. Blockchain is viewed as a highly disruptive and complex innovation that requires advanced technological competence and domain-specific integration (Ghaffarpasand et al., 2020; Celik et al., 2024). Without sufficient internal knowledge, firms struggle to initiate, scale, or sustain blockchain-related initiatives (Li et al., 2020; Mahmood et al., 2020). As Hernandez and Miller (2021) emphasised, senior management commitment is pivotal for successful digital transformation, and its absence remains a critical limiting factor. In quantity surveying, this issue is amplified by fragmented workflows and limited experience with large-scale digital projects (Chan & Lim, 2020; CIDB, 2024).

Regulatory Uncertainty and Legal Ambiguity

Blockchain implementation is further hindered by legal and regulatory ambiguities. A lack of comprehensive frameworks surrounding blockchain usage in contract documentation and project management limits its enforcementability and compliance (Rahman et al., 2020; Gurgun & Koc, 2021). Smart contracts, written in code rather than legal language, pose additional challenges regarding their alignment with existing legal standards (Pan et al., 2023). Zarour and Haron (2021) argued that construction stakeholders are hesitant to embrace blockchain without clear legal validation and standardisation. Moreover, Al-Bassam et al., (2021) highlighted that inconsistent policies and enforcement mechanisms increase adoption risk, particularly in transnational or large-scale projects.

Limited Collaboration Among Stakeholders

Successful blockchain integration in construction projects requires coordinated collaboration among all stakeholders, including the client, consultant, contractor, and regulatory bodies. However, this sector is characterised by siloed operations, adversarial relationships, and poor data-sharing practices (Demirkesen et al., 2024; Hasan et al., 2022). These challenges create barriers to the development of shared digital platforms and hinder the creation of trustworthy, real-time information systems (Malik et al., 2021; Celik et al., 2024). Aziz and Hamid (2020) further pointed out that divergent interests often lead to duplicated efforts and inefficiencies, limiting the collaborative potential of blockchain in delivering a unified source of truth across projects.

Potential for Misuse and Unethical Applications

Despite its promise to enhance transparency, blockchain is not immune to ethical risks. When misused, blockchain systems may enable unregulated or illicit activities, such as data tampering and money laundering (Zarour & Haron, 2021;

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Muneeb et al., 2022). The decentralised and anonymous nature of certain blockchain configurations, especially public networks, increases the risk of manipulation by malicious actors. As Hasan et al., (2022) warned that the lack of strong governance structures can lead to ethical breaches, especially in jurisdictions without robust regulatory frameworks. These concerns underscore the importance of robust compliance and audit mechanisms in blockchain platforms.

Privacy Concerns in Data Sharing

While blockchain's transparency facilitates traceability and accountability, it simultaneously raises serious privacy concerns, particularly in contract administration and financial transactions. Gurgun and Koc (2021) discussed the reluctance of construction professionals to share sensitive data on public or semi-public ledgers due to fears of corporate espionage or breaches of confidentiality. Lim et al., (2021) found that organisations prefer private blockchain because such networks may reduce the overall benefits of openness and interoperability. Additionally, Malik et al., (2021) argued that the trade-off between transparency and privacy must be carefully managed, especially when dealing with proprietary or competitive data.

High Implementation Cost

The financial burden of blockchain implementation ranging from system development to training and maintenance remains a key obstacle for small and medium-sized construction firms. According to Celik et al., (2024), high upfront costs are often disproportionate to perceived benefits, especially when return on investment is unclear. Demirkesen et al., (2024) noted that resource-constrained organisations often abandon blockchain adoption due to limited capital and uncertainty about long-term viability. Mahmood et al., (2020) similarly emphasised that funding challenges and the absence of scalable models hinder adoption across developing economies.

Integration Difficulties with Legacy Systems

Integrating blockchain solutions into existing construction IT systems is technically demanding. Most legacy platforms lack interoperability with distributed ledgers, leading to data silos and operational friction (Park et al., 2019; Hasan et al., 2022). Li et al., (2020) observed that aligning blockchain with enterprise resource planning (ERP) systems requires substantial investment and staff retraining. Furthermore, the absence of common technical standards and protocols across the industry makes seamless integration a challenge, delaying the full realisation of blockchain's potential in construction workflows (Pan et al., 2023; Chan & Lim, 2020).

Resistance to Change and Digital Transformation
Cultural resistance remains a deeply rooted issue in the construction industry's slow digital transformation. Traditional work methods, hierarchical decision-making, and scepticism towards emerging technologies contribute to a reluctance to change (Mustafa et al., 2024; Rahman & Ismail, 2019). In quantity surveying, blockchain is often perceived as overhyped and lacking proven value, which discourages firms from investing in pilot initiatives or workforce development (Mahmood et al., 2020; Aziz & Hamid, 2020). Lim et al., (2021) highlight that organisational inertia, especially in long-established firms, continues to be a non-technical yet powerful barrier to digital adoption.

Immaturity of Blockchain Technology
Despite rapid advancements, blockchain technology has remained in its early stages in the construction sector. As pointed out by Celik et al., (2024), the lack of industry-specific case studies and success stories contributes to uncertainty about blockchain's practical utility. Hasan et al., (2022) argued that the technology diffusion has been slow by limited empirical validation and pilot project outcomes. Similarly, Ghaffarpasand et al., (2020) caution that blockchain's operational limitations such as transaction speed, scalability, and data governance. These developmental issues create hesitation among decision-makers and investors alike.

Security Vulnerabilities
Although blockchain technology is generally considered a secure digital infrastructure, vulnerabilities remain, particularly in public blockchain environments. Lim et al., (2021) explain that while decentralised architectures protect against single-point failures, they are not immune to coordinated cyberattacks, such as the infamous 51% attack. Gurgun and Koc (2021) also highlighted concerns about data integrity, especially when sensitive project information is stored across distributed networks. Furthermore, Park et al., (2019) stressed the need for robust security frameworks and contingency protocols, especially for smart contract execution, to ensure that blockchain can be reliably used in high-stakes construction applications.

RESEARCH METHODOLOGY
This study adopted a quantitative research approach, using questionnaire surveys to explore the challenges faced by quantity surveyors in adopting blockchain technology for contract management. A survey was developed based on insights from the literature, and respondents were asked to rate each challenge on a 5-point Likert scale, where 1 represented "Not significant" and 5 represented "Extremely significant." The questionnaire was distributed via email and

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LinkedIn between April 15 and May 5, 2024. Using purposive sampling, about 600 questionnaires were distributed and 142 completed responses were received, resulting a response rate of 23.67%. According to Baruch (1999), a survey-based research response rate of 100% is rarely attainable, and Laguilles et al., (2011) noted that typical online survey response rates average around 20%. Therefore, the response rate achieved in this study can be considered both acceptable and sufficient for meaningful analysis.

Data collected from the survey were analysed using descriptive statistical techniques. Analytical tools such as Microsoft Excel and SPSS were employed to interpret the findings through measures of central tendency, frequency distributions, and dispersion, where Mean Rank Analysis was also used. The results were presented using visual aids to enhance clarity and comprehension. This methodological approach enabled the identification of key patterns and themes concerning the challenges faced by quantity surveyors, ultimately supporting the development of evidence-based challenges in utilising blockchain technology within the Malaysian quantity surveying profession.

To ensure validity, the questionnaire was developed based on an extensive literature review and subsequently reviewed by academic and industry experts for content accuracy. A pilot test involving 15 registered quantity surveyors refined its clarity and relevance. Reliability was confirmed through Cronbach's Alpha (values > 0.70), and mean rank analysis identified the relative significance of the identified challenges. Finally, the results were compared with findings from previous studies to establish external validity.

FINDINGS AND DISCUSSION

Key Challenges to Implementing Blockchain in Contract Management in the Malaysian Quantity Surveying Profession

In interpreting the findings, this paper established a benchmark mean value of 3.00 on the 5-point Likert scale as the threshold for acceptance. Consequently, challenges with mean values exceeding 3.00 were identified as significant barriers to blockchain adoption in the Malaysian quantity surveying profession.

Table 1: Mean Rank Analysis of Key Challenges in Blockchain Adoption

Challenges in the implementation of blockchain technology	Mean	Standard deviation	Ranking
Immaturity of Technology	4.49	0.769	1
Cost of Investment	4.46	0.603	2
Risk to Privacy	4.45	0.896	3
Unwillingness to Adapt	4.39	0.617	4
Threats to Security	4.35	0.755	5
Usage in Illegal Activities	4.15	0.982	6

Challenges in the implementation of blockchain technology	Mean	Standard deviation	Ranking
Absence of Management Support and Knowledge	4.11	0.923	7
Absence of Regulation Support	4.04	0.551	8
Absence of coordination, cooperation, and collaboration	3.82	0.718	9
Difficulties in Integrating Existing System	3.66	0.743	10

The survey results reveal that the immaturity of blockchain technology poses the most critical challenge (Mean = 4.49, SD = 0.769). Respondents expressed concerns about scalability, usability, and interoperability, which limit blockchain's capacity to support complex construction contracts. This finding corroborates prior studies by Celik et al. (2024) and Mahmood et al. (2020), who similarly noted that blockchain systems struggle to process large volumes of data and maintain efficiency. The limited availability of construction-specific platforms, as observed by Park et al. (2019) and Hasan et al. (2022), further reinforces these concerns. Thus, this study enhances existing literature by providing empirical evidence that technological immaturity remains the foremost barrier to adoption in the Malaysian context.

The second-ranked challenge is the cost of investment (Mean = 4.46, SD = 0.603). Survey responses indicate a strong consensus that high costs associated with infrastructure, training, and maintenance costs deter adoption, particularly among SMEs. This aligns with findings by Demirkesen et al. (2024) and Al Amri et al. (2019), who reported that the financial burden of blockchain often outweighs its perceived benefits in resource-constrained industries. However, this study builds upon earlier findings by illustrating that Malaysian quantity surveyors also regard investment as a long-term risk due to uncertain returns and the lack of industry incentives. This suggests that financial barriers are not merely immediate but also strategic, influencing organizations' willingness to commit resources.

Privacy concerns emerged as the third key challenge (Mean = 4.45, SD = 0.896). While blockchain is often praised for its transparency, respondents expressed reservations about exposing sensitive contractual and financial data. This concern echoes the findings of Gurgun and Koc (2021) and Lim et al. (2021), who reported that professionals are hesitant to share proprietary information on distributed ledgers. Simultaneously, this viewpoint contradicts overly optimistic perspectives such as those presented by Muneeb et al. (2022), which emphasize blockchain's role in enhancing trust. Within the Malaysian QS profession,

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transparency is viewed as a double-edged sword; it is essential for accountability yet can potentially undermine confidentiality without robust governance mechanisms.

The fourth-ranked barrier is unwillingness to adapt (Mean = 4.39, SD = 0.617). Respondents' hesitation to adopt blockchain reflects entrenched resistance to digital transformation within the construction industry. This result aligns with findings by Aziz and Hamid (2020) and Mahmood et al. (2020), who identified scepticism and organisational inertia as significant inhibitors. In contrast to international findings, the Malaysian context reveals that resistance is not only cultural but also closely linked to limited exposure and a lack of demonstrable case studies, which render blockchain adoption seem risky and unproven.

Finally, security threats (Mean = 4.35, SD = 0.755) were also perceived as a significant challenge. Despite blockchain's reputation for cryptographic security, respondents remain apprehensive about cyberattacks and vulnerabilities associated with smart contract execution. Lim et al. (2021) and Gurgun and Koc (2021) reported similar concerns, particularly regarding 51% attacks and data integrity. These findings confirm that while blockchain offers relative security compared to traditional systems, its risks are heightened in high-stakes sectors such as construction. Consequently, the results suggest that stakeholder trust in blockchain hinges on the establishment of robust security frameworks and regulatory safeguards.

Lower-ranked challenges such as illegal usage (Mean = 4.15), lack of management support and knowledge (Mean = 4.11), regulatory uncertainty (Mean = 4.04), as well as coordination and integration difficulties (Means = 3.82 and 3.66, respectively) are still relevant but are viewed as secondary. Interestingly, this contrasts with studies by Hasan et al. (2022) and Park et al. (2019), who identified coordination and integration as central barriers. This divergence implies that, in Malaysia, technological immaturity, costs, and privacy risks represent more immediate concerns, whereas systemic issues may only gain prominence after foundational barriers are addressed.

Recommendations for Overcoming Challenges in the Digital Transformation of Quantity Surveying Contract Management

Since the survey identified the immaturity of blockchain technology as the foremost challenge (Mean = 4.49), consistent with findings by Celik et al. (2024) and Ghaffarpasand et al. (2020), developing flexible regulatory frameworks has become imperative. Respondents' concerns regarding scalability and reliability echo findings that the immaturity of blockchain technology hampers contract modifications and large-scale adoption. Consequently, this issue responds to the calls by Rahman et al. (2020) and Zarour and Haron (2021) for adaptable legal

structures that maintain the integrity of blockchain records while enabling contractual flexibility. Establishing such frameworks would alleviate uncertainty about the irreversible nature of blockchain transactions and help reduce legal ambiguity (Gurgun & Koc, 2021).

Given that the cost of investment was ranked as the second major challenge (Mean = 4.46), consistent with Demirkesen et al. (2024) and Al Amri et al. (2019), it is critical to mitigate financial burdens that hinder adoption. Respondents highlighted that cost is not only an upfront barrier but also poses a strategic risk due to unclear returns, echoing Lim et al. (2021) and Hasan et al. (2022), who found that the lack of incentives discourages experimentation. Consequently, governments and industry bodies should provide targeted financial support through subsidies, tax relief, and grants, alongside pilot programs for SMEs. These measures would lower entry barriers and encourage organizations to trial blockchain solutions without committing to full-scale investment.

As the findings indicate, the unwillingness to adapt and lack of management support were reported as significant barriers (Mean = 4.39 and 4.11), aligning with Aziz and Hamid (2020) and Farid et al. (2019). Survey respondents echoed the literature claims that resistance is driven by limited awareness and a lack of demonstrable benefits (Chan & Lim, 2020; Othman & Chong, 2020). Consequently, tailored training for both technical staff and decision-makers can foster organizational readiness and reduce cultural inertia. Such initiatives would strengthen internal support for blockchain adoption and ensure the profession develops the necessary digital competencies (Li et al., 2020).

Considering that privacy risks ranked third (Mean = 4.45), in line with findings by Gurgun and Koc (2021) and Lim et al., (2021), enhancing data protection mechanisms is vital. Respondents' concerns echo Malik et al., (2021), who emphasised the transparency–privacy trade-off in blockchain systems. Consequently, investment should be directed toward privacy-enhancing solutions, such as permissioned blockchains and advanced encryption methods. These approaches can safeguard sensitive contract data while maintaining blockchain's strengths in transparency and accountability (Hasan et al., 2022; Zarour & Haron, 2021).

In light of the results that highlight coordination difficulties and system integration issues, albeit ranked lower (Means = 3.82 and 3.66), they still parallel the literature that identifies fragmentation and interoperability as persistent barriers (Celik et al., 2024; Park et al., 2019). Respondents' perceptions suggest that these challenges may become more pressing once technological and financial concerns are resolved. Consequently, industry-wide platforms for collaboration and hybrid solutions that ensure interoperability should be prioritized. This aligns

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with Al-Bassam et al. (2021) and Mustafa et al. (2024), who argue that collective action and knowledge sharing can reduce adoption friction.

As revealed by this study, security vulnerabilities were recognised as a significant challenge (Mean = 4.35), confirming the concerns raised by Lim et al., (2021) and Muneeb et al., (2022). Respondents' apprehensions about smart contract manipulation and cyberattacks reinforce the need for robust safeguards. Consequently, stakeholders should prioritise investments in cybersecurity, including multi-signature verification, advanced encryption, and regular audits, as suggested by Gurgun and Koc (2021). Enhancing security frameworks will reinforce stakeholder trust and promote broader blockchain adoption.

By addressing these key challenges through a combination of regulatory reform, financial incentives, education and training, privacy innovation, industry collaboration, and cybersecurity measures, the quantity surveying profession can successfully integrate blockchain into contract management. This approach will support a more transparent, secure, and efficient process; ultimately contributing to the digital transformation of the construction industry.

CONCLUSION

This research set out to explore the challenges associated with implementing blockchain technology in contract management within the Malaysian construction industry, focusing specifically on the quantity surveying profession. Through a structured quantitative research approach and supported by statistical analysis of 142 responses from registered quantity surveyors, the study identified key hindrances, including data integration issues, cybersecurity vulnerabilities, regulatory ambiguities, and the need for significant capacity building.

The literature review provided a robust theoretical foundation that was empirically reinforced by the survey results and validations. The findings underscore that while there is widespread recognition of blockchain's potential to enhance transparency and operational efficiency, its dual-edged nature with regard to technological complexity and regulatory shortcomings demands a strategic, phased implementation approach. This study recommends the development of proactive regulatory reforms, comprehensive training initiatives, financial incentives, and industrial collaborations as integral components of successful blockchain integration strategies.

Furthermore, the adoption of blockchain technology necessitates a fundamental rethinking of traditional contractual workflows and professional roles in quantity surveying. The strategic recommendations aim not only to mitigate the identified challenges but also to pave the way for sustainable digital transformation in contract management. The study ultimately contributes to both academic literature and industry practice by offering evidence-based insights that

can guide policymakers, industry leaders, and practitioners in leveraging blockchain technology to foster a more transparent, secure, and efficient contractual environment.

In conclusion, while the path to blockchain integration in the Malaysian construction industry is beset with challenges, the combination of strategic planning, regulatory support, and capacity building can drive successful adoption. By addressing these critical issues, the industry can harness blockchain's transformative potential, thereby ensuring improved contract management processes, enhanced stakeholder trust, and a more robust foundation for future construction projects.

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EVALUATING THE EFFECTIVENESS OF MOBILE-BASED DEFECT MANAGEMENT APPLICATIONS (DMAs) ON HOMEBUYER SATISFACTION IN HIGH-RISE CONDOMINIUM PROJECTS

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Abstract

Malaysia's high-rise condominium projects continue to grapple with construction defects, as many homebuyers report unresolved issues that adversely affect their satisfaction and trust. In response, Defect Management Apps (DMAs) have emerged as digital tools designed to streamline defect reporting and resolution processes. This study evaluates the effectiveness of DMAs in enhancing homebuyer satisfaction within Klang Valley's high-rise housing market. A mixed-methods approach was employed, combining quantitative data from 191 survey respondents with qualitative insights from 20 semi-structured interviews. The results reveal several key patterns. First, the adoption of DMAs does not necessarily correlate with satisfaction; while users appreciate the convenience, they express frustration when underlying service delivery issues persist. Second, satisfaction decreases as defect counts rise, underscoring the number of defects increases, highlighting the critical role of effective back-end coordination in managing substantial volumes of complaints. Third, generational and experiential differences play a significant role. Additionally, DMA effectiveness is shaped by factors such as usability, responsiveness, communication transparency, and real-time tracking capabilities. This study concludes that technology alone cannot guarantee satisfaction; it hinges on how effectively digital platforms integrate with supportive service processes.

Keywords: construction defects, homebuyer satisfaction, digital defect management, technology

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INTRODUCTION

The growing prevalence of high-rise residential condominiums in urban Malaysian cities, particularly in Klang Valley, has intensified the need for effective defect management during the post-construction period. As more homeowners take possession of stratified properties, ensuring timely and transparent defect rectification during the Defect Liability Period (DLP) has become essential for maintaining homebuyer satisfaction (Mohd Saufi et al., 2023). Traditional defect reporting methods, which often depend on manual forms and delayed communication, have been criticized for inefficiency, lack of transparency, and poor user experience (Kam et al., 2023). For instance, a recent industry survey reported that "80% of new homebuyers face defects within the first year," highlighting the prevalence of post-handover issues (REHDA, 2023). While such defects are common across various property types, high-rise developments present specific challenges due to their density, complex mechanical and electrical systems, and the collective management of shared facilities under strata title arrangements (Rahimin et al., 2024). These factors contribute to a higher volume of reported defects, more complicated coordination between contractors and management bodies, and greater expectations from multiple stakeholders in comparison to landed housing. Thus, concentrating on high-rise condominiums enables this study to capture the unique defect management challenges encountered in Malaysia's rapidly urbanizing residential sector.

In response to these challenges, developers have introduced mobile-based Defect Management Applications (DMAs) as digital solutions aimed at enhancing communication, tracking, and defect resolution (Agapiou et al., 2022; Abdul Basit et al., 2023). These platforms are designed to streamline processes for both homebuyers and building management teams by offering real-time updates, photo documentation, and direct reporting channels (Hashim et al., 2023). However, the limitations of traditional defect reporting methods warrant closer examination: manual forms are time-consuming, prone to misplacement, and lack transparency; phone calls or emails create inconsistent records; and delays in communication often frustrate homeowners (Kam et al., 2023). These shortcomings justify the introduction of mobile DMAs as structured platforms to improve defect tracking, enhance transparency, and establishing a digital record of all reported issues.

Despite the convenience, numerous studies and industry reports indicate that many DMAs still fall short in practice. Common challenges encompass limited responsiveness, unintuitive interfaces, and poor integration with contractor workflows (Chen et al., 2021; Martínez-Navalón et al., 2020). This misalignment between user expectations and the actual delivery of services may diminish the capacity of DMAs to enhance overall satisfaction (Abdul Basit

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et al., 2023; Azian et al., 2023). Effective communication, characterized by a willingness to assist and prompt service, has long been recognized as a significant contributor to significantly enhance customer satisfaction (Parasuraman et al., 1988; Gurmu et al., 2021). Classic service quality models emphasize that satisfaction is driven by the extent to which consumers' expectations are met by the service experience (Oliver, 1980; Zygiaris et al., 2022). In the context of housing defect management, if DMAs do not provide timely updates or user-friendly interactions, they risk failing to meet homeowners' expectations regarding service quality (Saleh et al., 2024). Against this backdrop, the objective of this study aims to evaluate the effectiveness of DMAs in enhancing homebuyer satisfaction in Klang Valley's high-rise housing market, while also understanding key factors that shape the user experience.

LITERATURE REVIEW

Technology and Defect Management in Residential Construction

The use of mobile applications for defect management is an increasingly relevant area of study, particularly in urban contexts such as Klang Valley, Malaysia (Abdul Basit et al., 2023; Kam et al., 2023). Given the rapid advancement of technology, mobile-based solutions offer significant improvements in accessibility, responsiveness, and overall service quality compared to traditional defect management systems (Aydınoğlu & Bovkır, 2020; Agapiou et al., 2022). Prior research indicates that when homeowners can report issues easily and receive swift feedback, their satisfaction with post-purchase services improves (Talebi & Bardsiri, 2023; Mohd Saufi et al., 2023). DMAs enable convenient defect reporting, status tracking, and direct communication, which heightens transparency and assures homebuyers that their concerns are being addressed (Hashim et al., 2023). This immediacy and openness can contribute positively to satisfaction levels because, timely responsiveness and clear communication are key dimensions of perceived service quality (Zygiaris et al., 2022).

The user experience is another crucial factor in the success of DMAs. Studies have suggested that user-friendly interfaces and intuitive usability lead to higher engagement and satisfaction with mobile applications (Martínez-Navalón et al., 2020; Abdul Basit et al., 2023). In the real estate context, if a defects management app is easy to navigate and notifies users about progress, homebuyers are more likely to feel in control and satisfied with the process (Chen et al., 2021; Azian et al., 2023). Conversely, a poorly designed app can cause frustration, which increases the stress associated with dealing with defects. As such, quality assessments of DMAs including usability testing are essential to ensure that they meet homebuyer expectations (Chohan, 2021; Rahimin et al., 2024).

The data-driven capabilities of DMAs also present opportunities to improve construction quality. Digital defect reports can be aggregated and analysed to identify recurring issues and their root causes (Faqih & Zayed, 2021; Abubakar et al., 2023). By leveraging insights from reported defects, developers and property managers can implement targeted improvements in construction practices and preventive measures (Aydınoğlu & Bovkır, 2020). This continuous feedback loop can not only increase current homeowners' satisfaction by reducing repeat problems but also to enhance the overall quality of future projects (Hashim Lim et al., 2024). In other words, effective defect management through DMAs can create a virtuous cycle in which customer feedback informs better building practices, leading to higher quality homes and thus more satisfied customers in the long run (Zhu et al., 2021; Saleh et al., 2024).

Digital Transformation and Defect Management Apps (DMAs)

The construction industry's digital transformation has seen the emergence of mobile apps for snagging and defect management worldwide. In Singapore, for example, the use of AI-powered defect tracking systems (integrated with their CONQUAS quality scheme) provides automated updates and analytics to pre-empt defect patterns. Hong Kong's adoption of Smart Facility Management integrates building management systems that handle defect reports as part of a larger smart home/building ecosystem. These international benchmarks highlight potential advanced features: automation (auto-scheduling repairs, AI-based defect recognition via photo analysis), better categorisation (machine learning to classify defect types and severity), and enhanced communication tools (chatbots or integrated chat with project teams).

Malaysia's DMA landscape is maturing as well, though many DMAs remain bespoke to developers, resulting in varying quality. A review of common DMA platforms (cited in Chohan et al., 2021; Saufi et al., 2023) indicates typical functions: defect report submission with photos, a list of reported items with status (e.g., "Open", "In Progress", "Closed"), and sometimes knowledge bases for common issues. However, consistent pain points reported include technical glitches, unintuitive interfaces, and lack of integration with contractors' workflows (leading to the app being bypassed by site teams who resort to calls or paper). These shortcomings often lead site teams to bypass the app entirely, reverting to phone calls or paper-based reporting, which undermines the intended benefits of digitalisation. Therefore, addressing these recurring weaknesses requires targeted improvements across communication, usability, and system integration, beginning with efforts to strengthen real-time information flow between homeowners and developers. The literature review suggests several recommendations to guide the improvement of mobile-based defect management applications.

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Improve Real-Time Communication

A critical first step is to resolve communication gaps. DMAs should incorporate real-time status updates and notifications to address the communication gap that is commonly observed in traditional systems. Homebuyers must be kept informed at each stage such as when a defect is acknowledged, when a contractor is assigned, scheduled repair dates, and confirmation of repair completion. Implementing push notifications or in-app alerts for these milestones would greatly enhance transparency and user confidence (Parasuraman et al., 1988; Gurmu et al., 2021). A messaging feature enabling two-way communication between the homeowner and the maintenance team could further strengthen the engagement and reduce the frustration caused by uncertainty (Hashim et al., 2023; Abdul Basit et al., 2023).

Enhance Usability and Accessibility

Developers should prioritise user-centric design upgrades for their DMAs. Key features should include an intuitive interface, seamless navigation, and multilingual support to cater to Malaysia's diverse population (Talebi & Bardsiri, 2023). Built-in tutorials or guided walkthroughs could assist less tech-savvy users in navigating the platform, especially older homeowners who were identified in this study as more likely to face usability challenges. Regular usability testing with real users can help uncover design pain points and guide iterative improvements (Martínez-Navalón et al., 2020). Interface features such as large buttons, simplified language and, clear visual cues can ensure accessibility across age groups and digital literacy levels.

Integrate Comprehensive Tracking and Analytics

The DMA should function not only as a reporting tool but also as an integrated defect management and analytics platform. Developers are encouraged to synchronise the app with their internal defect systems so that every step from defect receipt to final resolution is logged and, where appropriate, shared transparently with homeowners (Aydınoğlu & Bovkır, 2020; Chen et al., 2021). Features such as progress tracking dashboards and visual timelines can give users a clearer understanding of repair status. Advanced analytics could flag recurring issues or re-open tickets, enabling managers to identify underlying quality control problems (Faqih & Zayed, 2021). Over time, aggregated data can inform proactive improvements in construction quality and resource allocation, particularly when patterns emerge (e.g., consistent plumbing issues across units).

Implement AI-Driven Defect Categorisation

Defect misclassification has emerged as a significant challenge in many systems. Integrating an AI module into the DMA could assist by automatically

categorising and prioritising reports using image recognition and natural language processing (Sundaram & Zeid, 2023). For instance, the system could distinguish between minor cosmetic flaws and potentially serious structural defects, enabling developers to respond to urgent cases more efficiently. While final decisions would still involve human inspectors, AI can improve initial triaging and reduce classification ambiguity. Moreover, AI-powered chatbots could offer users instant support by answering frequently asked questions about the Defect Liability Period (DLP) and defect reporting procedures (Talebi & Bardsiri, 2023).

Continuous Training and Capacity Building

Even the most advanced DMA system requires capable and responsive personnel. Developers should ensure that both technical and customer service staff are trained not only in app usage but also in empathetic, solution-oriented communication (Zhu et al., 2021). A technological solution is only as strong as the human processes supporting it. The staff should be tasked with promptly updating defect statuses, answering queries via the app, and resolving tickets efficiently. A dedicated support team or hotline to address DMA-related issues could enhance response quality. In addition, internal audits of the defect handling process can identify systemic bottlenecks, ensuring accountability and timely resolution (Abubakar et al., 2023).

RESEARCH METHODOLOGY

This study employed a mixed-methods research design, integrating both quantitative and qualitative data to evaluate DMA's effectiveness. The quantitative phase focused on capturing usage patterns and satisfaction levels, while the qualitative phase provided in-depth insights into user experiences. Quantitative data were gathered through an online survey distributed to condominium homebuyers in Klang Valley. The survey, conducted with support from the National House Buyers Association (HBA) Malaysia and shared through relevant social media groups, targeted homeowners of approximately 36,837 strata units completed in 2022 and 2023 (NAPIC, 2024). Using Cochran's formula for sample size, a target of 380 responses was set; 191 valid responses were obtained after data cleaning, yielding a response rate of approximately 50%. The survey captured demographic details, number of defects experienced, use of DMAs, and satisfaction levels regarding defect resolution and construction quality.

Qualitative data were collected through 20 semi-structured interviews with homeowners who had used DMAs. Participants were recruited via purposive sampling to ensure a mix of different condominiums and developers in Klang

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Valley. Interviews continued until thematic saturation was reached, in line with qualitative research principles that suggest 12–15 interviews are often sufficient for saturation in a homogeneous group (Braun & Clarke, 2021). Each interview explored the participants' experiences with defect reporting and resolution, perceptions of the DMA's usefulness, and challenges they faced. The interviews (conducted in person or via video call) were recorded and transcribed with consent. All participants were assured of anonymity, and in reporting qualitative results, participants are referred to by their number (e.g., Participant 7).

The quantitative strand of the study highlighted overarching trends in DMA usage and satisfaction, including the inverse relationship between higher defect counts and lower satisfaction levels. These findings were further enriched by qualitative interviews that uncovered participants' concerns regarding unresolved or repeated defects. The integration of both strands allowed for triangulation, wherein statistical patterns were validated, clarified, and expanded upon through users lived experiences. This methodological synergy not only assessed the overall effectiveness of DMAs but also unveiled the underlying factors driving variations in satisfaction. This approach was selected because it aligns with methodological literature, asserting that triangulation through the integration of qualitative and quantitative integration enhances the credibility, depth, and explanatory strength of research outcomes (Olsen, 2004; Valencia, 2022).

FINDINGS AND DISCUSSION

Usage of DMAs and Satisfaction Levels

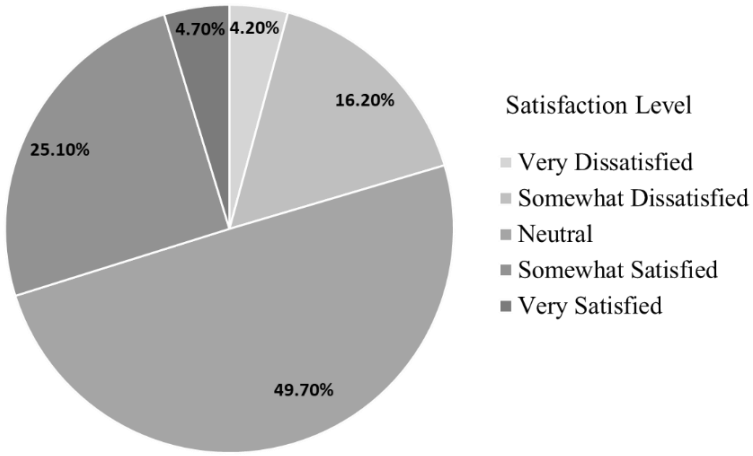


Figure 1: Homeowner satisfaction with the Defect Management App.

The survey data revealed that a large proportion of homeowners turned to DMAs to report and track these defects. Approximately 56% of respondents indicated that they used a mobile defect management app provided by the developer to lodge defect complaints. Despite this relatively high adoption rate, overall satisfaction with the DMA was low. As shown in Figure 1, only approximately 30% of users expressed satisfaction (25.1% "somewhat satisfied" and a mere 4.7% "very satisfied") with the app-based defect management process. The majority (about 50%) remained neutral, suggesting an ambivalence or mixed experience, and roughly one-fifth of users were dissatisfied to some degree with the app's performance in managing their issues. This indicates that adoption does not automatically translate into satisfaction, underscoring the gap between technology availability and effective service delivery.

From the qualitative feedback, even fundamental expectations such as being kept informed and receiving timely service were often unmet. One homeowner summarised: "The app makes it easy to submit defects, but I feel left in the dark afterward." (Participant 10). This lack of feedback was a common theme. While users valued the convenience of submitting reports, they expressed frustration when weeks passed without updates or confirmation of scheduled repairs. Satisfaction with communication and responsiveness was correspondingly low: only 29.9% of surveyed owners were satisfied with developer responsiveness, while 29.4% were outright dissatisfied. This reflects the same neutral/dissatisfied pattern seen in DMA satisfaction, suggesting that the app alone cannot compensate for weak communication practices. In terms of service quality models (Parasuraman et al., 1988), this represents a persistent "responsiveness gap," where the speed and clarity of communication fall short of expectations.

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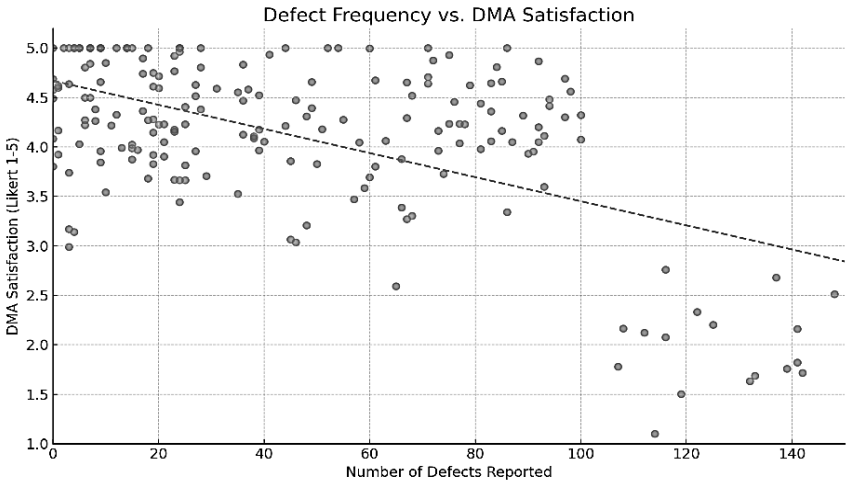


Figure 2: Relationship between number of reported defects and DMA satisfaction (with trend line)

Additionally, Figure 2 shows a clear negative correlation between the number of defects reported and satisfaction with the DMA. Statistical analysis confirmed significance ($p < 0.01$), with each additional defect associated with a –0.56 drop in satisfaction (on a 5-point scale). Satisfaction levels dropped sharply when defect counts exceeded 50, and homeowners with 100+ defects recorded the lowest scores (mean ~2.5/5). This suggests a compounding effect, where both the volume of defects and repeated failed repairs magnify dissatisfaction. In such cases, the DMA risks being perceived not as a solution but as an added layer of bureaucracy.

This study found a negative correlation between the number of defects a homeowner encountered and their satisfaction with the DMA. In general, homeowners who reported extremely high numbers of defects tended to rate the app and overall defect handling poorly. For instance, those who had more than 100 defects gave some of the lowest satisfaction scores (with a mean satisfaction around 2.5 on a 5-point scale). When defects are numerous, the capacity of the system (and the app) to manage them effectively becomes critical. Several interviewees with a high number of defects expressed frustration that the DMA and developers seemed overwhelmed. “After reporting the same issue three times, it still wasn’t fixed properly,” said Participant 7, who had one of the highest defect counts in the sample. This indicates that repeated occurrences of unresolved defects severely undermine satisfaction. In such cases, the convenience of the app offers little solace if the underlying problems persist or require multiple attempts to fix. This highlights that the true driver of

dissatisfaction is not the app interface but the underlying failure to resolve issues. The DMA becomes symbolic of inefficiency if repeated complaints go unresolved.

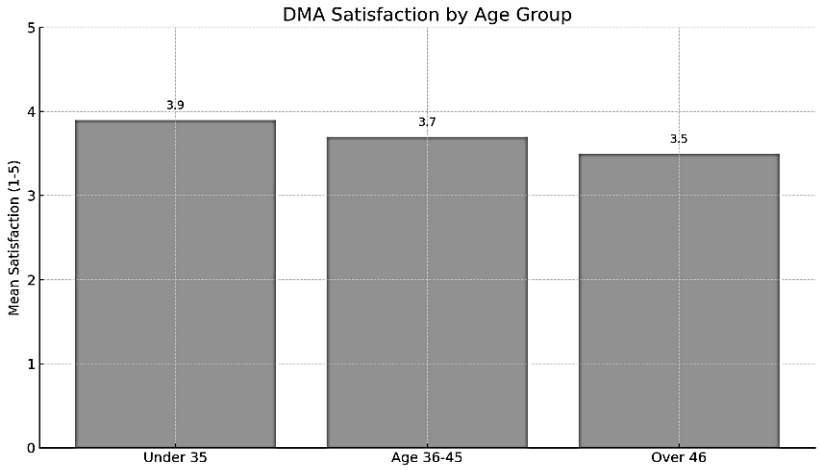


Figure 3: Homeowner Satisfaction by Demographic Groups

In addition, as illustrated in Figure 3, it is found that younger homebuyers reported higher satisfaction with the defect app than older homebuyers. In particular, respondents under 35 years old had the highest mean satisfaction (around 3.9 on the 5-point scale in this sample), compared to those in the 36–45 range (around 3.7) and those over 46 who had the lowest satisfaction (~3.5). ANOVA tests found age-based differences to be statistically significant ($p \approx 0.03$). This suggests that younger buyers were more positive about mobile-based defect management, whereas older owners were more critical or less pleased with the DMA experience, possibly due to usability hurdles or differing expectations. This generational divide mirrors findings in digital adoption research, where perceived ease of use and prior digital experience strongly shape satisfaction (Davis, 1989; Venkatesh et al., 2003).

This study also found that first-time homebuyers were more satisfied with the DMA than repeat (experienced) homeowners on average. First-time homeowners reported a mean satisfaction score of approximately 3.8, whereas those who had previously owned their property rated their satisfaction lower, around 3.5. This difference was statistically significant ($p \approx 0.02$). Researchers noted that experienced owners may have higher expectations or compare the app to prior defect management methods, making them more critical. In contrast, first-time homebuyers, with no prior baseline appeared, to view the DMA more favourably. Figure 4 illustrates these differences. First-time homebuyers had

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higher average satisfaction scores than experienced homebuyers in each age category. For instance, among homeowners under 30, first-timers rated their satisfaction as around 3.5/5 on average, compared to about 3.0/5 for non-first-timers.

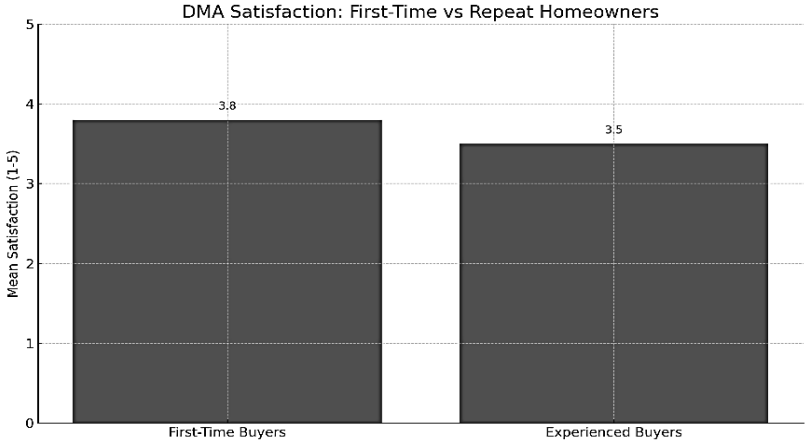


Figure 4: Homeowner Satisfaction by Demographic Groups

These patterns can be interpreted in light of expectations and familiarity. First-time homebuyers might have had lower initial expectations or simply felt grateful to have a formal system (the DMA) in place, whereas experienced owners had higher expectations and could compare the DMA's performance to previous experiences (or to an ideal standard) (Martínez-Navalón et al., 2020; Mohd Saufi et al., 2023). Older owners may also be less comfortable with mobile app technology or expect more personalised service, which could explain their lower satisfaction scores (Zygiaris et al., 2022). One older participant noted that he ultimately "had to hire a third-party inspector to follow up on the repairs," indicating a lack of trust in the app-mediated process (Participant 13). On the other hand, some younger first-time buyers expressed that while the app was "okay," they didn't know if it actually improved anything since they had no prior reference. This suggests a generational difference in how the DMA is perceived, potentially linked to tech savviness and expectations of digital services (Talebi & Bardsiri, 2023; Abdul Basit et al., 2023).

These pattern highlights a paradox in the current use of Defect Management Apps: DMAs have clearly improved certain aspects of the defect reporting process (such as convenience and documentation), yet they have not substantially improved overall homeowner satisfaction with defect handling (Kam et al., 2023; Rahimin et al., 2024). The app solves the "front end" of reporting but cannot mask deficiencies in the "back end" of service delivery. This

distinction is critical: satisfaction is ultimately tied to outcomes (repairs completed), not just processes (issues logged). This shows that although technology can streamline processes, the outcomes of those processes remain paramount in determining satisfaction (Parasuraman et al., 1988; Oliver, 1980).

One positive impact of DMAs is the simplification and centralisation of defect reporting. Homeowners no longer need to fill out physical forms or make repeated phone calls; everything can be logged through the app, creating a digital paper trail (Abdul Basit et al., 2023). This has made defect management more efficient and even environmentally friendly by reducing paperwork. Additionally, the app provides a single platform on which all defects are listed, which is convenient for both homeowners and building management to track issues. In principle, such centralisation is expected to make it easier for developers to analyse defect patterns across units, a benefit consistently highlighted in prior studies of defect management systems (Faqih & Zayed, 2021; Aydınoğlu & Bovkır, 2020). Indeed, the respondents recognised these advantages especially first-time buyers, who largely embraced the new system and, when their issues were fixed in a timely manner, felt that the app had been a useful innovation.

However, the limitations and shortcomings of the current DMAs undermine their full potential. A critical issue here is the lack of real-time updates and feedback through the app. This gap creates a feeling of being "left in the dark" (as one participant put it), which is essentially a tech-mediated continuation of the old communication problem. In terms of service quality, responsiveness is not just about doing the job quickly but, also about keeping the customer informed (Parasuraman et al., 1988; Gurmu et al., 2021). The DMAs under review failed to fully embody that principle; consequently, many users had to seek information through alternative channels, undermining the app's purpose of the app (Hashim et al., 2023; Chen et al., 2021). The app must reliably forward the complaint to the right party and then facilitate a prompt and, transparent response. Without timely updates, the app's ability to reassure and satisfy users is severely limited (Zhu et al., 2021). In service quality terms, responsiveness is not only about fixing defects but also about providing assurance through timely updates (Parasuraman et al., 1988). The absence of this feature erodes trust, sometimes prompting homeowners to bypass the app or hire third-party inspectors.

Another crucial aspect is the user interface and the design of these apps. While most users managed to use the apps, complaints about unintuitive navigation and the absence of features (like progress tracking or multilingual support) suggest that current DMAs may not fully adhere to user-centric design principles (Talebi & Bardsiri, 2023; Martínez-Navalón et al., 2020). In our context, something as simple as a progress bar or status indicator for each defect

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could significantly improve user experience by setting expectations (e.g., "In progress – repair scheduled for next week"). The fact that some homeowners reverted to phone calls highlights a technology paradox: poorly designed digital tools drive users back to analogue methods, negating digitalisation goals.

It is important to note that first-time homebuyers' higher satisfaction suggests that over time (and multiple property experiences), users become more discerning. This could mean that as DMAs become more common, simply having an app will not impress homeowners; the apps will be judged on how well they actually facilitate defect resolution (Abdul Basit et al., 2023). Developers should therefore not be complacent in deploying DMAs and assuming that DMAs will automatically improve customer relations and satisfaction. Instead, sustained satisfaction will depend on continuous feature upgrades and stronger back-end integration with contractor workflows and service culture that accompany it (Chen et al., 2021; Aydınoğlu & Bovkır, 2020).

By comparing these results with broader literature, an alignment with general customer satisfaction theory such as Oliver's expectation-confirmation model can be observed. If DMAs failed to meet the promise of efficient defect management (unconfirmed expectations), satisfaction remained low (Oliver, 1980; Zygiaris et al., 2022). On the other hand, when an app or system exceeded what little homeowners expected (for instance, a few interviewees were surprised and pleased when a defect got fixed faster than anticipated), it led to positive satisfaction that might not have existed with traditional methods.

DMAs have the capacity to either mitigate or exacerbate the defect management satisfaction problem. They mitigate it when implemented with a strong focus on user communication and effective issue resolution but, exacerbate it when they add complexity or raise expectations that are unmet (Talebi & Bardsiri, 2023; Saleh et al., 2024). Finally, the findings resonate with local industry observations. The mixed results suggest that while DMAs are a step in the right direction representing progress in digital transformation in built environment but are not a panacea. Their success depends on combining technological solutions with organisational capacity, regulatory standards, and a culture of customer-centred service. Without these, DMAs risk being seen as symbolic gestures rather than meaningful innovations.

In short, this study evaluated the effectiveness of mobile-based Defect Management Applications (DMAs) in enhancing homeowner satisfaction within Klang Valley's high-rise residential market. The results highlight several key patterns. First, adoption of DMAs does not equate to satisfaction; users value convenience but remain frustrated if underlying service delivery problems persist. Second, satisfaction declines as defect counts rise, underscoring the importance of effective back-end coordination to manage large volumes of complaints. Third, generational and experiential differences matter: younger and first-time buyers

tended to be more positive, whereas older and repeat buyers were more critical, reflecting differing levels of digital literacy and expectations. These findings reinforce the expectation–confirmation model, where satisfaction depends on whether outcomes meet or exceed prior expectations.

CONCLUSION

This study contributes to the growing literature on digitalisation in housing by showing that technology alone is insufficient to guarantee satisfaction; rather, satisfaction hinges on the interaction between digital platforms and the service processes they support. Future research could extend this work by conducting longitudinal studies to assess how satisfaction with DMAs evolves over time, exploring cross-country comparisons with more digitally advanced housing markets, and investigating the integration of emerging technologies such as blockchain, augmented reality, or predictive analytics. Such studies would deepen understanding of how digital tools can be embedded within organisational and regulatory frameworks to achieve sustained improvements in housing quality and consumer satisfaction.

In conclusion, DMAs represent a significant step forward in the digital transformation of Malaysia's housing industry. However, their current implementation remains limited in its impact on homeowner satisfaction. Closing this gap will require not only technological innovation but also robust service processes, effective communication, and a stronger culture of customer-centred defect management.

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NEUROCOGNITIVE IMPACTS OF SALUTOGENIC LANDSCAPE DESIGN IN NEIGHBOURHOOD PARKS: AN EEG STUDY ON COGNITIVE RESTORATION

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Abstract

This study examines how park users engage with different spaces, focusing on their experiences in environments enriched by salutogenic and restorative landscape attributes. Investigating the neurocognitive responses to park effects, an electroencephalography (EEG) experiment (n=20, within-subject) was conducted to measure mental performance during exposure to various salutogenic landscape attributes in Taman Aman, Petaling Jaya (TAPJ), and Taman Rekreasi Indah, Shah Alam (TTSA). The analysis includes six primary parameters: Attention, Engagement, Excitement, Interest, Relaxation, and Stress. Statistical analysis (paired t-test with Holm-Bonferroni correction) were conducted to assess significant differences between the EEG metrics across locations. The findings indicate that exposure to salutogenic landscapes resulted in a reduction in mental fatigue, with higher Relaxation and lower Stress at TTSA than TAPJ ($t= -7.94$, $p < .001$; $t= 5.87$, $p < .001$), higher Excitement at TAPJ ($t = 3.46$, $p= .003$), higher Attention and Interest at TTSA ($t= -3.30$, $p= .004$; $t= -2.23$, $p= .038$), and non-significant differences for Engagement ($p=.226$). These findings enhance our understanding of the relationship between spatial design and cognitive recovery in urban green spaces, providing valuable insights for landscape architects and urban planners in designing healthier, more restorative urban environments.

Keywords: Neighbourhood Park, Neurocognitive, Psychological impact, Salutogenic design

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INTRODUCTION

Urban residents face heightened stress risks due to a hectic lifestyle and other contributing urban stressors. Research on the relationship between psychological well-being and urban design has increased in recent years. Scholars have long debated the impact of urban life on stress, considering factors like overcrowding, poor environmental quality, traffic, and work-life balance (Ward Thompson *et al*., 2016). These challenges adversely affect people's health, particularly their mental well-being. Urban green spaces, especially neighbourhood parks, have received a lot of attention in recent years for their ability to improve people's well-being and promote positive human behaviour in the living environment (Shobri *et al.,* 2021). While research shows that parks promote social and recreational activities for physical well-being, there is still a gap in identifying how spatial design effects mental performance, particularly in terms of reducing mental fatigue. Parks with salutogenic and cognitively restorative attributes can promote mental recovery, yet the neurocognitive evidence in real settings remained limited. Little is known about the association between the human mind and the environment (Akpınar, 2021), specifically how our brain (cognitive) corresponds with the environment they experienced.

Urban green spaces have an important function in mental health and cognitive restoration (Olszewska-Guizzo *et al*., 2022). It is crucial to understand how landscape components contribute to cognitive and psychological well-being. Salutogenic design principles, based on Antonovsky's (1996) Sense of Coherence (SOC) theory emphasise an environment that promotes psychological resilience and mental well-being. However, there is a lack of actual neuropsychological evidence to support these ideas. This study uses EEG-based neurocognitive analysis to assess the cognitive and psychological effects of salutogenic neighbourhood parks. Most studies on the restorative potential of green spaces use self-reported data rather than objective neuropsychological markers. The use of EEG performance metrics offers a more scientifically grounded approach to investigating how different landscape design attributes influence cognition, stress and relaxation. Therefore, this study aims to investigate the EEG-based mental performance metrics across various salutogenic landscape attributes in neighbourhood parks, and identify which attributes are associated with increased relaxation and reduced stress.

LITERATURE REVIEW

The Impact of Landscape Design on Neurocognitive Function

Landscape design could have an important role in supporting cognitive restoration, which includes reducing mental fatigue and improving cognitive functioning. According to the Attention Restoration Theory (Kaplan, 1995), exposure to natural environments can improve attention and cognitive restoration.

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Researchers discovered that recognising this relationship assists urban designers in improving environmental quality and indirectly encouraging positive behaviours (Ward Thompson *et al*., 2016). Many scholars observed that people living environment influences their emotions and psychological well-being (Xingrui & Ibrahim, 2024). Studies from throughout the world shows that applying neuro-based design is viable. In Edinburgh, a mobile EEG study found that walking from urban busy streets to green spaces promoted restorative neural processes and improved happiness (Aspinall *et al.,* 2015). A study in Finland observed that nature stimuli increase Alpha activity and physiological restoration (Grassini *et al.,* 2022). In Japan, contemplative gardens and forest therapy sessions increased cognitive function and mood, served as model for therapeutic garden for hospital and parks (Hiramasu *et al.,* 2022). Experimental research indicates that time spent in natural settings offers both perceived and actual benefits, such as reducing cognitive fatigue and improving mood. The Attention Restoration Theory (Kaplan, 1995) and the Stress Reduction Theory (Ulrich, 1991) propose that natural environments can replenish cognitive resources depleted by daily activities. Neuroimaging studies with EEG and functional magnetic resonance imaging (fMRI) (Yen *et al*., 2023; Grassini *et al*., 2022) demonstrated increased alpha brainwave and reduce amygdala activity in natural setting, indicating a relaxed but attentive state that is important for mental restoration.

Salutogenesis and Salutogenic Design

The term salutogenesis was first coined by sociologist Aaron Antonovsky in 1979 whose research focused on stress, health, and well-being. His research examined ways to improve or provide health benefits (Bauer *et al*., 2020). Antonovsky presented the scientific community with the salutogenic phrase and idea of Sense of Coherence (SOC). He defines the SOC as a person's reflection of life in response to stressful situations (Mittelmark, 2016). The concept of salutogenesis then expanded to the design fields. Alan Dilani (2008) introduced Psychosocially Supportive Design, which incorporates SOC theory into architecture to improve the healthcare facilities design. Golembiewski (2012) takes this a step further by incorporating neurological components into architectural design for mental health care, with a focus on cognitive recovery through rehabilitation approaches. Maikov (2016) has extended these principles to landscapes using the Emotional Character Line Method (ECLM) to create therapeutic garden spaces. Each space combines visual, sensory, environmental, cultural and social components to promote mental health and mental resilience in a variety of settings.

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METHODOLOGY

This study employed a quantitative approach using EEG field experiments at selected neighbourhood parks. The details regarding the selection of study sites and attributes, as well as the EEG experimental protocol, are as follows:

Salutogenic Design Attributes: Experimental Stimulus

The salutogenic design attributes were based on the basis of the salutogenic and cognitive landscape stimuli that derived from the conceptual model we had developed in our previous research (Syed *et al*., 2023; Thani *et al*., 2022)). Figure 1 shows the details of the salutogenic and cognitive design attributes.

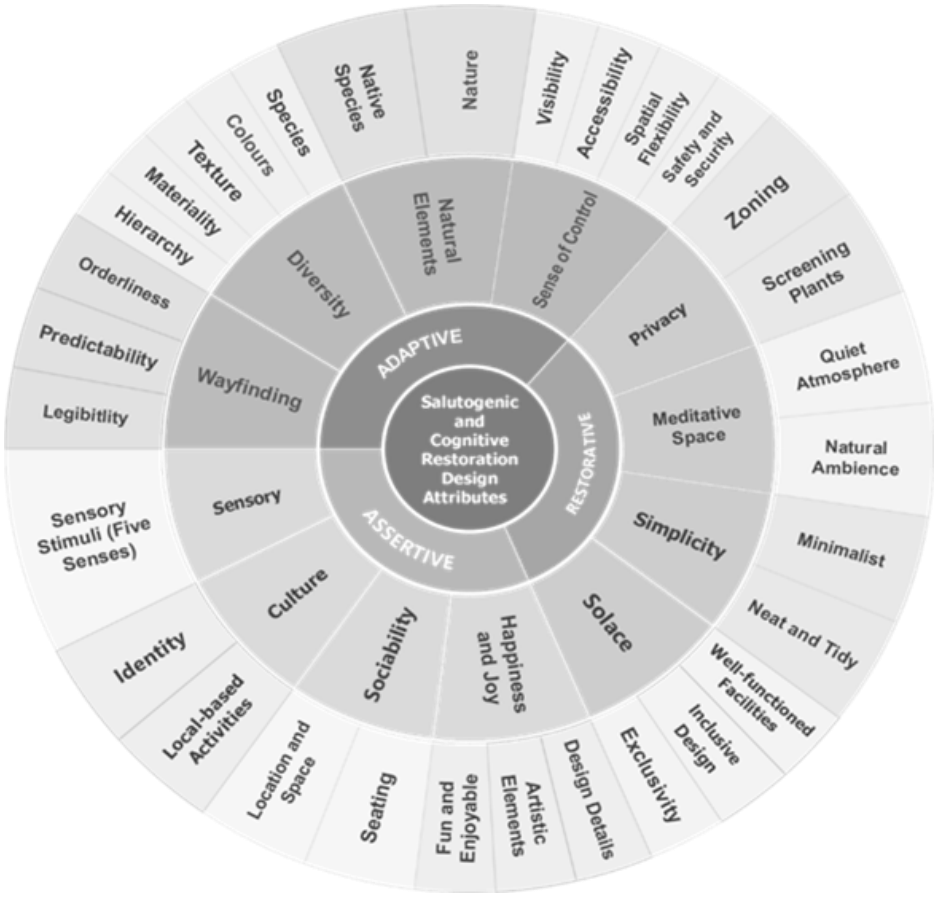


Figure 11: Salutogenic and Cognitive Design Attributes
Source: Authors (2022, 2023)

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Each of the salutogenic design attributes are briefly defined as follows:

Adaptive stimuli
Stimuli that trigger involuntary attention, enhancing focus and environmental awareness, promoting a sense of control and increasing user concentration.

Restorative stimuli
Stimuli that promote relaxation through open space, waterbodies, vistas, minimal elements, and lush greenery.

Assertive Stimuli
Stimuli that promote sense of welcoming and belonging through sensory, cultural, tactile, and vibrant landscape elements.

Study Sites
Two neighbourhood parks, Taman Aman in Petaling Jaya (TAPJ) and Taman Rekreasi Indah (Tasik Tengah) in Shah Alam (TTSA), were selected for this study. These parks are located in urban residential areas and primarily serve as green spaces for local residents. Based on our previous research on salutogenic and cognitive attributes (Thani *et al*., 2022), result from the site assessments indicates that TAPJ and TTSA possessed excellent salutogenic and cognitive restorative stimuli, which are important variables to be assessed in EEG field experiment. Figures 2 and 3 show the selected locations for EEG experimental study at both neighbourhood parks.

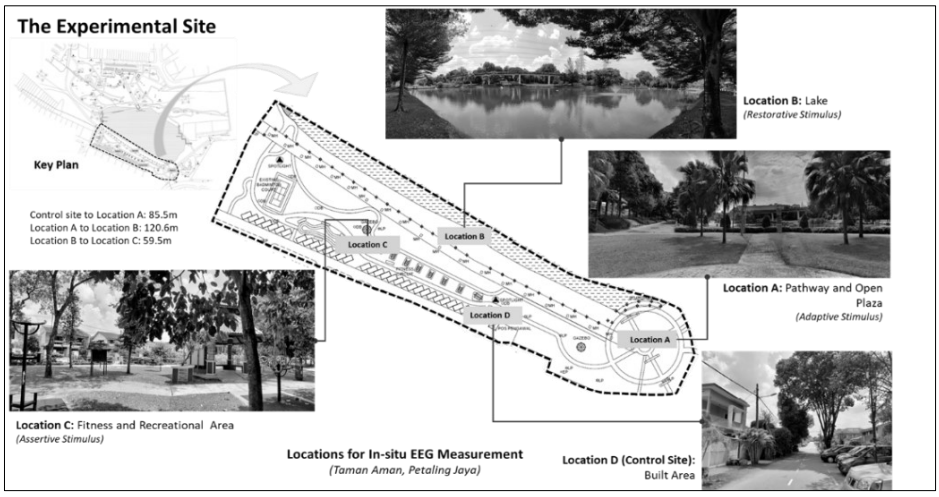


Figure 2: Selected locations at Taman Aman for EEG field experiments
Source: Authors (2025)

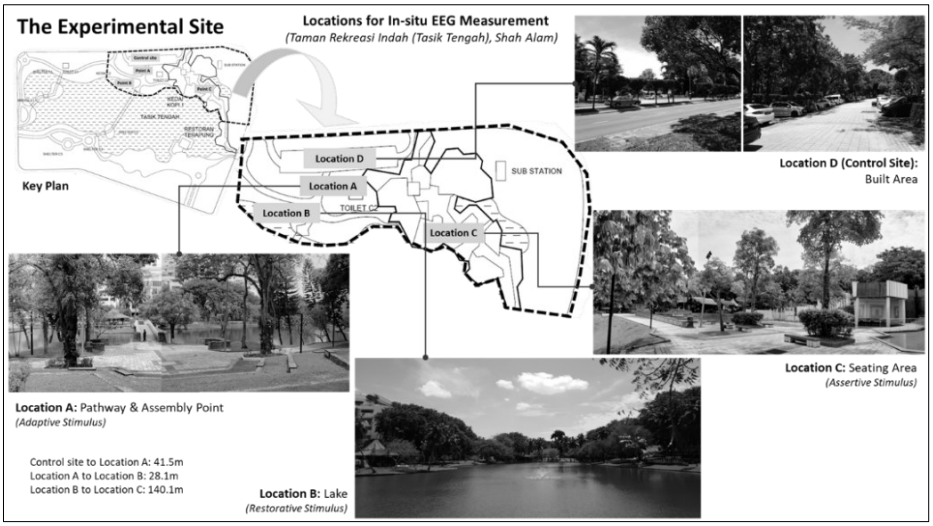


Figure 3: Selected locations at Taman Rekreasi Indah for EEG field experiments
Source: Authors (2025)

Subjects

The convenience sampling method was used to recruit participants for this study. Recruitment involved forwarding a request for voluntary participation to park users at both sites. A total of 20 subjects, aged 20 to 33 years, were recruited, ensuring gender balance (n=10 males and n=10 females). This study followed Declaration of Helsinki and obtained ethical approval from Universiti Malaya Research Centre (UMREC) prior to the commencement of data collection involving human subjects. The participant's anonymity, safety, and confidentiality were guaranteed, and participant's consent were obtained before experiment.

Experimental Protocol

A day prior to the experimental schedule, participants were notified via text message. They were instructed to follow certain instructions, such as getting sufficient sleep and rest, avoiding physically demanding activities, refraining from applying hair wax or spray, and not taking any medications the day before the experiment.

During the day of experiments, participants received detailed information about the study's procedures, and written consent was obtained. The EEG device was calibrated and installed on each participant's head. Participants were asked to close and open their eyes alternately for two minutes to obtain the baseline data. Next, they were instructed to walk to the experimental location, sit on a chair facing the selected landscape scene for three minutes, followed by

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closing their eyes for two minutes before moving to another sit-and-view location. Once the recording for all scenes was completed and the device was removed, participants received a token of appreciation and were dismissed. The overall duration of experiment was approximately 30 to 45 minutes per participant. Figure 4 shows the EEG headset and a participant wearing the equipment during experiment.

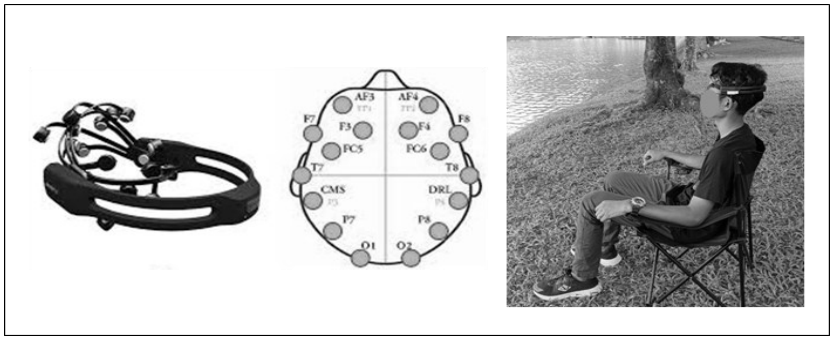


Figure 4: EEG Emotiv EPOC+ device (left), 14 electrodes (middle) and participant wearing the device during field experiment
Source: Authors (2023)

EEG Data Acquisition and Analysis

The brainwave data were collected using the Emotiv EPOC+ EEG device. This non-invasive device offers the benefit of 14 electrodes data acquisition, corresponding to the international 10 –20 position system (Wehrman *et al*., 2021). During the experiment, the brainwaves were captured by connecting the headset with the software via USB Bluetooth to the laptop. Figure 5 shows the EEG signal of mental performance captured during experiment.

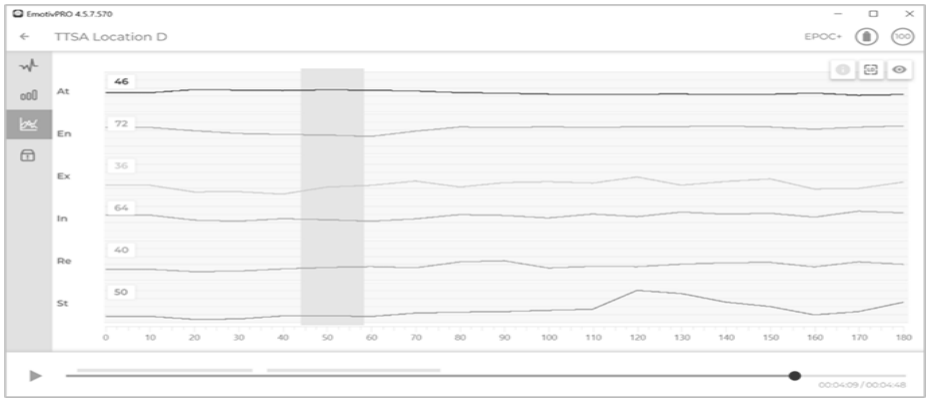


Figure 5: EEG mental performance signal captured during field experiments
Source: Authors (2025)

For data analysis, the EEG signal processing was conducted through EmotivPRO software. After data cleaning and artifact removal, the mental performance analysis pipeline was selected to generate the mean value of mental performance for each parameter. In this analysis pipeline, the EEG signal for mental performance metrics data were converted to CSV file and averaged to get the mean value of each parameter (*Performance Metric Reports |EmotivPRO Analyzer*, 2024). The extracted mean values then exported to SPSS v27 for further statistical analysis. The key parameters measured is shown in Table 1.

Table 10: Key parameters of Mental Performance Metric

Performance Metric Parameters	Indicator
Interest (In)	Measure a stimulus's attraction or displeasure.
Excitement (Ex)	Measure the intensity of reaction or stimuli.
Engagement (En)	Measure person's level of engagement during a task.
Attention (At)	Measure prolonged concentration on a single job.
Relaxation (Re)	Measure relaxation after intense focus.
Stress (St)	Measure mental tension during a task.

Source: www.emotiv.com (2025)

RESULTS AND DISCUSSION

Mental Performance Distribution Across Locations

The EEG mental performance is varied from location to location and reflects the different characteristics of the landscape attributes in each park. The distribution of mental performance at both parks is shown in Figure 6.

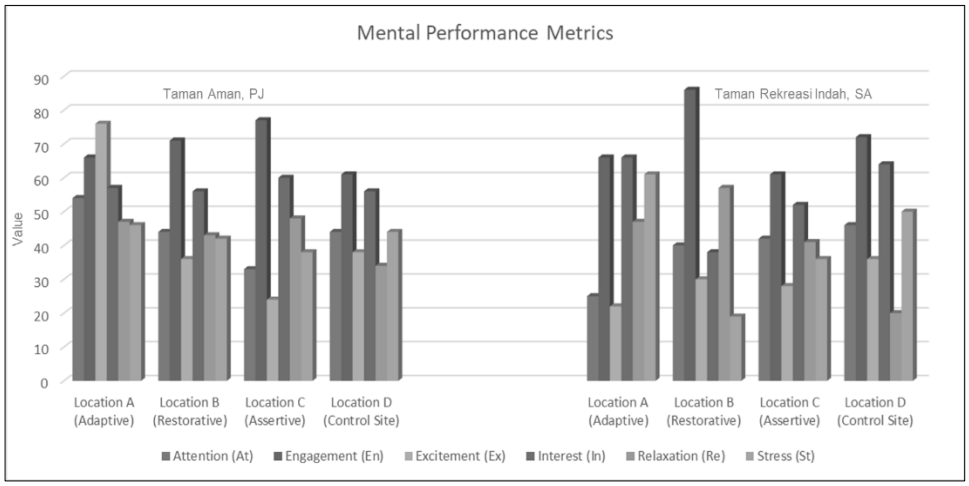


Figure 6: Distribution of EEG mental performance across locations at TAPJ and TTSA
Source: Authors (2025)

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For Attention (At), the highest attention was measured at TAPJ Location A (*adaptive* stimuli) with 54 values, followed by TTSA Location C (*assertive* stimuli) with 42 values. This suggests that structured landscapes, particularly adaptive spaces, promote mental engagement and concentration, supporting the Attention Restoration Theory (ART) by Kaplan (1995). For Engagement (En), the highest value was found at Location A at both TAPJ and TTSA (*adaptive* stimuli) with 66 values. These results suggested that Engagement (En) is associated with cognitive and sensory stimulation, which is prominent in environment that have clear direction, visibility and implying visual susceptibility (Attar, 2022; Darfler *et al*., 2022). TAPJ showed highest levels of Excitement (Ex) at Location A with 76 values. In TTSA, the Excitement (Ex) levels averagely lower than in TAPJ with only 36 values.

Overall, the mental performance showed higher levels of excitement in TAPJ than TTSA. The possible reason could be influenced by the availability of more recreational and leisure facilities in TAPJ than in TTSA. A study by Farooq et al. (2020) observed that structured pathways, diverse vegetation and interactive elements contribute to emotional attachment. For Interest (In), the highest values (52) were recorded at TTSA Location C, emphasising the influence of semi-structured landscapes that encourage exploration and curiosity. TTSA Location B had the highest relaxation scores, emphasising the idea that restorative landscapes with lush greenery, picturesque vista, shade and water elements promote mental relaxation. The lowest stress levels were found at TTSA Location B. Consistent with paired t-tests (n = 20, Holm-Bonferroni), Relaxation was higher and Stress lower at TTSA than TAPJ ($t = -7.94$, $p < .001$; $t = 5.87$, $p < .001$), Excitement higher at TAPJ ($t = 3.46$, $p = .003$), Attention higher at TTSA ($t = -3.30$, $p = .004$), and Engagement non-significant ($p = .226$) (refer Table 2).

Table 2: Statistical summary of EEG mental performance metrics

Metric	TAPJ Mean ± SD	TTSA Mean ± SD	Mean Diff (TAPJ − TTSA)	t(df=19)	p (Holm)	Cohen's dz
Attention	55.2 ± 4.8	61.8 ± 6.5	-6.5	-3.30	0.011	-0.738
Engagement	58.9 ± 8.3	56.5 ± 5.1	2.4	1.25	0.226	0.280
Excitement	59.0 ± 6.2	53.2 ± 5.3	5.7	3.46	0.011	0.774
Interest	57.2 ± 4.9	61.3 ± 5.4	-4.1	-2.23	0.076	-0.499
Relaxation	48.6 ± 5.1	64.5 ± 6.5	-15.9	-7.94	<.001	-1.776
Stress	66.3 ± 7.1	53.6 ± 8.0	12.6	5.87	<.001	1.313

Note: Mean difference is TAPJ minus TTSA; negative values indicate higher scores at TTSA. Holm–Bonferroni correction applied across six mental performance metrics.

This confirms that natural, restorative environments with minimal urban interventions significantly reduce stress responses (Wang *et al*., 2020). These findings are consistent with Attention Restoration Theory (Kaplan, 1995) and Stress Recovery Theory (Ulrich, 1983), both of which emphasise the

restorative and cognitive benefits of green spaces, particularly in urban environments.

Mental Performance and Salutogenic Landscape Attributes

The results show how different landscape typologies influence mental performance by highlighting the neurocognitive impacts on cognitive engagement, relaxation and stress recovery. Table 3 tabulate the relationship between mental performance and salutogenic landscape attributes.

Table 3: Relationship between mental performance and salutogenic landscape attributes

Salutogenic Attributes	Location (Highest Value)	Mental Performance Findings	Landscape Typologies
Adaptive	TAPJ Location A / TTSA Location C	High attention and excitement, suggesting cognitive stimulation.	An open space surrounded by plants, walkways, and promenade. Outdoor cafeteria
Restorative	TTSA Location B/ TAPJ Location C	Lowest stress, highest relaxation, optimal for mental restoration.	A lake surrounded by greenery Outdoor gym, promenade
Assertive	TTSA & TAPJ Location C	High engagement and interest, balancing interaction and relaxation.	Social and recreational spaces
Control Site	TTSA & TAPJ Location D	Average EEG responses, lacking distinctive restorative or stimulating features.	Parking spaces and roadside

The findings shows that *adaptive* landscapes provide a dynamic interaction between built and natural elements that stimulate cognitive functions and improve mental focus (Browning *et al*., 2020). A study by Darfler et al. (2022) noticed that presence of clear spatial layout, structured pathways and visual focal points has been associated with increased sustained attention and mental alert. In addition, interactive spaces such as outdoor cafeterias in TTSA provide multisensory stimulation that promotes higher neural activity, thus increasing engagement and cognitive alertness (Akpinar *et al*., 2021). These findings are consistent with Attention Restoration Theory (Kaplan, 1995), which posits that structured environmental elements increase attention by providing directed cognitive engagement. Based on the findings, it was observed that the areas with restorative landscapes like lake and lush greenery recorded the highest relaxation and lowest stress in the EEG mental performance readings. *Restorative* landscapes, characterised by dense vegetation, water elements and open natural vistas facilitate psychophysiological recovery from stress (Wu *et al*., 2022). The presence of blue spaces (such as lakes and water bodies) is associated with enhanced relaxation and lower cortisol levels, an important biomarker of stress

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(Ward Thompson *et al*., 2016). *Assertive* landscapes integrate elements that encourage active participation and social interaction like outdoor gym in TAPJ and outdoor cafe in TTSA. The presence of recreational spaces such as outdoor fitness area and interactive plazas stimulates sensorimotor and cognitive functions and promotes engagement without inducing excessive stress (Zeng *et al*., 2021). These landscapes provide a transitional balance between cognitive arousal and relaxation that supports emotional resilience and sustained mental well-being. These findings are consistent with Cognitive Load Theory (Sweller, 2011), which suggests that environments with moderate cognitive demands optimise mental engagement and minimise cognitive overload, that will help in reducing mental fatigue. Control sites are characterized by low landscape diversity and minimal natural elements, which result in reduced cognitive and emotional engagement. Research has shown that urban hardscapes devoid of greenery fail to facilitate cognitive restoration or emotional relief, leading to increased mental fatigue and stress accumulation (Browning *et al*., 2020).

CONCLUSION

This study highlights the significant impact of landscape attributes on neurocognitive function, mental well-being and stress recovery. By categorising landscapes into *adaptive, restorative* and *assertive* based on salutogenic attributes, the findings provide a structured framework for designing urban environments that support mental health. *Adaptive* landscapes attributes enhance cognitive engagement and alertness through structured design, clear wayfinding, and dynamic visual elements. *Restorative* attributes promote relaxation and stress reduction by incorporating open spaces, water features and minimal interventions to create tranquil environments that facilitate mental restoration. *Assertive* landscapes strike a balance between engagement and relaxation by integrating sensory stimulation, cultural elements, and social spaces, fostering a sense of belonging and emotional resilience. In contrast, control sites lacking these beneficial elements show minimal cognitive or emotional benefits, emphasising the importance of deliberate urban landscape design. Future research should focus on longitudinal EEG studies to assess neurocognitive changes over time and further explore how different landscapes influence mental well-being. By incorporating EEG-based restorative attributes into park design guidelines, local authorities can incorporate these findings into practical health promotion strategy in relation to urban design and landscape planning.

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ETHICAL STATEMENT

The authors adhere to the ethical procedures from Declaration of Helsinki and Universiti Malaya Research Ethics Committee (UMREC) (Ref. No: UM. TNC2/UMREC_1109) before commencing the data collection.

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DOUBLE-TRACK RECOVERY STRATEGY TO ADDRESS THE SUSTAINABLE RECOVERY FOR COMMUNITIES IMPACTED BY THE SEMERU ERUPTION, INDONESIA

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Abstract

Sustainable recovery has become an emerging issue in cyclical disasters like the Semeru Volcano. This study aims to explore community recovery strategies of affected communities after the Semeru eruption through the track of socio-economic recovery and preparedness strengthening. This research uses a qualitative approach to pursue a community recovery strategy. The collected data were analysed utilising the Colaizzi method. This study has identified double systematic tracks employed by the communities to recover from the impacts of disasters and confront subsequent hazards. The first track involved reactivating social activities to restore social cohesion effectively within the relocated community. Concurrently, livelihood restoration occurs through adaptation and diversification. In the second track, the resilience of the community was strengthened. Preparedness continues to increase among individuals, families, and communities, both those undertaken independently and in collaboration with the government and non-government organisations. This study suggests that pursuing double tracks of socio-economic recovery and resilience enhancement represent a strategic way for achieving sustainable recovery. Hence, local governments can adopt double-track strategies to develop disaster-prone areas, particularly Semeru Volcano.

Keywords: Double Track, Communities, Semeru Eruption, Sustainable Recovery

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INTRODUCTION

More than 62 million people have been directly affected by disasters over the past two decades (UNDRR, 2023). In the long run, disasters can cause societal trauma that affects social order, including changes in societal dynamics, social norms, and collective well-being. Long-term losses also affect local economic sectors and broader development effects (Tasri et al., 2022). In extreme cases, disasters cause displacements and affect the demographics, social structure, and economic development.

Semeru is one of the most active volcanoes in Java, and it has a short cycle of events. On 4 December 2021, it experienced an eruption that significantly impacted various sectors on the housing, infrastructure, social, and economic sectors, with losses amounting to IDR 1.8 trillion (USD 110.6 million). Since March 2022, various government organisations (GOs) and non-government organisations (NGOs) have been carriying out post-disaster recovery efforts. However, eruptions occurred again in 2022 and 2023.

Sustainable post-disaster recovery management is an essential activity for disaster resilience. The principle of post-disaster recovery, as emphasised in the Sendai Framework for Disaster Risk Reduction (SFDRR), is to restore life to a better and safer level (Dube, 2020). Sustainable disaster recovery must involve community participation, considering social and cultural dynamics. Sustainable recovery also leads to increased community resilience to face impending disasters.

There is still little research on sustainable recovery, especially in aligning community strategies for recovery while facing cyclical disasters such such as the Semeru Volcano Eruption. Researchers selected some previous studies to look at research gaps. Daly (2020) showed that in the case of the 2004 Aceh tsunami, sustainable livelihood programmes were ineffective. In the case of cyclone Aila on 25 May 2009 in Bangladesh, Islam and Wahab (2020) showed that although the recovery was led by the community, there was no preparedness. Zhou (2022) described the dimensions for a more comprehensive but non-cyclical disaster-sustained recovery, namely, for the earthquake on 12 May 2008 in China. For this reason, this study explored the initiatives of affected communities through a double-track strategy to recover from the 2021 Semeru eruption while facing the possibility of further eruptions.

This study was aimed at exploring the recovery strategies of affected communities after the Mount Semeru eruption through the tracking of socio-economic recovery and the strengthening of preparedness.

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LITERATURE REVIEW

Community Participation in Sustainable Recovery

The literature on sustainable recovery describes critical principles for ensuring that sustainable post-disaster recovery is underway in disaster-affected areas. First, ensuring that rehabilitation and reconstruction planning leads to long-term planning (Irawan et al., 2021). Second, community participation should be ensured in post-disaster planning, decision-making, and management processes (Islam & Wahab, 2020; Tatebe & Miyamoto, 2021). Third, post-disaster implementation must have a disaster risk reduction perspective to deal with future disasters (Smith & Wenger, 2007). Finally, ensuring post-disaster implementation contributes to sustainable development indicators (Dube, 2020). Long-term post-disaster recovery requires ongoing support and resources to rebuild infrastructure, restore services, and provide ongoing support for individuals and families affected by disasters (Iuchi & Mutter, 2020).

In the context of community participation, people affected by disasters are not limited to participation in rehabilitation and reconstruction projects. They also have initiatives to recover from post-disaster situations to rise quickly (Dhungana & Curato, 2021). The forms of these initiatives do not depend on the presence or absence of rehabilitation and reconstruction projects. However, self-pursued recovery initiatives are still limited to the recovery orientation at the household level. At a higher level, community-led recovery initiatives are where community groups collectively design and manage recovery (Dhungana & Curato, 2021; Paripurno et al., 2022). In the broader spectrum of disaster management, this process is also called a coping mechanism by the community to solve problems and deal with stress (Bachri et al., 2023; Otsuyama et al., 2019).

Social capital formed from social bonds between individuals and groups within the community influences the post-disaster recovery process. Social networks, norms, and beliefs can spark cooperation and collective action among community members, ultimately improving their livelihoods (Feinberg et al., 2023; Sobhaninia, 2023). Furthermore, social capital helps address societal challenges, such as limited resources, geographic isolation, crises, and potential conflicts (Irawan et al., 2021).

Livelihood capacity and livelihood diversification also affect the sustainable recovery process (Liu et al., 2022), which depends on the recovery and expansion of economic activities and the development of various livelihood opportunities (Islam & Wahab, 2020). A livelihood is said to be sustainable if it can overcome and improve itself from stress and disaster, maintain or improve the capacity of assets, and provide a sustainable livelihood for the future (Liu et al., 2022).

Community Preparedness for Volcanic Disasters

Disaster preparedness is critical to sustainable recovery (Smith & Wenger, 2007). Lack of disaster preparedness can result in property damage and heavy human casualties (Kurata et al., 2022). Preparedness for volcanic eruption disasters is related to individual, household, and village preparedness. Household preparedness includes cognitive, physical-operational, financial, social, and psychological dimensions (Najafi, 2022). Meanwhile, village-level preparedness is influenced by governance, early warning information systems, and village contingency planning (Irawan et al., 2023; Kurniawan et al., 2022)

Knowledge of hazards is essential in perceiving the impact of disasters on the preparedness to respond (Kurata et al., 2022). Effective media and information dissemination are the most significant factors affecting preparedness for volcanic eruptions. So, the public is encouraged to seek information about volcanic eruption warnings from media and valid information sources (German et al., 2022). External knowledge is usually obtained from programmes and information provided by GOs and NGOs and the media (Kurniawan et al., 2022).

However, tacit knowledge and local knowledge that have been produced for a long time determine the level of preparedness (Firdaus et al., 2023). Local knowledge is formed because of the community's emotional attachment to its environment, which is called place attachment. Place attachment is a bonding between individuals or groups and their environment. The bond that is created between the individual and a place is shaped by the complexity of emotional, social, symbolic, spiritual, ecological, and cultural factors (Purnomo, 2017; Swapan & Sadeque, 2021) This bond triggers the community to continue to survive in its territory from generation to generation so that the intensity of economic activities and land use in the volcanic area continues to grow (Bachri et al., 2024). Intergenerational heritage also includes knowledge that is essential to maintaining the preparedness and resilience of community institutions in the volcanic region (Wardekker et al., 2023).

The discussion above is a brief overview of the current state of the literature review for this study to identify the recovery phenomena with a double-track approach to achieve a sustainable recovery. Recovery efforts must go hand in hand through a double-track strategy. The double-track strategy in this study led to the understanding that preparedness and recovery are no longer understood as sequences of a disaster (pre and post) but have become a unitary agenda, especially when facing cyclical disasters such as the Mount Semeru eruptions.

RESEARCH METHODOLOGY

This research used a qualitative approach known as phenomenology to focus on the perceptions of People Affected by the Semeru Eruption (PASE) to reveal the facts that arose on the ground. The PASE of various backgrounds and

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occupations, who had all been affected by the Mount Semeru eruption and relocated to Bumi Semeru Damai (BSD), were interviewed to obtain their stories and document their experiences. Purposive sampling was used to locate the affected communities living in BSD based on their village of origin and current occupation. The provincial BPBD officer, District BPBD officer, and Mount Semeru monitoring post officer were interviewed to validate the support provided by the government. Site checks were conducted at the locations mentioned by the interviewees to obtain a first-hand picture and validation. The purpose of the study was explained to the interviewees, and formal consent was obtained by having them sign a consent form. The list of interviewees is shown in Table 1 using codes for reasons of confidentiality of the interviewees. Figure 3 shows a site-check map of crucial points in the participants' stories.

Table 1: A List of the Research Participants

	Code	Sex	Age Range	Occupation	Interview Date
1	S012023-F	F	51-60	Merchant	October, 2023
2	L092023-M	M	51-60	Farmer, Village Volunteer	September, 2023
3	SA032024-F	F	41-50	Women's Group	March, 2024
4	N032024-M	M	41-50	Chairman of KUBE	March, 2024
5	SR022024-M	M	51- 60	Hamlet Coordinator	February, 2024
6	RO302024-M	M	31-40	Sand Miner Labourer	March, 2024
7	LI052024-M	M	41-50	Supervisory Post	May, 2024
8	AN052024-F	F	41-50	District BPBD	May, 2024
9	AR042024-M	M	31-40	Provincial BPBD	April, 2024

Data collected through semi-structured interviews and face-to-face Focus Group Interviews (FGI) regarding a series of open-ended questions led to sustainable recovery strategies. The critical questions are: 1) What is the impact of disasters and relocation? 2) How to restore livelihoods? 3) How do we knit social bonds? 3) What is the current knowledge of disaster risk? 4) How can preparedness and mitigation be pursued? The semi-structured interview technique is versatile and flexible, and it allows new questions to arise because of the answers given by the resource person. This way, information mining can be done more in-depth during the session.

This study uses analysis with the Colaizzi technique. The six steps we have taken according to the stages of Colaizzi are shown in Figure 1. The steps are as follows; 1) Transcribing the interview results using semi-verbatim techniques and extracting significant statements into a code. 2) Formulate general restatements or meanings for each significant statement extracted from the participant's narratives. 3) Aggregating formulated meanings into groups of similar types/clusters. 4) synthesizing all theme clusters into a comprehensive description of the experience articulated by participants. 5) Identifying the

fundamental structure of the phenomenon through an analysis of the exhaustive description of the phenomenon that aligns with the study's aims. 6) Validating through a follow-up appointment with participants to validate the essence of the information with participants.

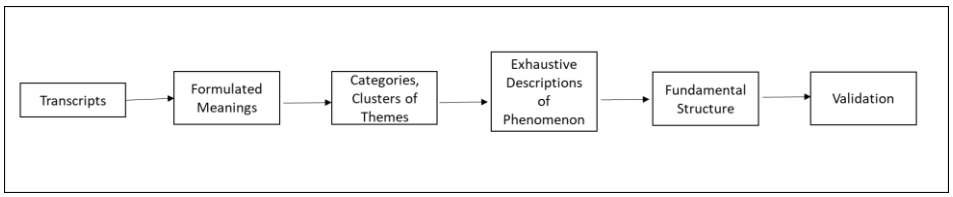


Figure 1: Stages of Colaizzi in Research Adopting Shosha
Sources: Shosha (2012)

ANALYSIS AND DISCUSSION

Disaster Impact, Relocation, and Efforts to Defend the Area

The PASE experienced a very significant impact due to the Mount Semeru eruption in 2021. They acknowledge the impact of this eruption, the largest of its kind, since the 1976 Kebondeli disaster, which resulted in 110 deaths. According to data from the Regional Disaster Management Agency (BPBD), the eruption on 4 December 2021 resulted in severe damage to 1107 houses, moderate damage to 95 houses, and light damage to 657 houses, including damage to environmental infrastructure. Also, the damage and losses to transportation infrastructure, water resources infrastructure, irrigation networks, clean water, and sanitation infrastructure amounted to IDR1.3 trillion (USD81 million). In addition, the economic and social sectors suffered damage and losses of IDR111.6 billion (USD6.97 million), including impacts on agriculture and animal husbandry, industries, tourism, MSMEs, health facilities, educational facilities, and places of worship.

As a result of the eruption, the PASE could not stay at home, perform routine tasks, or carry out social community activities. For approximately three months or even up to a year, they lived in refugee camps, relying on assistance from GOs and NGOs. Their primary source of livelihood, agriculture, suffered huge losses; the land could not produce, their livestock died, and activities such as sand mining ceased, as conveyed by the following interviewees.

"Semeru has a lot of land for residents to plant salak fruit. The Pronojiwo residents, who were the largest producers of salak fruit, suffered heavy losses due to the Semeru eruption. Their cattle died and they could not farm the land." - L092023-M.

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The participants from the BPBD explained that the relocation policy was implemented because the affected area could not be occupied as it was in the red zone. Before the relocation was carried out, the government consulted with the PASE. As a result, the government decided to relocate the PASE to Sumbermujur Village, about 6-7 km from their original location, as shown in Figure 2. Then, the government provided an area of ± 81.55 Ha for occupation by the 1951 households. This policy, referred to as Regency Decree No. 188.45/191/427.12/2022, concerned the relocation master plan for the PASE. According to the government, this was the best location as the land was available and ready for occupation, the people would have access to their livelihoods, and it was away from the red zones.

"When determining Sumbermujur Village as the location for relocation, the Regency worked very quickly. Land use permits from the Minister of Environment and Forestry were quickly obtained for the forest areas. Dialogues with residents, those who would be relocated and the native residents of Sumbermujur, were also carried out; although there were protests and disapproval from residents, a solution was found so that the Ministry of Public Works and Public Housing (PUPR) could quickly begin constructing the houses and complete them in less than three months." - AN052024-F.

The residential relocation and construction process was carried out by the government through the PUPR Ministry and NGOs with a target of three months between January and March 2022 for completion. The Central Government built the main building (permanent structure) using the panel method. Non-government organisations (NGOs) built the kitchen side in a semi-permanent building. The government admitted that they did not involve the PASE in the development process and preferred to use externally trained personnel due to the demands of the rapid target and administrative issues. The resettlement of the PASE from the refugee camp to the relocation area was completed following the verification and validity of the data through joint inspections by the village government, local government, and central government. In addition to building 1951 houses, the government also built public facilities, places of worship, fields, schools, trade stalls, and health facilities.

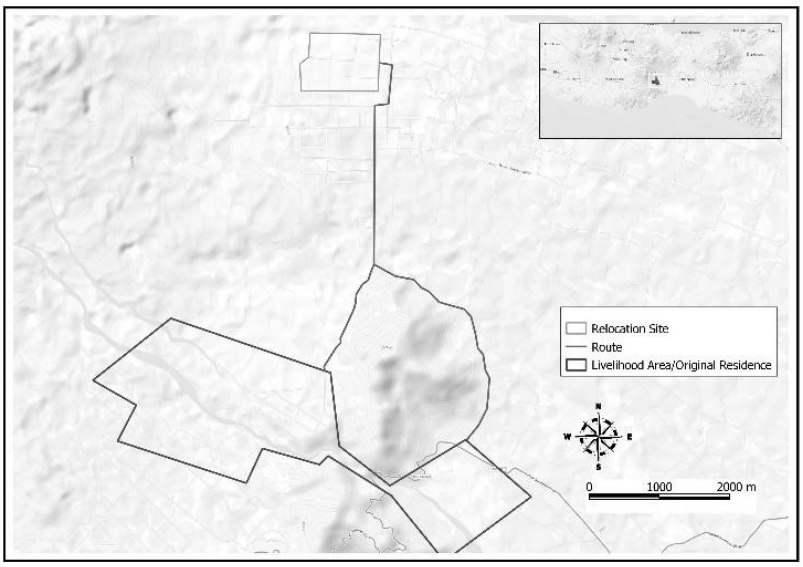


Figure 2: The location of the PASE's place of origin and the relocation area.
Source: Analysis (2024)

The PASE are still motivated to maintain the area and remain in the disaster-prone area because of their attachment to the environment, a bond that was built in the past. The ancestors of the PASE built their social life order, livelihood systems, land heritage, and shelters on the slopes of Mount Semeru. The long-standing bonds of shared identity, culture, and experiences among the PASE have fostered bonds with the environment and in collective action. This condition is a powerful representation of the wisdom of the Javanese people, who value the heritage of their ancestors and ties to the life-giving environment (Hasan et al., 2023). The bond between the Javanese people and the environment is also expressed by their livelihood patterns that depend on the natural potential: arable land and mining resources (Sardjuningsih et al., 2023). Human bonding with the environment strongly refers to place attachment (Swapan & Sadeque, 2021).

In the relocated area, the PASE have limited access to land for farming or at least supervise the land daily because they have moved away. Their new residence, a 36-m^2 building close to their neighbours, does not provide them with the rural landscape they were used to. The design of the relocation area does not allow for produce from fields, which are usually in the backyard of the house building. In addition, most of the PASE are separated from their relatives or neighbours.

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"Yes, how else? We are already traumatised by the past events. So, we chose to live here even though we could not farm around the houses like we did in Curah Kobo'an. The neighbours and relatives do not all live in the same block. Now, we are also confused about the status of the land we left behind, the one the government said we should not live on." – S012023-F.

Community Efforts to Recover

The findings of this study showed that what the PASE have done to recover after the eruption has been to restore livelihoods adaptively. In addition, the PASE believe that social capital is the path to a quick recovery from the crisis caused by the eruption (Figure 3).

Social cohesion has begun to grow through community group activities, worship, and mutual assistance in the new neighbourhood. There are at least four places of worship, three social facilities, a football field, and a family park. In addition, they also continue to visit the destroyed houses and farms on their original land to maintain their heritage and ancestral ties. The resource person mentioned the importance of social capital for the recovery process.

"Here, the social facilities are quite tight. It is crucial to show group activities. If activities such as yasinan have begun to run, ladies and gentlemen. That is very important for srawung." - SA032024-F.

Social capital is a significant supporting factor in recovery (Ómarsdóttir et al., 2022). The PASE have been able to transform their social relationships and social ties into social capital. Social bonds, reciprocity, and collective attitudes are essential in providing opportunities for communities to recover from disasters more effectively and to increase resilience before, during, and after disasters (Sobhaninia, 2023; Szreter, 2004).

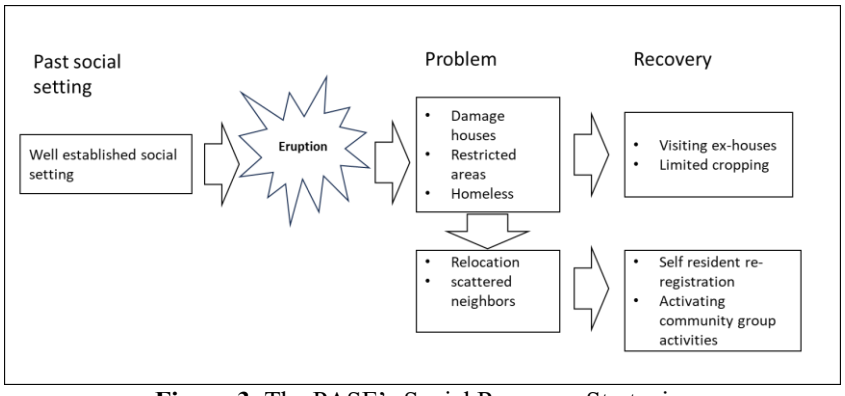


Figure 3: The PASE's Social Recovery Strategies
Source: Analysis (2024)

For the PASE, their social capital is formed from their social ties. Social capital in the community is the basis for building resilience because it is crucial for improving the overall welfare and development (Monteil et al., 2020). Social norms and beliefs can spark cooperation and collective action among community members through social networks, ultimately improving their livelihoods (Feinberg et al., 2023). Furthermore, social capital helps address societal challenges, such as limited resources, geographic isolation, crises, and potential conflicts (Sobhaninia, 2023).

This research also found that the PASE have adaptive livelihood strategies for recovery. As presented in Figure 4, they no longer just work to restore farmlands. They think adaptively by doing more than one type of work to replace another in a crisis. The farmers are trying to change the function of their land and are carrying out agricultural activities while working, sometimes not in the fields, as sand labourers. They have also been considering increasing the selling value of their agricultural products.

"Due to the eruption, garden products cannot be sold, so farmers are considering processing fruits, such as salak and bananas, into advanced products. This is a strategy to obtain income from selling these processed products. Salak is processed into chips, and bananas in addition to being chips, can be processed into jam. In Supiturang Village has many types of salak fruit. Among the salak fruits, the most famous are Salak Pondoh and Salak Gula Pasir. Both types of salak are very suitable for processed salak chips. This innovation can increase the added value of the products by up to 70%." N032024-M.

Besides agriculture and sand mining, some heads of families have become migrant workers, moving to islands outside Java to become construction workers (unskilled labour). At the same time, those who choose to stay in the resettlement houses are trying to take advantage of the narrow houses and yards to sell/trade.

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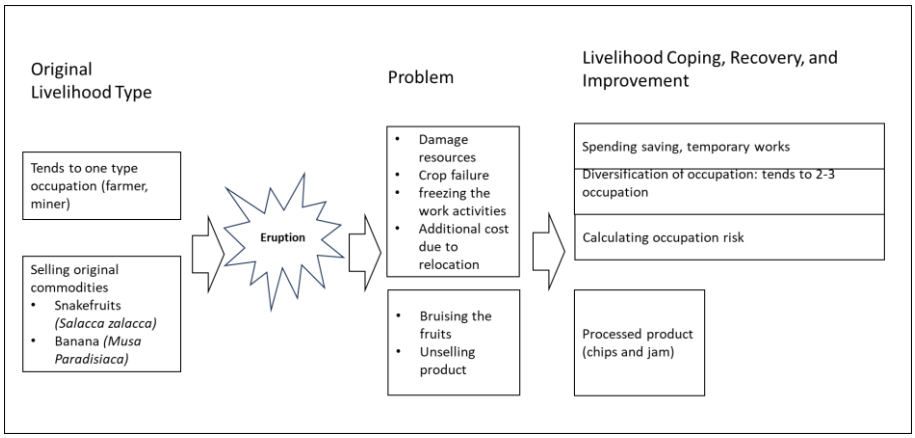


Figure 4: The PASE's Livelihood Recovery Strategies
Source: Analysis (2024)

In addition to restoring livelihoods, this strategy is also an effort to restore assets because they have spent their savings and sold their remaining assets during their stay in the camp. This adaptive method also provides them with a choice of daily, weekly, and seasonal sources of income. Furthermore, the adaptive efforts made by the PASE are a strategy to increase their resilience in the face of cyclical disasters. Diversification of livelihoods in various professions, such as agriculture, non-agricultural work, and other occupational activities have become a key strategy to reduce the impact of a crisis and increase resilience (Liu et al., 2022).

The PASE have calculated the risk of crop failure if an eruption were to strike again and the high cost of restoring the land affected by the eruption. There must be enough income and savings to deal with a crisis. That is why they have also become miners, whereby, once they go down into the mine, they can earn IDR100000-200000 (USD6.25-12.53). However, it looks as though the miners have enough income compared to those waiting for an income from their crops. Other family members who are living in the house try to earn additional income by offering sewing, washing and other services that earn them a daily income of IDR20000-50000 (USD1.25-3.13).

In another track, the PASE are striving to strengthen in parallel their capacity and knowledge in dealing with disasters by accessing the information and training conducted by GOs and NGOs. Although they have lived with the threat of eruptions for decades, the 2021 eruption provided a different experience. They recognised the increasing importance of information and early warnings about eruptions and the arrival of the lava flow, especially when they began to move into the rice fields/gardens and sand mining areas. The PASE who are active in the sand mining area must equip themselves with mobile/smartphone

devices because early information about potential eruptions/lava flow can be obtained there. Information is disseminated through mobile short message service (SMS) and, most intensively, through a WhatsApp group.

"An EWS has been built. The community, especially miners, can access it through a WA group and a siren has been installed."– L092023-M.

The WhatsApp group, which is a means of disseminating early warnings, is comprised of local government officers, decision-makers, the Semeru volcano monitoring post officer, village heads, and miners. In addition, the central government built an early warning system (EWS) in 2023. This early warning relies on sensors that detect volcanic activity and then, disseminate this warning through three sirens that can be controlled by the PVMBG, BPBD, and village heads. The early warning flow is illustrated in Figure 5.

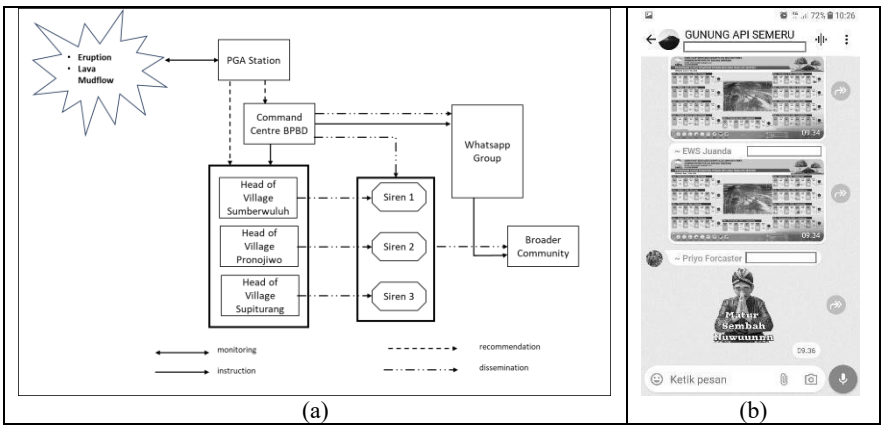


Figure 5: (a) The Flow of the EWS for Eruptions and Rain Lahars and (b) the WhatsApp Group
Source: Analysis (2024)

Strengthening the preparedness capacity is also done through socialisation activities and disaster-resilient village programmes. The programmes are carried out by GOs and NGOs targeting village governments and community representatives to build capacity for managing community-based disaster risks. The community has recruited volunteers to raise preparedness.

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Table 2: The PASE's Preparedness Strengthening Programme

Programme	Time	Powered by
Disaster resilient village	2022	NGO & GO
Regular socialisation	Regular	GO
EWS development	2023	GO
Mini simulation	2022, 2023	GO & University
Development of Semeru eruption contingency plan	2023	GO

Source: BPBD Lumajang District

The discussion above shows that this research has clearly shown that the recovery sought by PASE has gone through many ways while facing the threat of disaster simultaneously. Researchers grouped various ways taken by PASE to recover in double-track. The first track is efforts to recover social capital and diversify economic livelihoods adaptively. Second, simultaneously build preparedness capacity to respond appropriately to potential impending disaster risks. PASE has an understanding and awareness of the surrounding disaster conditions. This understanding triggers the community to increase preparedness. The practice of double-tracking through disaster recovery and preparedness in tandem enables recovery from long-term disasters.

CONCLUSION

This research clearly showed that the strategy of the PASE for recovering from disaster impacts is not only an adaptive strategy for diversifying livelihoods and efforts to recover social capital but also for increasing knowledge about disaster mitigation and preparedness to deal with cyclical disasters. There is no longer a boundary between pre- and post-disasters. A sustainable recovery strategy is carried out by recovery along with preparedness efforts.

Recovery through double-tracking leads to sustainable recovery efforts. Track 1 involves restoring the socio-economic aspects. After the eruption, livelihoods have been restored by diversifying the livelihoods (trading, farming/farming, mining sand) rather than depending on only one type of occupation: farming or sand mining. In addition, social cohesion has begun to grow in the relocation community through community group activities and worship because the setting of the social environment is very much different than in their hometown. Track 2 involves understanding the risks and improving the level of preparedness—a pattern of public awareness of disaster risks for themselves and their production sources. The PASE have also increased their knowledge about disaster mitigation and preparedness behaviour for future disasters.

This study recommends that local and national governments strengthen specific skills so that the PASE can have various other skills at work. Innovation and robust market access are necessary to add value to the product.

Simultaneously, agencies must strengthen the resilience of the PASE by building effective EWSs that can reach everyone and developing preparedness skills through periodic drills.

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ASSESSING THE RESILIENCE INDEX OF VILLAGES AFFECTED BY THE SEMERU ERUPTION IN LUMAJANG, INDONESIA

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Abstract

Thousands of villages in Indonesia are at risk of and affected by cyclical disasters, such as the Mount Semeru volcanic eruption, making it necessary to measure the resilience index (RI) of such villages. This research was aimed at assessing the RIs of villages facing cyclical disasters. A quantitative approach with the adoption of the Baseline Resilience Indicators for Communities (BRIC) and Resilience Index Measurement and Analysis (RIMA) models was used in this study to calculate the index by means of five sub-resilience indices (SUBs) and 18 indicators. The data was obtained through the collection of secondary data, surveys, and focus group discussions (FGDs) with 12 participants. The study measured the RIs of six villages after the eruption. Sumbermujur Village had the highest RI (62.14), while Sumberwuluh Village had the lowest RI (39.34). Pronojiwo Village obtained an index of 55.28, while Oro-oro Ombo Village and Sumberurip Village obtained indices of 49.63 and 43.94, respectively. The RI of a village is not only contributed by the components of disaster preparedness or access to basic services but also the ability to build infrastructure, strengthen social aspects, and increase economic productivity. This study contributes to efforts to utilise more secondary data from villages and sub-districts that were provided annually to assess the RIs of villages based on the BRIC and RIMA models.

Keywords: Village Resilience Index, Assessment, RIMA, BRIC, Semeru Eruption

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INTRODUCTION

A volcanic area is like two sides of a coin. On the one hand, it attracts people to depend on it for their livelihood, and on the other hand, volcanic eruptions seriously threaten the livelihood of the people. Brown et al. (2017) recorded that more than 29 million people worldwide live within just 10 km of an active volcano and about 800 million people live within 100 km of one. There were 278368 fatalities due to volcanic eruptions between the period of 1500 and 2017. Indonesia has 13% or 127 of the world's volcanoes, which pose a constant threat to the community. Preparedness efforts, through continuous monitoring and assessing of the resilience index (RI), are essential to deal with volcanic eruptions, especially in countries such as Indonesia.

Preparedness efforts to deal with volcanic eruptions should not only come from the community but the government also has a significant role to play in developing knowledge and preparedness systems to enable the community to respond adequately (Bachri et al., 2015; Kurata et al., 2022). In Indonesia, the village is the smallest government unit. It can be the first line in supporting the preparedness and resilience of the community. According to data from the Central Statistics Agency (BPS), there are 83971 villages in Indonesia. The National Board for Disaster Management (BNPB) mentioned that 60.7% (50970) of the villages in Indonesia are located in disaster-prone areas. The government of Indonesia has launched the Disaster Resilient Villages program for implementation in villages at risk of disasters. It is being supported with village funds that are disbursed annually. Therefore, it is crucial that a study on the RI be conducted to monitor the participation of the villages in developing community resilience in Indonesia.

The eruption of the Semeru volcano on 4 December 2021 had a significant impact on the people's livelihood. According to data from the Regional Disaster Management Agency (BPBD), the eruption hit parts of six villages in two sub-districts, resulting in casualties, and the destruction of livelihood assets, the economy, infrastructure, environment, and social assets. The eruptions, which continued in 2022 and 2023, have been a part of the life cycle of the people for a long time. So, the best choice for the community is to coexist with the volcanic eruptions by developing their preparedness management and providing mechanisms to support the preparedness of the community. This study aimed to assess the RIs of six villages affected by the 2021 Mount Semeru volcanic eruption.

LITERATURE REVIEW

Resilience Index (RI)

The concept of resilience is often based on the basic idea of CS Holling (1973), which considered resilience as a measure of the persistence of a system and its ability to absorb changes and disturbances and maintain the exact relationship

between population or country variables (Karsai et al., 2020). The idea of resilience has contributed positively to reducing disaster risk and increasing the capacity of people and communities. However, there are still differences of opinion on resilience. Resilience has been developed as an essential reference in formulating government policies, programs, and strategies. Resilience is a relatively measurable concept that helps to understand how communities, households, and regions cope with shocks and disruption triggers (Altieri et al., 2015; Khusna et al., 2023).

Village Resilience can be defined as how villages and community institutions respond to economic, social, or environmental shocks (Irawan, Farihah, Prasetyo, Devy, et al., 2024). The mechanism is to recognise threats in the territory and organise community resources to reduce vulnerabilities while increasing the capacity to reduce the risk of a disaster. A disaster-resilient village is defined as one that can independently adapt to and face disaster threats and can quickly recover from any adverse effects if it is hit by a disaster (Bachri et al., 2023; Nurmala et al., 2023). In Indonesia, the Village Resilience Policy has been formulated in the Regulation of the Head of BNPB Number 1 of 2012 concerning disaster-resilient villages in the context of post-disaster recovery.

Resilience measurment of the village using social, economic and environmental indicators that together form a resilience capacity structure (Imbach et al., 2017; Mondal et al., 2023). Village resilience data will help decision-makers develop more effective measures to increase community resilience. Resilience assessments also improve understanding of which regions or communities have the lowest and highest resilience and can be used to track the progress of community resilience (Borda-Rodriguez & Vicari, 2015). In reducing vulnerabilities and risks, resilience assessments can guide the allocation of resources, the development of infrastructure and the protection of sensitive areas against cyclic disasters (Fuchs et al., 2012). However, it is still very difficult to build a paradigmatic village resilience assessment evaluation tool for cyclic disasters and reveal the driving factors underlying it.

The RI has been translated into several models with different contexts. In the context of cities, a city/urban RI model has been developed that accommodates the characteristics of urban disasters, including climate change adaptation (Suárez et al., 2016). In Portugal, the SoResiliere has been developed to measure the RI specific to social resilience (Jacinto et al., 2023). The district/province RI is a familiar measuring tool in Indonesia. This index is measured at the provincial and district levels as a variable for calculating the disaster risk index. This index is measured using 71 indicators covering aspects of development and disaster risk management in the province or district (BNPB, 2018). However, this index cannot be used for the lower levels, namely the village level. So, the challenge in this study was to develop an RI at the village level, which is the lowest level of the government system in Indonesia.

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The Baseline Resilience Indicators for Communities (BRIC) and Resilience Index Measurement and Analysis (RIMA) Models

The Hazard & Vulnerability Research Institute at the University of South Carolina developed the BRIC, which is a comprehensive hierarchical index consisting of 49 indicators divided into six subdomains of resilience, among others: social, economic, institutional, infrastructure and housing, community capital, and the environment. The BRIC uses indicators to describe demographic characteristics, especially in its approach to disasters. For example, working-age people are generally better able to help themselves and others than minors, children, or people with disabilities. The BRIC also uses indicators of access to basic services that affect resilience. For example, good access to transportation facilities or communication infrastructure can be critical during and after a disaster (Scherzer et al., 2019).

The variables in the BRIC include (a) social resilience, which is directed at community involvement in groups, such as youth groups, religious groups, and sports groups. This indicator is intended for active community involvement. It is assumed to form social networks that often provide informal support during disasters and recovery; (b) economic resilience, which focuses on the benefits of a functioning and healthy economy for the community in a disaster situation, not solely the resilience of individual businesses; (c) institutional resilience, which is related to aspects of community governance and crisis management; (d) infrastructure and housing, which are related to housing quality, evacuation points and shelters, and the provision of emergency services; and (e) the environment, which has to do with natural capacities in relation to a community's exposure to specific hazards and previous experience of disasters (Burton, 2015; Cutter et al., 2010).

The RIMA is a resilience measurement instrument that is used by organisations related to the United Nations, such as the WFP and IFAD. It defines resilience capacity as the access to basic services, economic and livelihood assets, social safety nets, and adaptive capacity (Mondal et al., 2023). It is developed through four leading indicators: a) access to basic services, which shows the ability of people to meet their basic needs, including the quality, effectiveness, and accessibility of basic services. For example, access to drinking water, primary schools, livestock markets, transportation, and health services; (b) economic and livelihood assets, including productive and non-productive assets, which are indicators of people's life situations and affect people's behaviour when their assets are disrupted, for example, home ownership, jewellery ownership, and land; (c) social safety nets, which are a form of protection for all people affected by disasters; and (d) adaptive capacity, which is the ability of communities to adapt to disasters even with new scenarios as a result of environmental change. Adaptive capacity can be in the form of work diversification and participation in development activities that generate income (d'Errico et al., 2020).

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The BRIC and RIMA have basically adopted village disaster resilience standards by adapting the disaster resilience of a place (DROP). Although DROP was designed for application in the United States, the similarities in the nature of disaster resilience make it applicable to the context of other countries. It has also been adopted and adapted in several other countries, such as Australia, Norway, Thailand, and Zimbabwe, to measure the RI within different contexts. The model assumes that natural systems interact with social systems, creating an inherent vulnerability and disaster resilience in those communities. The model has a comprehensive framework for assessing the overall disaster resilience of communities. It can pinpoint specific components that can improve or reduce disaster resilience (Scherzer et al., 2019). However, this method relies on primary data (surveys, focus group discussions (FGDs), and interviews) and not so much on secondary data. Meanwhile, villages in Indonesia always update their village profile data and information annually, which means these are worth using as secondary data. By utilising the village profile data and information, index measurements can be carried out more cheaply and easily, making it possible to reach villages in Indonesia.

Referring to the variables of RIMA and BRIC in the literature above, this study selected and combined several determinants from both that were relevant for the villages and communities to become more resilient after being affected by the Mount Semeru volcanic eruption. Indicators were chosen that could be supported by the secondary data from the villages or sub-districts. The selected indicators were: (a) access to services that could function and were available in the village to meet the basic needs of the community after the eruption, including health services, education, clean water, and transportation facilities; (b) the social capacity, including that of the working- and school-age groups, and social and religious institutions, to restore the social capital of the community after the eruption; (c) the economic capacity of micro, small, and medium enterprises (MSMEs), small industries, and agriculture to grow and restore the community's economy; (d) the infrastructure capacity in the form of road and communication networks to support all the activities in the community; and (e) village preparedness, which is a component of preparedness in dealing with cyclic disasters, including volunteer groups, early warning systems (EWSs), evacuation signs and instructions, and distance to BPBD offices.

RESEARCH METHODOLOGY

This study used a quantitative method to obtain information about the RI of villages through field surveys, secondary statistical data collection, and FGDs. The villages that were the units of analysis in this study were those affected by the Mount Semeru eruption in 2021.

As shown in figure 1. The location of the study is in six villages where directly affected by the Semeru Volcano Eruption in 2021. They are: Sumber

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Wuluh, Sumber Mujur, Supiturang, Sumber Urip, Oro Oro Ombo, and Pronojiwo Village in Lumajang Regency, East Java Province.

Table 1: Impact of Eruption on Public Facilities and Houses at the Research Site

Sub-District	Affected Villages	Affected Public Facilities	Heavily Damaged Houses
Pronojiwo	Pronojiwo	1 district connecting bridge, one mosque	820 unit
	Oro-oro Ombo	2 Primary School, 1 Pre-School	
	Sumberurip	1 Junior High School	
	Supiturang	4 Primary School, 3 Pre-School, 1 Village health facility, 1 Integrated service post/Posyandu	
Candipuro	Sumberwuluh	4 Primary School, 2 Pre-School, 1 Village health facility	287 unit
	Sumbermujur	1 Junior High School, 1 Mosque	

Source: BPBD Lumajang Regency, 2022

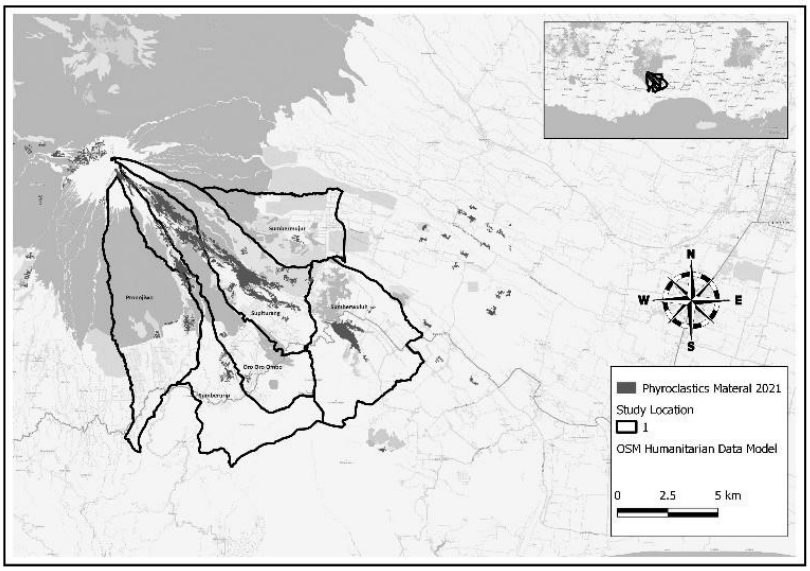


Figure 1. Research Location
Source: Researcher (2023)

Data Collection Procedure

This study made greater use of secondary data through the collection of village profile data and sub-district statistics. Field surveys were conducted to gather data on village preparedness, namely, EWSs, and village evacuation signs and instructions. FGDs were carried out to validate the secondary data that had been

collected and to gather the latest information about village preparedness. Updated data that had been missed in the village profile data and sub-district statistics were obtained through the FGDs. To validate the preparedness data, the FGD participants provided information on the EWS installation points, dissemination coverage, and evacuation signs and instructions. Researchers conducted a Focus Group Discussion (FGD) with 12 participants representing key stakeholders to provide information according to the selected indicators, as shown in Table 2.

Table 2. Participants in the FGD of Each Villages

Stakeholders	Element	Number
Sub-District Govt	Representatives of Sub District Government	1 person
Village Government	Head of Village	1 person
	Head of village development division	1 person
	Head of village welfare division	1 person
Hamlet Administrator	Head of hamlet (1 per hamlet)	3 persons
Others	village volunteers (man and women)	2 persons
	Women group	1 person
	Religious group	1 person
	MSME representatives	1 person
Total		**12 persons**

Indicators and Data Analysis

This study selected indicators inspired by the BRIC and RIMA that were relevant to the context of the research area and the availability of the data. The indicators of social capacity, economic capacity, and infrastructure capacity for this research were adopted from the BRIC model, while the variables of access to basic services and village preparedness were adopted from the RIMA model.

Table 3: The Variables Used to Measure Resilience Index (RI)

Variable / SUB	Indicators	Remarks	Sources(s)
Access to basic services	1. Access to education services	Percentage of schools to the total population of school-age residents.	(Hizbaron et al., 2018) (Cox & Hamlen, 2015) (Kaur & Singh, 2022) (Scherzer et al., 2019) (Mondal et al., 2023)
	2. Access to health facilities	Average number of health facilities for every 1000th of the population.	
	3. Acces to clean water	Percentage of clean water service by the total number of households.	
	4. Acces to public transportation Facilities	Average number of public transportation services or every 1000th of the population.	
Social capacity	5. Number of working-age residents	Percentage of labour force to the total population.	
	6. Gross school participation rate	Percentage of students to the total school-age population.	
	7. Number of social institutions	Average number of social institutions for every 1000th of the population.	
	8. Number of worship facilities		

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Variable / SUB	Indicators	Remarks	Sources(s)
		Average number of worship facilities for every 1000th of the population.	
Economic capacity	1. Number of employees	Percentage of actively employed individuals to the total population of working-age individuals.	
	2. Number of MSME capacity	Average number of MSMEs to every 1000th member of the labour force.	
	3. Number of small industry	Average number of small industries to every 1000th member of the labour force.	
	4. Amount of agricultural land	Total amount of productive agricultural land per square kilometre (km^2) of land.	
Infrastructure capacity	5. Amount of main road network	Total amount of main roads per km of road.	
	6. Number of communication tower	Average number of communication towers for 1 every 1000th of the population.	
Village Preparedness	7. Number of village volunteers	Percentage of volunteers to the total population,	
	8. Amount early warning system coverage	Percentage of the population with access to EWSs.	
	9. Number of evacuation signs and instructions	Number of evacuation signs and instructions by the total main roads.	
	10. Proximity with BPBD	Distance to BPBD offices.	

Source: Researcher (2023)

Resilience Index (RI) Development

One of the advantages of adopting the BRIC or RIMA is its clear and easy-to-understand design. The analysis by BRIC or RIMA is based on adding hirers and average calculations (Scherzer et al., 2019). The resulting indicators are analysed by summing them in their SUBs in the min-max transform and averaging them to produce a SUB (Formula 1). The regenerated SUB scores are transformed in the min-max formula and then, added up to create the final community RI. All the indicators in the subdomain and all the SUBs are given equal weight. The formula for the calculation is given below:

Min-Max Transformation: $x' = \frac{X - Xmin}{Xmax - Xmin}$ (1)

SUB score: $SUB = 1/n \sum_{i=1}^{n} X'i$ (2)

Village Resilience Scor = (nAccess basic services + nSocial capacity + nEconomic capacity + nInfrastructure capacity + nVillage Preparedness) (3)

Formula 1 compiles all the values of an indicator (or subsequently a SUB) into a score range of 0-1. X shows the resultant value of each component

for a particular indicator, Xmin is the minimum value of the indicator, and Xmax is the maximum value of the indicator. Formula 2 explains the calculation of the SUB, where all the indicators (X') are sure subdomains that are added up and divided by the total number of n indicators in that subdomain. Formula 3 shows the calculation of the composite RI, which is the sum of six SUB scores consisting of (1) access to basic services, (2) social capacity, (3) economic capacity, (4) infrastructure capacity, and (5) village preparedness. IBM® SPSS® 21 was used to analyse the quantitative data.

ANALYSIS AND DISCUSSION

Indicators to measure the components of the village RI were compiled and produced, as shown in Table 4. The data that led to 18 indicators from the six villages produced a SUB that described the RI of each village. Figure 2a shows that Sumbermujur Village had the best access to basic services among the other villages, and health services and clean water were significant contributors to the basic services SUB. Oro-oro Ombo Village had the lowest access to basic services. Although educational services were very good, health facilities and clean water services were inadequate.

Figure 2b shows that Supiturang Village had the best social capacity among the other villages, adequate worship facilities, and a high level of school participation, which were significant contributors to the social capacity SUB. Oro-oro Ombo Village had the lowest social capacity due to the lack of social institutions and inadequate worship facilities.

Figure 2c shows that Sumberurip Village had the best economic capacity. This was contributed by the percentage of workers in the labour force and the number of MSMEs and small industries. In terms of infrastructure, roads, and good communication, Pronojiwo Village had the best infrastructure SUB among the other villages (Figure 2d). Meanwhile, for village preparedness (Figure 2e), Sumbermujur Village was the most prepared to face a disaster as it was equipped with village volunteer groups, evacuation signs and instructions, and adequate EWSs. However, ultimately, the RI was measured from the contribution of five SUBs to a composite RI to compare the RIs of the six villages.

Table 4: Summary of Sub-Index Statistics and Village Resilience Indicators

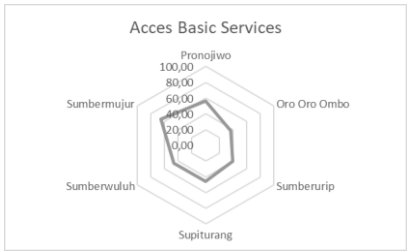
Variable / Sub-Indeks	Indicator	Mean	Std. Dev.	Min.	Max.
Access basic services	Number of education facilities	0.76	013	0.5571	0.9223
	Number of health services	1.15	0.22	0.79	1.48
	Number of clean water services	26.89	32.58	1.51	69.42
	Number of public transportation services	2.02	0.61	1.21	2.85
Social capacity	Number of working-age individuals	68.08	2.30	64.82	70.37

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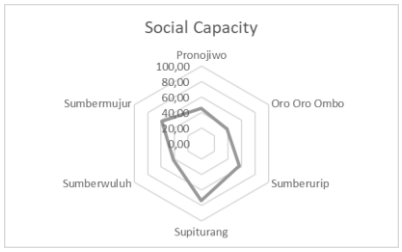
Variable / Sub-Indeks	Indicator	Mean	Std. Dev.	Min.	Max.
	Gross school participation rate	80.63	13.11	59.05	96.75
	Number of social institutions	0.47	0.17	0.22	0.67
	Number of worship facilities	6.81	1.67	5.12	9.61
Economic capacity	Number of employees	71.59	23.66	39.18	93.41
	Number of MSMEs	3.29	2.30	1.19	7.04
	Number of small industries	0.98	0.49	0.20	1.45
	Amount of agricultural land	9.51	8.08	2.65	23.24
Infrastructure capacity	Number of main road networks	59.17	19.91	21	74
	Number of communication towers	0.29	0.07	0.18	0.37
Village Preparedness	Number of village volunteers	0.68	0.10	0.55	0.83
	Number of EWSs	81.67	8.16	70	90
	Number of evacuation signs and instructions	0.27	0.12	0.15	0.48
	Proximity to BPBD offices	2.34	0.39	1.91	2.99

Source: Analysis (2023)

The preparedness aspect has been improving since the Mount Semeru eruption in 2021. For example, the villages have strengthened their disaster management groups/organisations and conducted various preparedness trainings, such as simulations. The EWS for eruptions has been strengthened through several electronic devices, radio, HT, and social media with mechanisms that are beginning to be structured. However, this does not seem massive and sustainable. The newly integrated EWS, which has been strengthened with the support of the BNPB, does not seem to have had a significant impact. The evacuation signs installed by the government are still insufficient to cover the entire village area.



(a)



(b)

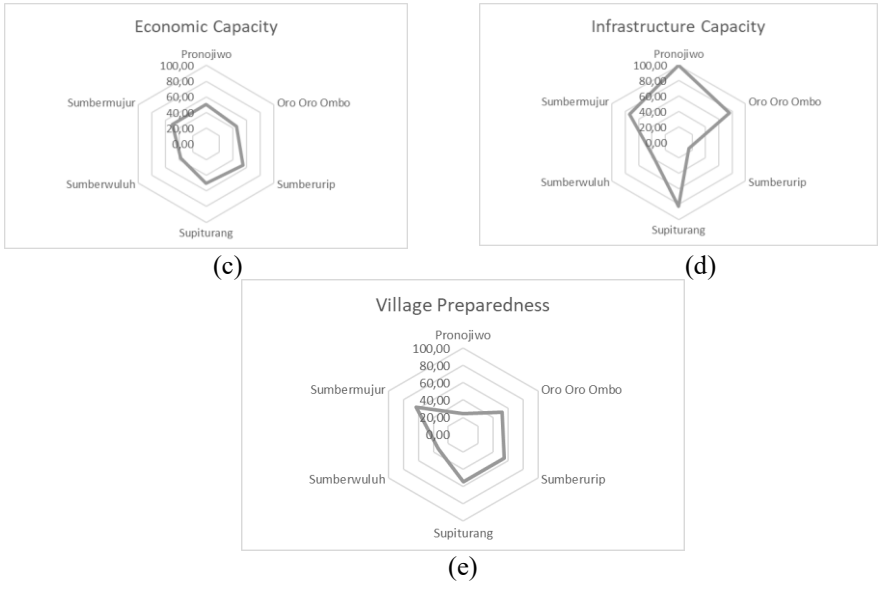


Figure 2: The Access to Basic Services SUB (a), Social Capacity SUB (b), Economic Capacity SUB (c), Infrastructure Capacity SUB (d), and (e) Village Preparedness SUB.
Source: Analysis (2023)

Resilience Indices (RI) of the Villages

The contribution of the five SUBs in Figure 2 resulted in the composite RI of each village. The average RI of the villages was 62.37, with a standard deviation of 9.32. Sumbermujur Village had the highest RI (62.14), slightly more than that of Supiturang Village (61.51). Sumbermujur Village is currently the destination for relocation development through the building of permanent shelters for residents affected by the eruption. Meanwhile, Sumberwuluh Village had the lowest RI (39.34). Pronojiwo Village, Oro-oro Ombo Village, and Sumberurip Village had RIs of 55.28, 49.63, and 43.94, respectively. In Figure 3, the degree of contribution of each SUB to the composite RI of each village is evident.

Table 5: The Resilience Indices (RI) of the Examined Villages

Village	Access to Basic Services	Social Capacity	Economic Capacity	Infrastructure Capacity	Village Preparedness	Composite RI
Pronojiwo	56,52	45,34	50,32	100,00	24,20	55,28
Oro Oro Ombo	37,38	37,86	44,53	76,12	52,26	49,63
Sumberurip	39,76	56,08	54,25	15,03	54,57	43,94
Supiturang	45,85	73,17	50,13	83,48	54,94	61,51
Sumberwuluh	46,20	41,95	37,16	37,74	33,67	39,34
Sumbermujur	65,77	58,79	50,00	73,52	62,61	62,14

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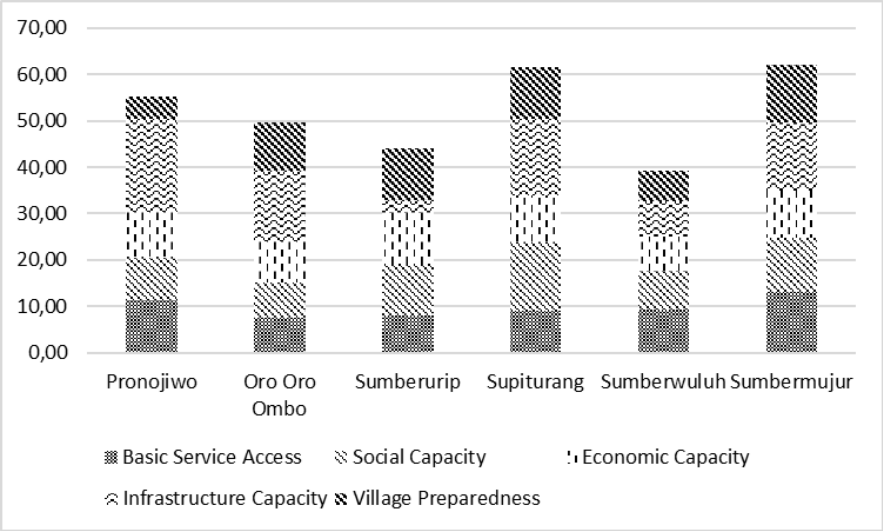


Figure 3. The Contribution of Each SUB to the Composite Resilience Index (RI)
Source: Analysis (2023)

Due to their high village preparedness scores, Sumbermujur Village and Supiturang Village had the highest RI. The preparedness component of these villages was the best of the examined villages. The ratio of the number of disaster volunteers in the villages showed that these villages possessed a better personnel capacity compared to the other villages. The EWS and adequate evacuation signage allow people to use multiple routes to save themselves. The proximity to BPBD offices enables emergency assistance to be distributed more quickly. Good preparedness variables show that communities can adapt and develop resilience mechanisms to face disasters. The mechanism can be developed as a preparedness mechanism through information and data system governance, evacuation strategies, and disaster assistance management. This development is usually built through an organic mechanism in society, starting with the emergence of awareness, which later becomes community behaviour (Irawan, Farihah, Prasetyo, Azizah, et al., 2024; Kurniawan et al., 2022).

The access to basic services variable contributed significantly to the RI of Sumbermujur Village. Its facilities were better than those in the other villages, especially in terms of education, health, and clean water services. Health and education facilities are considered quite sensitive to the income and poverty conditions of village communities, which is one factor that contributes to the RI of villages. The construction of village health and education facilities that are easily accessible to the community provides opportunities for the community to save more, reduce expenses, and improve nutrition and nutrition standards (Naufal & Maret, 2023).

On the other hand, Supiturang Village, which had an RI that was similar to that of Sumbermujur Village, had social and infrastructure capacities that contributed significantly to its RI. Infrastructure does have a strong impact on supporting village resilience (Gromek & Sobolewski, 2020). The infrastructure capacity was contributed by the main roads and quite capable communication network. Meanwhile, the social capacity was mainly contributed by the optimal participation of schools and available worship facilities. Regarding the economic capacity, Sumbermujur Village was supported by good productive agricultural land as the community's main livelihood. Meanwhile, Supiturang Village was supported by its worker population in various sectors.

CONCLUSION

The evaluation of the RIs of villages affected by the eruption of the Mount Semeru volcano in 2021 was inspired by the BRIC or RIMA calculation models. By considering the context and availability of data, especially in the village and sub-district documents, six variables were adopted for the village RI, namely, (a) access to basic services, (b) social capacity, (c) economic capacity, (d) infrastructure capacity, and (e) village preparedness. This article successfully exposed the RIs of the six villages after the eruption. Sumbermujur Village had the highest RI (62.14), while Sumberwuluh Village had the lowest RI (39.34). The RIs of Pronojiwo Village, Oro-oro Ombo Village, and Sumberurip Village were 55.28, 49.63, and 43.94, respectively.

The contribution of each SUB to each village's composite RI, especially that of Sumbermujur Village and Supiturang Village, was unique. Disaster resilience is not always contributed by the preparedness component in dealing with disasters or access to good basic services such as in Sumbermujur Village. However, resilience can also be supported by adequate infrastructure and social capacities that allow communities to build social cohesion. It is also supported by worker productivity and the availability of workspaces in the village through agriculture, MSMEs, and small industries.

The RI in this study was successfully built by utilising secondary data, namely, village profile data and sub-district statistics. The data comprised village statistical data that are constantly being updated every year. This method allows village governments to independently compile the RI by measuring village resilience every year and formulating disaster management policies. This RI is sufficient for decision-making to formulate government policies, especially at the village level, for example, by building village infrastructure and basic community facilities oriented to long-term resilience by considering environmental, social, and economic variables. In addition, it is also integrated and continues to build preparedness at the village and community levels.

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THE IMPACT OF MASS RAPID TRANSIT (MRT) ON RESIDENTIAL PROPERTY PRICES IN MALAYSIA: A CASE STUDY OF THE SG. BULOH – KAJANG (SBK) LINE

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Abstract

The relationship between transportation infrastructure and property prices is crucial in urban studies and real estate research, particularly in rapidly urbanizing regions like Malaysia. One crucial factor influencing real estate pricing is its proximity to well-planned and effective transportation hubs. Research continuously shows that homes near major highways or public transportation frequently fetch higher prices, reflecting the premium price paid for convenience and shorter commute times. Despite several studies being undertaken on the correlation between railway stations and property values, Malaysia, as a developing country, still lacks studies in this area of research. This paper focuses on the impact of Mass Rapid Transit (MRT) stations on residential property prices along the Sg. Buloh – Kajang (SBK) line in Malaysia. Through observational methods of data collection, the characteristics of MRT stations, including station type, facilities, and connectivity, were identified. Of the 31 stations, 9 were selected to reflect the residential property prices in the neighbourhood. This study focused on analysing residential property prices as the dependent variable using a secondary dataset. Key station characteristics such as platform type, location, parking, and distance to the station were analyzed to understand their influence on property prices. The result showed a different strength of relationship between the dependent and independent variables. The findings will assist policymakers and urban planners make informed decisions regarding transportation and housing development, optimizing the placement of new stations to enhance property values and urban connectivity.

Keywords: Housing prices, Residential property prices, Mass Rapid Transit, Transportation, Train station

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INTRODUCTION

The deployment of Mass Rapid Transit (MRT) has brought about a significant transformation in global urban environments, impacting both residential real estate markets and transportation dynamics. MRT stations significantly improve connectivity inside cities by offering a rapid, dependable, and effective form of public transportation, which attracts potential investors and homeowners to remote neighborhoods. In the neighborhoods surrounding MRT stations, this improved accessibility frequently causes a spike in housing demand, which in turn raises property values. Therefore, it is crucial to investigate the influence of MRT stations on house values from the viewpoint of economists, real estate developers, and urban planners to investigate the impacts of MRT stations on house values. Comprehending these impacts facilitates stakeholders in making knowledgeable choices concerning housing policies, urban development tactics, and infrastructure expenditures. This study examined the complex effects of MRT stations on housing prices, looking at both the immediate and long-term effects on urban real estate markets.

The relationship between Mass Rapid Transit (MRT) and housing prices has been a focal point of urban studies and economic research for several decades. The underlying theory posits that improved public transportation infrastructure, such as MRT stations, enhances the accessibility and desirability of residential areas, thereby influencing housing demand and property values. This phenomenon is grounded in classical urban economic theories, such as Alonso's Bid-Rent Theory and the concept of transit-oriented development (TOD). According to (Mahato, 2022), the research indicates a positive correlation between urban rail transit network accessibility and residential property appreciation, particularly in suburban areas, supporting the theory that improved public transportation enhances accessibility and desirability, thus influencing housing demand and property values.

Empirical studies from various global cities also provide robust evidence supporting the positive correlation between proximity to MRT stations and increased housing prices. For instance, research conducted worldwide has revealed consistent patterns and trends that highlight the significant impact of public transportation infrastructure on real estate values (Adeolu Emmanuel et al., 2024; Rennert, 2022; Leontev & Mayburov, 2021; Zolnik, 2020). These studies attribute the price differentials to reduced commuting times, enhanced convenience, and improved overall quality of life.

However, the effects of MRT stations on housing prices are not uniformly positive and can vary based on several contextual factors. The stage of urban development, the existing transportation network, local housing market conditions, and socioeconomic factors all play significant roles in moderating these impacts. For example, in already well-connected and densely populated

urban centers, the introduction of MRT stations might lead to significant housing price increases due to the high demand for accessible urban living spaces. Conversely, in emerging cities or less dense areas, the impact might be more gradual and less pronounced. Zhu et al. (2024) indicate that home prices are strongly impacted by the placement of service facilities surrounding metro stations, with a concentration effect that is particularly noticeable in urban areas.

Additionally, the benefits of MRT stations extend beyond mere price appreciation. The development of MRT infrastructure often stimulates broader economic activities, such as commercial developments and employment opportunities, which further contribute to the desirability and livability of the surrounding areas (Raj & Naem, 2022). The initial economic activities, in turn, will create a ripple effect that can enhance urban growth and development on a larger scale.

Despite the general trends observed, the specific impacts of MRT stations on housing prices necessitate careful, localized analysis. Factors such as the exact location of stations, the design and efficiency of the transit network, and the integration with other modes of transportation can all influence the outcomes. As cities continue to expand and evolve, understanding these dynamics becomes increasingly crucial for policymakers, urban planners, and real estate developers aiming to foster sustainable and equitable urban development.

In conclusion, the introduction of MRT stations is a significant determinant of housing market dynamics, influencing prices and urban growth patterns. This research aims to further elucidate the complex interplay between MRT stations and housing prices, providing valuable insights into the benefits and challenges associated with transit-oriented urban development.

LITERATURE REVIEW

The Urban Land Use and the Role of Transportation

Transportation is a critical factor in urban land use development, as highlighted by various theories. Sector Theory emphasizes the need for transportation links to the Central Business District (CBD) and connections within industrial and residential areas, especially low-cost housing. Von Thunen's theory posits that land rent is determined by workplace access. Littman (2022) agrees, noting that transportation costs significantly impact land use.

Effective land use planning supports urban development, road construction, and transportation-related activities. As Morimoto (2021) observes, land use and traffic planning can keep pace with slow city growth. Historically, walking was the primary mode of urban transportation, leading to inefficient mobility and compact, mixed-use urban forms (Rodrigue, 2020). Despite changes in transportation modes, many modern cities retain these historical urban forms.

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Rodrigue (2020) further explains that urban forms have evolved with transportation advancements, leading to the development of new clusters in peripheral areas and a shift toward polycentric urban structures. These changes are accompanied by new mobility trends and transformations in the CBD, traditionally the main commuter destination served by public transit.

Since the Industrial Revolution, transportation advancements have driven economic growth. Every phase of the global economy has witnessed the emergence or modification of distinct transportation technologies, which have impacted the processes of production, distribution, and consumption. Fundamental waves of economic growth have been associated with transportation technologies such as seaports, rivers and canals, railways, roads, and airways. In the 19th century, the creation and use of rail infrastructure were pivotal during the second phase of the Industrial Revolution, facilitating resource exploitation, new area settlement, and expanded mobility. This development created significant economic and societal potential (Rodrigue, 2020). In Malaysia, the need for efficient transportation has driven railway development since the early 1990s.

Morimoto (2021) notes that rapid metropolitan population growth has led to housing shortages and the expansion of sprawling suburbs. Large suburban communities often establish and expand railway lines as public transportation systems grow. Developed nations focus on urban design that prioritizes public transit and explore transit-oriented development (TOD) to enhance urban mobility and connectivity. TOD is thought to be the best urban regeneration strategy for integrating the city's separated land use sprawl into a walkable area, high density, transportation, non-motorized reliance, shifting modes, mix-use land, and a dense network of streets and paths (Ramlan et. al., 2021).

In summary, transportation is crucial in shaping urban land use, influencing economic opportunities, and guiding the development of urban forms. The evolution of transportation technologies continues to transform cities, promoting efficient land use and sustainable urban development. Other than that, the importance of transportation such as railways has contributed to the increasing and decreasing demand indirectly effects the prices of property. This has been shows in many researchers by conducted the researchers to understand the relationship between railway station development and housing prices (Mathur, 2020; Suhaimi et. al., 2021 and Zhu et al., 2024).

Train Station Characteristic

A railway station, also known as a train station, serves as a crucial hub where trains stop to load or unload passengers and goods. These facilities are vital components of any rail network, providing essential services and infrastructure that facilitate efficient transportation (Architecture of Train Stations, 2022).

Typically, a railway station consists of one or more platforms, tracks, and a station building that houses ticket sales and waiting areas. According to the guidelines for railway scheme approval in Malaysia, the design and functionality of a railway station must encompass several critical aspects, including location, size, platform type, station facilities, design and safety requirements, and parking provisions (Land Public Transport Agency, 2021).

Key features of a railway station include platforms, ticketing, and fare facilities, waiting areas, signage, accessibility features, security measures, timetable information, parking spaces, restaurants, retail shops, information desks, and connections to public transportation. Platforms are the designated areas where passengers wait to board trains. These platforms are typically located alongside the tracks and can vary in design, including island, side, split, and stacked island configurations. An island platform is positioned between two tracks, while a side platform is situated adjacent to a single track. Split platforms feature multiple levels, each serving a different track, and stacked island platforms offer a vertically compact design.

Ticketing and fare facilities are another critical component of a railway station. Passengers can purchase tickets at counters or through ticket vending machines, usually strategically placed at station entrances. This setup ensures ease of access and efficient flow of passengers entering the station. Additionally, waiting areas provide a comfortable space for passengers before boarding, while clear signage helps guide them through the station. Accessibility features, such as ramps, lifts, and tactile guides, ensure the station is navigable for all passengers, including those with disabilities.

Security measures and timetable information are essential for maintaining a safe and well-organized station environment. Adequate parking facilities cater to passengers who drive to the station, while restaurants and retail shops enhance the overall passenger experience by offering convenience and comfort. Information desks offer help and guidance, while connections to public transportation, such as buses and taxis, facilitate seamless travel to and from the station.

Different countries exhibit unique characteristics in their railway station designs. In Malaysia, for instance, MRT stations are designed with distinct features based on the MRT manual. The MRT stations in Malaysia include seven underground stations and twenty-four elevated stations, each with a specific design theme. Elevated stations follow a *wakaf* design theme, while underground stations have unique themes that reflect their specific locales and environments (Cheung, 2015).

Connectivity is a vital aspect of MRT stations in Malaysia. These stations link to city centers, shopping malls, commercial centers, other railway stations, bus hubs, and taxi stands. Certain MRT stations provide over 8,000

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parking spaces, and most stations outside Kuala Lumpur's Central Business District (CBD) are serviced by feeder buses. Additionally, stations are equipped with lay-bys for passenger drop-offs and covered walkways to ensure safe and comfortable access to the station.

MRT stations in Malaysia are also equipped with comprehensive facilities. These include escalators, lifts, customer service centers, ticket vending machines, toilets, prayer rooms, and public telephones. Facilities for disabled individuals are a priority, with features such as lifts, ramps, tactile guides, and warning strips along walkways and platforms ensuring accessibility for all passengers.

In summary, a railway station is a multifaceted facility that plays a crucial role in the transportation infrastructure. In Malaysia, MRT stations exemplify a well-rounded approach to station design, incorporating essential features and facilities that cater to a wide range of passenger needs. These stations not only provide vital connectivity and accessibility but also enhance the overall passenger experience through thoughtful design and comprehensive amenities.

Mass Rapid Transit (MRT) Sg. Buloh – Kajang (SBK) Line

Malaysia has launched the Mass Rapid Transit (MRT) project as a component of a sustainable and integrated transportation network for Greater Kuala Lumpur. The primary goals of the MRT project are to reduce travel times, ease traffic congestion, and encourage more people to use public transit (MRTcorp, 2012). The Sg. Buloh-Kajang line is the first line planned for the MRT network. It was introduced on July 8, 2011, by YAB Dato' Sri Mohd Najib Tun Abdul Razak, the previous Prime Minister. There are 31 stations along the 51 kilometers that separate Sg. Buloh and Kajang. Figure 1 shows the timeline of the MRT's development.

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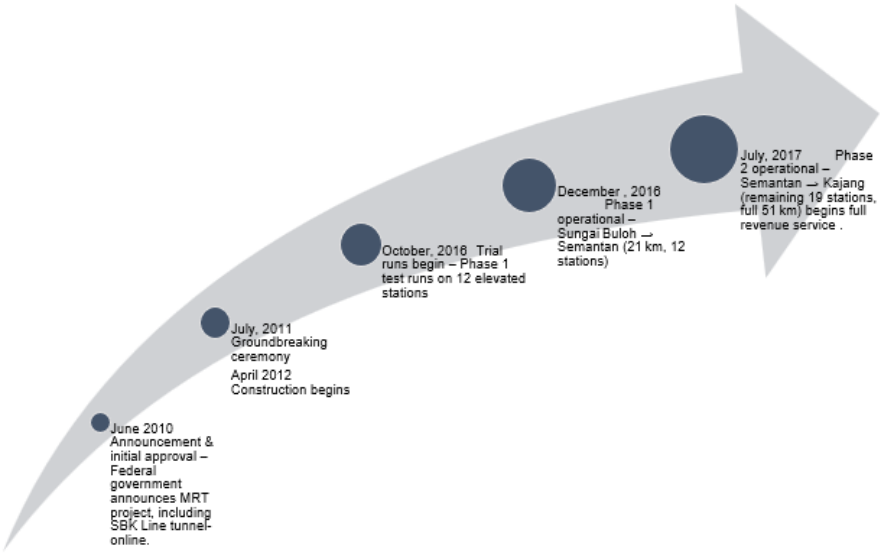


Figure 1: Timeline of MRT Development

The groundbreaking Mass Rapid Transit (MRT) project commenced in July 2011. This MRT construction consisted of two parts. Sg. Buloh saw development in its first phase till the Semantan Station. The path became accessible to the public in December 2016. The second phase extends from Kajang Station to Semantan. The path became accessible to the public in July 2017. According to MRT Corp, a total of 58 trains are available to operate on the 51-kilometer section of the mass rapid rail system. Phase One consists of about 31 stations, whereas the elevated stations include 24 stations. Seven other stations are underground. These subterranean stations span a 9.5-kilometer stretch beneath the heart of Kuala Lumpur (MRT Corp annual report, 2015). According to the MRT Corp annual report, an estimated 400,000 people use the train daily. The MRT railway station is split into three sections: the north, center, and south areas. The route spans 51 kilometres.

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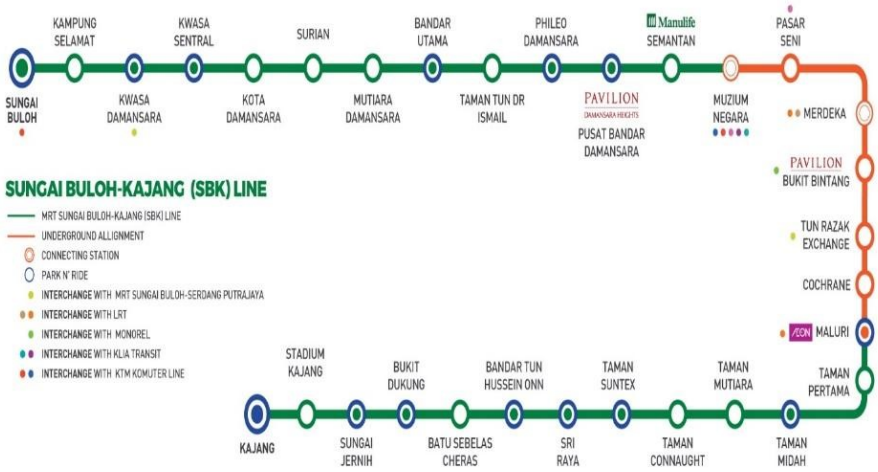


Figure 2: Sg. Buloh – Kajang (SBK) Line
Source: www.mrt.my

As shown in Figure 2, the north section is from Sungai Buloh Station to Phileo Damansara Station. In contrast, the central station is from Pusat Bandar Damansara Station to Maluri Station. Taman Pertama Station to Kajang Station is located in the south section.

RESEARCH METHODOLOGY

This study employed a quantitative approach to evaluate the influence of the MRT-SBK Station on residential property values using a comprehensive and systematic methodology. The methodology comprised three distinct phases: observation and auditing, elimination and selection of stations, and selection of residential property. Each phase was designed to progressively narrow down the focus and ensure accurate and relevant data collection and analysis research. During Phase 1, the station's characteristics were identified by reviewing relevant literature. A systematic observation of all 31 stations was then carried out using a checklist that was previously devised. For Phase 2, a total of 9 stations were chosen based on careful observation. The selection of residential properties was undertaken to establish their prices. A total of 5,310 housing price data were obtained from the valuation and property service department in Malaysia using the valuation management system, covering the years 2010 to 2020. Table 1 illustrates the data sources pertaining to the effects of MRT stations on residential property prices.

Table 1: Data Sources for the Effects of MRT Station on Residential Property Prices

Variable	Dependent variable – residential property prices	Independent variable – Location	Independent variable – Parking	Independent variable – linked bridge	Independent variable – type of platforms	Independent variable - distance
Indicators	The housing prices	Northside Southside	Landed parking. Elevated parking No parking	Linked bridge available. No linked bridge	Island type platform Side type platform	< than 500 meters to 4,000 meters.
Source	Valuation management system (VMS) - sources from Valuation and Property Service Department, Malaysia	Observation from all 31 stations along the SBK line	Observation from all 31 stations along the SBK line	Observation from all 31 stations along the SBK line	Observation from all 31 stations along the SBK line	Google map

All the data were then analyzed using regression analysis to determine the significance of stations' characteristics and their effect on housing prices. However, the central side of the location has been removed as the area has a smaller housing scheme.

ANALYSIS AND DISCUSSION

The descriptive analysis shown in Table 2 includes the mean and standard deviation. The result of the location factors shows a mean value of 0.2710, suggesting that approximately 27.1% of the properties in the north or south are considered more desirable or accessible, affecting housing prices. The standard deviation of 0.444452 indicates a moderate variability affecting housing prices. The moderate mean value suggests that a significant number of properties are in desirable locations, which aligns with the strong positive impact of location on property values. Based on the descriptive result, the mean for the type of platform factors is 0.1790, which shows that about 17.9% of the properties are near a specific type of platform, either island or side types. The standard deviation of 0.38342 reflects a relatively high variability in the types of platforms. A lower mean suggests a smaller number of properties in close proximity to specific platform types, but those that generally experience a favorable effect on value are demonstrated by the regression findings

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Table 2: Descriptive analysis result

Variable	Mean	Standard deviation
Location	**0.2710**	0.44452
Type of platform	**0.1790**	0.38342
Linked bridge	**0.6517**	0.47646
Parking	**1.0735**	0.78598
Distance	**1.7647**	0.96763

The mean of 0.6517 for the linked bridge factors shows that around 65.17% of the properties are near stations with linked bridges. The 0.47646 standard deviation indicates a fairly high variability, suggesting that a significant number of properties are either close to such bridges or not at all. A high proportion of properties near linked bridges, despite the negative impact on value, suggests these structures are common in the studied area. Meanwhile, the mean of 1.0735 implies that, on average, properties have a little over one parking facility available. The last factor, which is distance, has a mean value of 1.7647. This suggests that, on average, homes are relatively close to the MRT station, as the distance considered, ranges from 0 to 4000 meters.

Table 3: Regression Result.

Variable	Coefficient	Std. Error	t-Statistic	P-value
Location	**0.469**	0.010	46.423	<0.001
Type of platform	**0.049**	0.011	4.329	<0.001
Linked bridge	**-0.196**	0.018	-11.132	<0.001
Parking	**0.051**	0.010	-5.037	<0.001
Distance	**0.010**	0.004	-2.251	>0.001

Table 3 shows the detailed hedonic regression result. The positive coefficient for the location variable indicates that properties in certain locations have significantly higher prices. The result shows that the housing station located in the south or north of the railway will significantly contribute to housing prices. This is because it is statistically significant (t-statistic of 46.423 and p-value < 0.001), showing a very strong influence of location on housing prices. The positive coefficient of 0.049 suggests that properties near certain types of platforms (e.g., islands or side types) are more valuable. This might reflect preferences for specific platform types due to noise levels, views, or perceived safety. The coefficient is statistically significant (t-statistic of 4.329 and p-value < 0.001), indicating a reliable impact of platform type on housing prices.

The results also show the negative coefficient for linked bridges implying that housing near stations with linked bridges tends to be less valuable. This could be due to increased foot traffic, noise, or other disturbances associated with linked bridges. The result is statistically significant (t-statistic of -11.132 and

p-value < 0.001), indicating a strong negative impact of linked bridges on housing prices. The positive coefficient indicates that parking facilities near stations are associated with higher housing prices. This makes sense as parking facilities increase convenience for residents who commute by car. This finding is statistically significant (t-statistic of 5.037 and p-value < 0.001), suggesting a meaningful positive effect of parking availability on housing prices. This indicates that the presence of parking facilities near stations tends to elevate residential property prices. The negative coefficient for distance suggests that housing prices decrease as the distance from the nearest station increases. This is consistent with the expectation that closer proximity to transit stations is valued more highly. The result is statistically significant (t-statistic of -2.251 and p-value > 0.001), indicating a notable impact of distance on property values, although it is less statistically significant compared to other variables in the model.

CONCLUSION

The implementation of Mass Rapid Transit (MRT) significantly influences urban residential real estate markets by enhancing connectivity, reducing commuting times, and improving overall quality of life. This study aims to analyze the significant impact of MRT stations on residential property prices. Several key insights were uncovered through a comprehensive analysis of residential property prices around the MRT-SBK line in Malaysia from 2010 to 2020. Station characteristics such as the location of the station, type of platform, parking facility, linked bridge facility and distance to the station have shown an impact on residential property prices.

These findings have important implications for policymakers, urban planners, and real estate developers. Understanding the nuanced effects of MRT stations on housing prices can guide more informed decisions regarding housing policies, urban development strategies, and infrastructure investments. Enhancing transit accessibility, thoughtfully designing station amenities, and balancing the benefits of linked bridges and parking facilities can foster sustainable and equitable urban growth. Overall, this research underscores the transformative impact of MRT stations on urban real estate markets. Explaining the composite interplay between transit infrastructure and housing prices provides valuable insights that can help shape the future of urban development in cities worldwide.

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DEVELOPING A COMPREHENSIVE FRAMEWORK FOR ASSESSING COMMUNITY RESILIENCE TO PUBLIC HEALTH EMERGENCIES IN HENAN PROVINCE: INSIGHTS FROM SCIBERT ANALYSIS

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Abstract

In the wake of frequent global pandemic outbreaks, the assessment of community resilience has emerged as a critical task for ensuring public health and safety. This study develops a comprehensive framework for evaluating community resilience to public health emergencies, focusing on communities in Henan Province, China. The research integrates a systematic literature review with advanced methodologies, including the SciBERT algorithm for indicator extraction, K-means clustering analysis, elbow method, silhouette analysis, and the Analytic Hierarchy Process (AHP). The resulting framework identifies key dimensions—Spatial Design and Infrastructure, Community Services and Support, Landscape and Ecology, and Medical and Safety Measures—that are essential for enhancing community resilience. The framework was validated through case studies in both urban and rural communities, revealing significant differences in resilience performance and highlighting the need for tailored strategies. This study offers a scientifically validated tool for public health managers and community planners, aiming to strengthen community resilience and improve response capabilities in future public health crises.

Keywords: Community Resilience, Public Health Emergencies, SciBERT Algorithm, Community Planning

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INTRODUCTION

Problem Background

In the context of frequent global pandemic outbreaks, the importance of community resilience has become increasingly prominent. Community resilience refers to the ability of a community to respond to and recover from sudden public health events. The pandemic has exposed numerous shortcomings in communities' responses to emergencies, including inadequate medical facilities, chaotic management, and uneven resource distribution. These issues have not only disrupted the normal functioning of communities but also posed serious threats to the health and safety of residents. Therefore, establishing an effective community resilience assessment framework has become a critical issue that needs to be addressed (Praptika et al., 2024).

Research Objectives

The primary objective of this study is to develop a comprehensive and reliable framework for assessing community resilience in the face of public health emergencies. This framework aims to identify key factors that contribute to resilience, allowing for targeted improvements in community planning and response strategies. By focusing on these critical areas, the study seeks to enhance the ability of communities to withstand and recover from future public health crises.

Research Significance and Innovation

The significance of this study lies in providing public health managers and community planners with a scientific and systematic assessment tool to help them identify and strengthen the weak links in communities, thereby enhancing overall community resilience (Galanis, 2018). The innovation of this study is reflected in several aspects. First, the integration of the SciBERT algorithm and the Delphi method ensures the scientific and authoritative extraction of indicators (Thierry et al., 2023a). Second, the use of the elbow method and silhouette analysis determines the optimal number of indicator classifications, ensuring the reasonableness and accuracy of the classification (Shahapure & Nicholas, 2020). Finally, the Analytical Hierarchy Process is used to evaluate the extracted indicators by experts, forming the final assessment system (Gnanavelbabu & Arunagiri, 2018).

LITERATURE REVIEW

Definition and Importance of Community Resilience

Community resilience refers to the ability of a community to respond to and recover from various emergencies and crises (Robertson et al., 2021).

A resilient community can quickly restore normal operations after a disaster, minimizing the impact on residents' lives and social order (Kammouh et al., 2019). With global climate change and the frequent occurrence of public health events, the importance of community resilience has become increasingly evident. Research indicates that community resilience depends not only on robust physical infrastructure but also on social capital, community cohesion, and effective resource allocation (Pfefferbaum et al., 2017). Thus, understanding and enhancing community resilience has become a key focus for governments and research institutions worldwide to better protect residents' health and safety during future crises (Joerin et al., 2012).

Current Research on Community Resilience Assessment

Existing research on community resilience assessment mainly focuses on the following areas: spatial design and infrastructure, environmental quality and green spaces, technological integration and smart systems, medical and safety measures, and community management and resident participation (Yi et al., 2023). Effective spatial design and infrastructure can enhance a community's emergency response capabilities; for instance, spacious public areas and well-designed road networks provide efficient evacuation routes during emergencies (Wang et al., 2023). High environmental quality and well-designed green spaces not only improve residents' quality of life but also offer psychological support and comfort during crises (Valinejad et al., 2023). The application of smart technologies plays a crucial role in improving community management efficiency and emergency response speed; for example, smart surveillance systems and smart energy management systems optimize resource use and safety monitoring in communities (Ariyaningsih & Shaw, 2023). Comprehensive medical and safety measures are core components of community resilience, including adequate medical facilities, emergency medical services, and effective security patrols, which significantly enhance a community's ability to respond to public health emergencies (Dabelko-Schoeny et al., 2022). Furthermore, residents actively participating in community activities and management are more likely to unite and face challenges together during crises, strengthening community cohesion and resilience (L. Shi et al., 2023).

RESEARCH METHODOLOGY

SciBERT Algorithm

This study employs the SciBERT algorithm to analyze relevant literature and extract key indicators for assessing community resilience (T. N. Dinh et al., 2024). SciBERT can automatically identify and extract important information and indicators from the literature, providing data support for the research. Using the SciBERT algorithm, a significant amount of literature data related to

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community resilience was extracted, and the most representative assessment indicators were selected (Vilares et al., 2021).

The literature screening process is illustrated in Figure 1. Initially, a literature search was conducted in databases such as Web of Science, resulting in 348 relevant articles. After removing duplicates, 324 articles remained. Screening the abstracts of these articles led to the exclusion of 211 articles that did not meet the research requirements. Subsequently, the remaining 113 articles underwent full-text review, and 74 were excluded based on their relevance to the research topic and availability of complete text. Ultimately, 39 articles were retained for qualitative analysis.

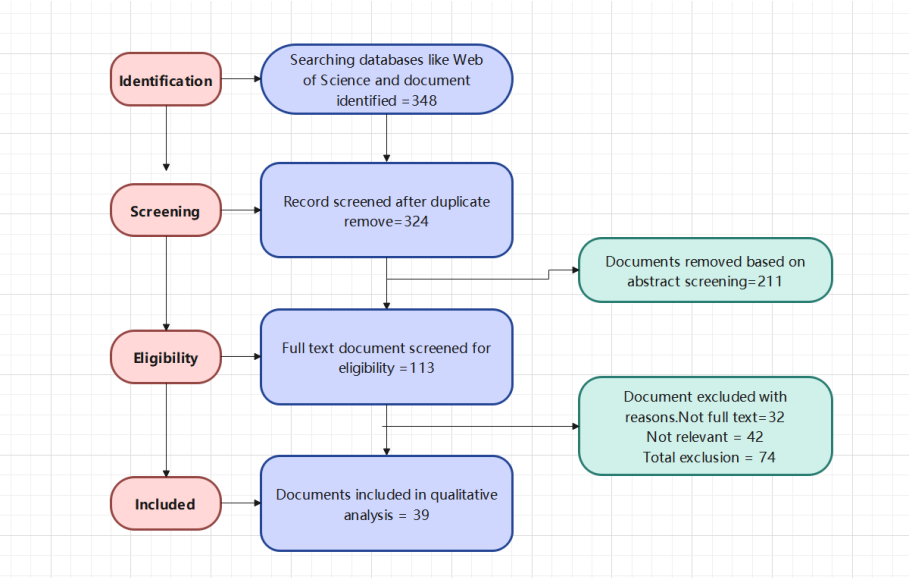


Figure 1: Flow Diagram of the Literature Screening Process
(Author's Creation)

K-means Clustering and Elbow Method and Silhouette Analysis

To ensure the extracted indicators are reasonable and representative, K-means clustering analysis was conducted. K-means clustering is a commonly used unsupervised learning algorithm that effectively assigns data points to different clusters. By applying K-means clustering to the extracted indicators, the study preliminarily identified several categories of indicators.

To determine the optimal number of clusters for K-means clustering, the elbow method and silhouette analysis were employed. The elbow method involves plotting the total sum of squared errors (SSE) for different numbers of clusters and selecting the number of clusters at the "elbow" point, where the SSE

starts to level off. Silhouette analysis evaluates the compactness of data points within clusters and the separation between different clusters (Lenssen & Schubert, 2024).

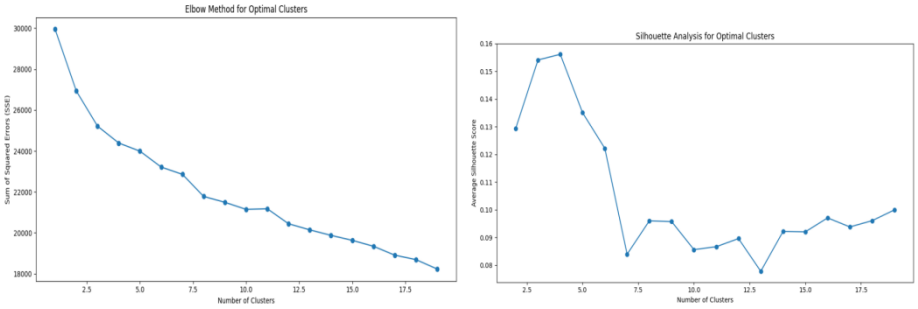


Figure 2 Elbow Method and Silhouette Analysis for Determining Optimal Clusters *(Author's Creation)*

Through these methods, the study determined that the optimal number of clusters is four. Figure 2 shows the elbow method and Silhouette Analysis results, suggesting it as an ideal number (C. Shi et al., 2021). Combining these methods, the study concluded that four clusters is the optimal classification number.

Indicator Review and Framework Refinement

After identifying the initial four categories of indicators—Spatial Design and Infrastructure, Community Services and Support, Landscape and Ecology, and Medical and Safety Measures—this study undertook a thorough review to ensure their scientific validity and relevance. The review process involved several steps: First, the selection of indicators was informed by a comprehensive literature review and consultations with eight experts in urban planning, architecture, landscape design, and ecological environment, selected based on their expertise and research background in community resilience. Data was collected from these experts through structured interviews and Delphi questionnaires, focusing on the relevance, practicality, and applicability of each indicator.

Second, specific issues identified during the expert consultation, such as overlap between indicators or lack of clarity in their application, were addressed through iterative feedback and refinement. Indicators that were deemed impractical, redundant, or too general were eliminated, while those that were essential and contextually relevant were retained and detailed in the framework. The final framework thus represents a robust and contextually appropriate tool for assessing community resilience, with specific strengths in its adaptability and

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comprehensiveness, though challenges remain in ensuring its wide applicability across diverse communities.

Analytical Hierarchy Process (AHP)

Following the establishment of the final indicator framework, this study employed the Analytical Hierarchy Process (AHP) to evaluate the weights of each indicator. AHP is a method that combines subjective judgment with mathematical analysis, widely used in multi-criteria decision analysis (Arshad et al., 2020).

To assess community resilience, a three-level hierarchical indicator system was established, comprising a goal level for overall resilience, a criteria level for four main indicator categories, and an indicator level for specific assessment indicators within each category. A panel of experts in urban planning, architecture, and community resilience then conducted pairwise comparisons of indicators, rating their relative importance on a 1-9 scale to build a judgment matrix. The Consistency Ratio (CR) was used to check the reliability of these comparisons; a CR value above 0.1 prompted experts to re-evaluate their ratings, ensuring the final matrix accurately reflected their consensus on indicator importance.

Table 1: Demographic Information of Participating Experts (Author's Creation)

Expert Code	Gender	Title	Research Field
Expert A	Male	Lecturer	urban and rural planning
Expert B	Male	Lecturer	urban and rural planning
Expert C	Male	Senior Designer	Architecture
Expert D	Male	Lecturer	Architecture
Expert E	Male	Lecturer	urban and rural planning
Expert F	Female	Senior Engineer	Landscape Design
Expert G	Female	Associate Professor	Ecological Environment
Expert H	Male	Associate Professor	Architecture

Next, the consistency of the judgment matrix was tested to ensure the consistency of the experts' scores. If the consistency test failed, the experts' scores needed to be adjusted until the matrix's consistency index met the requirements. Then, the eigenvector method was used to calculate the eigenvectors of each judgment matrix, ultimately deriving the weights of each indicator. The weights corresponding to the eigenvectors reflect the relative importance of each indicator in the overall community resilience assessment. Finally, the weights at each level were comprehensively calculated to obtain the final weight of each specific

indicator. These weights will be used in subsequent comprehensive assessments of community resilience, guiding practical applications.

RESULTS AND DISCUSSION

Theme Extraction Using SciBERT Algorithm

Table 2: Frequency and Source Distribution of Resilience Indicators (Author's Creation)

Indicator	Freq	Files	Indicator	Freq	Files
Accessibility of Medical Facilities	66	24	Community Squares and Gardens	6	6
Training and Drills	35	14	Indoor Ventilation Systems	6	5
Emergency Rescue Plans	33	10	Special Plans for Vulnerable Groups	6	3
Control Entry Points	31	6	Regular Waste Removal	6	3
Emergency Passageways	20	5	Community Lighting	6	3
Daily Health Monitoring in the Community	19	10	Social Distancing Measures	5	3
Provision of Telemedicine Services	18	4	Digital Information Service Platforms	5	4
Psychological Health Support Services	17	4	Transparency and Accountability Mechanisms	5	3
Contactless Identity and Temperature Detection	16	3	Community Greening Rate	5	5
Effective Organizational Management	16	4	Air Quality Monitoring	5	4
Pedestrian and Vehicle Separation Design	16	6	Community Interaction and Mutual Aid Platforms	5	3
Availability of Emergency Equipment	11	5	Plant Species that Promote Air Quality	5	4
Community Public Area Video Surveillance Systems	9	4	Social Support Networks	4	3
Accessibility of Daily Community Services	9	5	Use of Environmentally Friendly Materials	4	4
Flexible Space Reserved for Emergencies	8	4	Support Friend	4	4
Unidirectional Systems to Reduce Contact	8	4	Recovery Reconstruction	4	3
Stockpiling and Distribution of Emergency Supplies	8	4	Community Assist	4	4
Clear Navigation Signage	7	6	Resilience Preparedness	3	3
Value Community	3	4	Respond Crises	3	3

The research team utilized the SciBERT algorithm to extract themes from 39 SCI articles on community resilience in public health emergencies. To

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ensure the representatives of the indicators, frequency and source thresholds were set for the extracted phrases. Specifically, phrases that appeared more than three times and were sourced from more than two articles were selected. Table 2 presents the final 39 phrases identified as candidate indicators.

Clustering Analysis Results

Using the elbow method and silhouette analysis on the 39 extracted phrases, as shown in Figures 2 and 3, the optimal number of clusters was determined to be four. The clustering analysis results indicated that the best four categories are Medical and Safety Measures, Spatial Design and Infrastructure, Community Services and Support, and Landscape and Ecology (Punhani et al., 2022).

Indicator Review and Framework Refinement

Following the initial classification, the study conducted a further review and adjustment of these indicators. First, through a literature review and expert consultation, feedback was collected to identify and address potential issues in practical application. Consequently, some indicators that were impractical or redundant, such as support friend, recovery reconstruction, community assist, resilience preparedness, value community, and respond crises, were removed. This process verified and adjusted the indicator system to ensure its applicability to different types of communities and public health emergency scenarios. Figure 3 presents the final framework diagram.

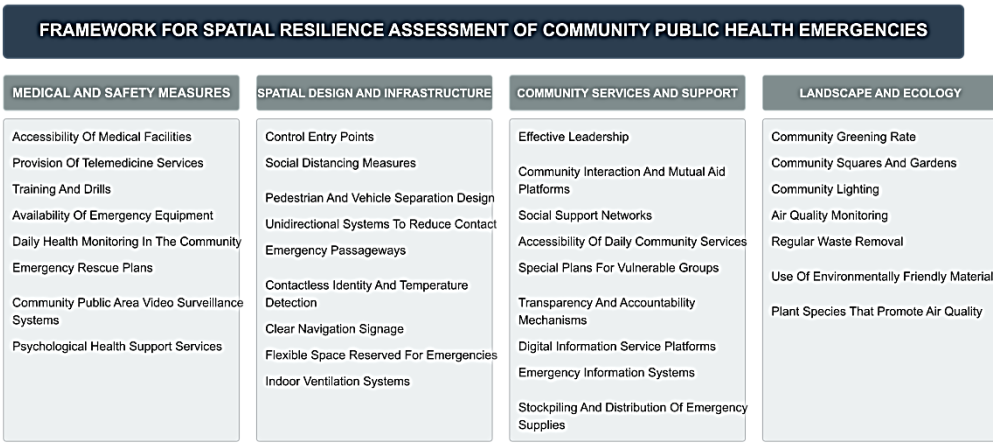


Figure 3: Framework for Spatial Resilience Assessment of Community Public Health Emergencies (Author's Creation)

Indicator Weight Calculation Results

Table 3: Weight of Resilience Indicators (Author's Creation)

indicator	Wi	indicator	Wi
Availability of Emergency Equipment	0.0748	Community Public Area Video Surveillance Systems	0.0222
Emergency Rescue Plans	0.0743	Flexible Space Reserved for Emergencies	0.022
Training and Drills	0.0707	Contactless Identity and Temperature Detection	0.0203
Accessibility of Medical Facilities	0.0668	Transparency and Accountability Mechanisms	0.0195
Effective organizational management	0.0565	Indoor Ventilation Systems	0.0188
Emergency Information Systems	0.0398	Digital Information Service Platforms	0.0178
Control Entry Points	0.0395	Community Interaction and Mutual Aid Platforms	0.0155
Emergency Passageways	0.0391	Unidirectional Systems to Reduce Contact	0.0151
Special Plans for Vulnerable Groups	0.0373	Pedestrian and Vehicle Separation Design	0.0149
Accessibility of Daily Community Services	0.037	Social Support Networks	0.0144
Stockpiling and Distribution of Emergency Supplies	0.0344	Community Greening Rate	0.0137
Psychological Health Support Services	0.0342	Air Quality Monitoring	0.013
Provision of Telemedicine Services	0.0339	Clear Navigation Signage	0.0116
Daily Health Monitoring in the Community	0.0323	Social Distancing Measures	0.0108
Community Squares and Gardens	0.0319	Plant Species that Promote Air Quality	0.0066
Regular Waste Removal	0.0292	Use of Environmentally Friendly Materials	0.006
Community Lighting	0.0261	Availability of Emergency Equipment	0.0748

To ensure the reliability and consistency of the assessment framework, experts with extensive experience in fields relevant to community resilience, including urban planning, architecture, and emergency management, were invited to evaluate the indicators using the Analytical Hierarchy Process (AHP). These experts performed pairwise comparisons of the importance of each indicator, evaluating their relative significance within their respective categories to construct a judgment matrix reflecting the weights of the indicators. The

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consistency of the experts' evaluations was assessed using the Consistency Ratio (CR) to ensure logical soundness, and any inconsistencies identified were addressed by revisiting the experts' judgments to refine the matrix. The results, as illustrated in Table 3, show that "Availability of Emergency Equipment" has the highest weight at 0.0905, highlighting its crucial role in enhancing community resilience in response to public health emergencies. Other significant indicators include "Emergency Rescue Plans" (0.0899), "Training and Drills" (0.0855), and "Accessibility of Medical Facilities" (0.0808), emphasizing the importance of medical and safety measures. Additionally, indicators like "Effective Organizational Management" (0.0425) and "Control Entry Points" (0.0447) underscore the critical role of management and infrastructure in public health emergencies.

Community Scoring Analysis

To further validate the effectiveness and applicability of the constructed assessment framework, this study conducted case studies on two communities in Henan Province: one rural community which named Liujingzhai Village and one urban community which named Fenghuangcheng Community. By evaluating these two communities in detail, the study aims to better understand the differences and commonalities in resilience building across different types of communities, thereby providing a basis for formulating differentiated policies and measures.

Table 4: Comparison of Resilience Indicators Between Community A and Community B (Author's Creation)

Index	Liujingzhai Village	Fenghuangcheng Community
Availability of Emergency Equipment	0.181	0.362
Emergency Rescue Plans	0.3596	0.3596
Training and Drills	0.2565	0.4275
Accessibility of Medical Facilities	0.1616	0.404
Control Entry Points	0.0894	0.1788
Emergency Passageways	0.1326	0.1326
Effective organizational management	0.17	0.1275
Psychological Health Support Services	0.1652	0.1239
Provision of Telemedicine Services	0.123	0.164
Daily Health Monitoring in the Community	0.1173	0.1564
Emergency Information Systems	0.12	0.09
Special Plans for Vulnerable Groups	0.0562	0.0843
Accessibility of Daily Community Services	0.0834	0.1112
Community Public Area Video Surveillance Systems	0.0268	0.1072

Index	Liujingzhai Village	Fenghuangcheng Community
Stockpiling and Distribution of Emergency Supplies	0.0518	0.0777
Flexible Space Reserved for Emergencies	0.1245	0.0747
Contactless Identity and Temperature Detection	0.046	0.115
Indoor Ventilation Systems	0.1065	0.0852
Community Squares and Gardens	0.1045	0.0836
Regular Waste Removal	0.0576	0.096
Community Lighting	0.0344	0.0688
Unidirectional Systems to Reduce Contact	0.0513	0.0684
Pedestrian and Vehicle Separation Design	0.0336	0.0672
Transparency and Accountability Mechanisms	0.0438	0.0292
Digital Information Service Platforms	0.0268	0.0536
Clear Navigation Signage	0.0262	0.0524
Social Distancing Measures	0.0369	0.0369
Community Interaction and Mutual Aid Platforms	0.0585	0.0351
Social Support Networks	0.0324	0.0432
Community Greening Rate	0.036	0.018
Air Quality Monitoring	0.017	0.017
Plant Species that Promote Air Quality	0.0172	0.0086
Use of Environmentally Friendly Materials	0.008	0.008
Total	2.9556	3.8676

The results show that the Fenghuangcheng Community scores significantly higher than the rural community in indicators such as "Availability of Emergency Equipment," "Training and Drills," and "Accessibility of Medical Facilities," indicating that the urban community has stronger resilience in these key areas, likely due to more comprehensive infrastructure and greater resource investment. However, the Liujingzhai Village community scores higher than the urban community in indicators such as "Effective Organizational Management" and "Psychological Health Support Services," reflecting closer community relationships and stronger organizational management capabilities in rural areas when facing emergencies.

These results demonstrate significant differences in resilience performance across different types of communities, underscoring the importance of developing differentiated strategies tailored to each community. For urban communities, it is essential to continue enhancing the availability of emergency equipment and medical facilities. For rural communities, improving emergency management and psychological support services is crucial.

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CONCLUSION

In the context of frequent global pandemic outbreaks, assessing community resilience has become a crucial task to ensure public health and safety. This study aimed to establish a comprehensive framework for evaluating community resilience to potential future public health emergencies. By integrating a systematic literature review, SciBERT algorithm for indicator extraction, K-means clustering analysis, elbow method and silhouette coefficient analysis, and Analytic Hierarchy Process (AHP), this study developed a robust indicator system encompassing multiple dimensions.

The findings indicate that Spatial Design and Infrastructure, Community Services and Support, Landscape and Ecology, and Medical and Safety Measures play vital roles in enhancing community resilience. The framework offers theoretical guidance and practical references for community planning and management, ultimately aiming to bolster communities' resilience and response capabilities in future public health crises.

This study contributes a scientifically validated and systematic assessment tool for public health managers and community planners, enabling them to identify and strengthen weak points within communities. The innovative aspects of this study include the use of the SciBERT algorithm and the Delphi method for scientific and authoritative indicator extraction, the combination of elbow and silhouette methods to determine optimal classification numbers, and the application of AHP for expert evaluation of the final assessment framework.

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ASSESSMENT AND PREDICTION MODEL FOR COMMUNITY RESILIENCE IN CHINA BASED ON GANS AND RANDOM FOREST REGRESSION

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Abstract

Community resilience is a vital aspect of urban planning and disaster management, especially in rapidly urbanizing countries like China, where frequent natural disasters pose significant threats. This study addresses the challenge of assessing and predicting community resilience in China by developing an innovative model using Generative Adversarial Networks (GANs) and Random Forest Regression. The model specifically tackles issues of data insufficiency and prediction inaccuracy in traditional methods. The study surveyed 33 diverse communities across various regions in China and generated 300 additional virtual samples using GANs to enhance model robustness. The model incorporates the Analytic Hierarchy Process (AHP) to ensure scientific accuracy in determining indicator weights. Results indicate a substantial improvement in predictive performance, with a Mean Squared Error (MSE) of 0.00055 and a coefficient of determination (R^2) of 0.99578. This study contributes a novel framework for evaluating community resilience, providing a scientific foundation for disaster prevention and mitigation strategies in urban governance.

Keywords: Community Resilience, GANs, Random Forest Regression, Urbanization, Disaster Prevention

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INTRODUCTION

Research Background

As global climate change intensifies and natural disasters become more frequent, community resilience has emerged as a crucial research topic in urban planning and public administration. As the most populous country in the world, China's assessment of community resilience is of paramount importance for safeguarding the lives and property of its residents and enhancing the overall level of urban governance (Zhao et al., 2023). In recent years, the acceleration of urbanization has increasingly exacerbated the risks and challenges faced by communities (Hu et al., 2023). Natural disasters such as earthquakes, floods, and typhoons occur frequently, posing significant threats to the lives and properties of community residents (Ma et al., 2021). Concurrently, the socioeconomic structure of communities is continuously evolving, with issues such as population aging and the increase in migrant populations imposing higher demands on community resilience (Ma et al., 2021). Therefore, constructing a scientifically sound community resilience assessment model to promptly identify and address vulnerabilities in communities facing disasters and to enhance comprehensive disaster prevention and mitigation capabilities holds significant practical importance (Suleimany et al., 2022).

Research Objectives

The primary objective of this study is to develop a Chinese community resilience assessment and prediction model based on Generative Adversarial Networks (GANs) and Random Forest Regression. This model aims to address issues of data insufficiency and prediction inaccuracy present in traditional assessment methods. Specific objectives include extracting key indicators affecting community resilience to construct a systematic assessment framework, using the Analytic Hierarchy Process (AHP) to determine the weights of these indicators to ensure scientific accuracy in the assessment results, and employing GANs to generate additional virtual samples for quantitative assessment and prediction of community resilience using Random Forest Regression.

Research Innovations and Significance

This study demonstrates innovation in several key areas. The introduction of Generative Adversarial Networks (GANs) facilitates the creation of numerous virtual samples, addressing the issue of inaccurate evaluation results caused by insufficient data in traditional methods. GANs enhance model generalization by generating new samples that are consistent with the characteristics of actual data. Utilizing the random forest regression algorithm enables the quantitative assessment and prediction of community resilience. Random forest regression is effective in handling high-dimensional data and possesses strong noise resistance,

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thereby improving the accuracy and stability of the model's predictions. Additionally, a comprehensive community resilience assessment indicator system is developed through literature review and expert discussions. This system encompasses both tangible resources and infrastructure, as well as soft indicators such as social relationships and information dissemination, providing a holistic view of community resilience. These innovations offer novel methods and tools for evaluating community resilience and provide a scientific basis for the formulation and implementation of disaster prevention and mitigation policies, thus holding significant theoretical and practical value.

LITERATURE REVIEW

Community Resilience

Research on community resilience began in the late 20th century and has become an important field of study with the increasing focus on climate change and disaster management (Xu et al., 2021). Community resilience is generally defined as the capacity of a community to respond to, adapt to, and recover from disasters. Early studies primarily concentrated on defining the concept and constructing theoretical frameworks for community resilience (Ma et al., 2021). As research progressed, scholars increasingly focused on evaluating community resilience through quantitative indicators (Zhao et al., 2023). The importance of these assessments lies in their ability to inform strategies that safeguard lives and property, enhance urban governance, and address the challenges of rapid urbanization, which are critical in disaster-prone regions.

Internationally, significant progress has been made in community resilience assessment (Suleimany et al., 2022). For instance, the United States National Academy of Sciences proposed a community resilience assessment framework based on social, economic, institutional, and environmental dimensions (Mieler et al., 2015). Similarly, the Australian Disaster Resilience Institute identified seven dimensions for assessing community resilience, including social capital, community competence, and information and communication (Dinh & Pearson, 2015). These studies provide an essential theoretical foundation and reference for this research.

In China, research on community resilience assessment started relatively late but has developed rapidly (Guo et al., 2020). Chinese scholars have proposed community resilience assessment models tailored to the Chinese context (Ntontis et al., 2020). For example, some scholars have developed indicator systems for community resilience assessment, focusing on disaster prevention and mitigation capabilities, social support networks, and economic recovery abilities (Xu et al., 2021). Others have introduced methods based on multivariate statistical analysis and fuzzy comprehensive evaluation. These studies offer valuable insights for this research. These efforts are crucial in

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enhancing the resilience of communities, thereby supporting urban governance and ensuring the safety and well-being of the population amid the pressures of rapid urbanization.

RESEARCH METHODOLOGY

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a method that decomposes complex decision-making problems into a hierarchical structure, allowing for layer-by-layer analysis and comparison to determine the relative importance of various factors (Wang et al., 2020). In this study, key indicators influencing community resilience are identified through literature review and expert interviews (Pilevar et al., 2020). The experts selected for the interviews were professionals with extensive experience in urban planning, disaster management, and public policy, chosen based on their academic qualifications and practical expertise in these fields. An interview guideline was developed to ensure consistency, focusing on collecting data related to the significance of various resilience indicators. Subsequently, multiple experts are invited to conduct pairwise comparisons of these indicators, constructing a judgment matrix. The judgment matrix was developed by systematically comparing each pair of indicators, with experts providing their assessments based on the data collected during the interviews. AHP is then used to calculate the weights of each indicator, ensuring the scientific validity and accuracy of the assessment results (Lyu et al., 2020).

Generative Adversarial Networks (GANs)

Generative Adversarial Networks (GANs) are deep learning models that generate new data through adversarial training (Jeong et al., 2022). In this study, GANs are utilized to generate a large number of virtual community samples, addressing the insufficiency of actual survey data. The specific method involves first collecting basic data from real communities, which refers to the selected 33 diverse communities across China, encompassing urban, suburban, and rural areas to train the generator and discriminator (Shoshan et al., 2021). These communities were chosen to provide a comprehensive representation of different socio-economic conditions, infrastructure levels, and disaster risks. This training enables the generator to produce new samples that resemble the actual data distribution (Mescheder et al., 2018). Through repeated training, meaning multiple cycles of adjusting the generator and discriminator based on feedback, through repeated training, the generated virtual samples effectively enhance the model's generalization capability and predictive accuracy (Wiese et al., 2020).

Random Forest Regression

Random Forest Regression is an ensemble learning algorithm based on multiple decision trees (Kumar et al., 2020). In this study, the random forest regression algorithm is employed for the quantitative assessment and prediction of community resilience (Lyu et al., 2020). he specific method involves combining actual survey data, which refers to the data collected from the 33 diverse communities across China, including detailed demographic, socio-economic, and resilience-related information, with virtual samples generated by GANs to construct training and testing sets (Irfan et al., 2022). The random forest model is then trained and used to predict community resilience. The effectiveness of the model in practical applications is evaluated through cross-validation (Pilevar et al., 2020).

RESULTS AND ANALYSIS

Framework Derived from Literature Review and Expert Discussions

The community resilience assessment framework presented in Figure 1 is derived from extensive literature review and expert discussions conducted by the research team. To ensure the scientific rigor of the framework, the team reviewed a substantial number of studies on community resilience assessment, drawing on frameworks proposed by authoritative institutions such as the United States National Academy of Sciences and the Australian Disaster Resilience Institute. Additionally, several experts in community development and disaster management were consulted for in-depth discussions and feedback. This multi-layered and multi-faceted research approach ensures the framework's theoretical and practical reliability and feasibility.



Figure 1: Community Resilience Evaluation Framework (Author's Creation)

The assessment framework in Figure 1 includes five primary dimensions: connectivity and care, resources, adaptive capacity, disaster management, and information dissemination. These dimensions and their specific indicators were selected based on an extensive review of the literature and expert consultations, ensuring that they reflect the most critical aspects of community resilience as identified in previous studies. Each dimension encompasses several

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specific indicators, such as sense of belonging, community expectations, emergency preparedness, and information exchange. These indicators were chosen for their relevance and proven impact on community resilience in the context of disaster management, as highlighted in prior research. Evaluating these elements provides a comprehensive understanding of a community's overall capability to respond to disasters and emergencies, thereby offering a scientific basis for the formulation and implementation of community disaster prevention and mitigation policies. This framework is informed by key insights from the literature, particularly regarding the importance of both tangible and intangible resources in enhancing community resilience.

Weight Calculation Using Analytic Hierarchy Process (AHP)

Table 1: Demographic Information of Participating Experts (Author's Creation)

Expert Code	Gender	Title	Research Field
Expert A	Male	Lecturer	urban and rural planning
Expert B	Male	Lecturer	urban and rural planning
Expert C	Male	Senior Designer	Architecture
Expert D	Male	Lecturer	Architecture
Expert E	Male	Lecturer	urban and rural planning
Expert F	Female	Senior Engineer	Disaster
Expert G	Female	Associate Professor	Disaster
Expert H	Male	Associate Professor	Government management

The weight results calculated using the Analytic Hierarchy Process (AHP) are derived from the systematic analysis and pairwise comparisons conducted by eight experts from fields such as community development, disaster management, and public policy. As shown in Table 1, these experts, leveraging their extensive professional knowledge and practical experience, conducted detailed comparisons and weight evaluations of various community resilience assessment indicators. To ensure the scientific validity and accuracy of the results, the experts adopted a rigorous set of criteria, including the scope of impact, importance, and performance of each indicator in different contexts.

Table 2: Weighted Indicators for Assessing Community Resilience (Author's Creation)

Indicator	Weight
Emergency Preparedness	0. 1999
Emergency Services	0. 0942
Disaster Resource Reserve	0. 0916
Disaster Prevention	0. 0666
Community Leadership	0. 0591
Sense of Belonging	0. 0568
Post-disaster Services	0. 0471
Service Access	0. 0459
Information Communication	0. 0426
Care for Vulnerable Groups	0. 0373
Resident Well-being Contribution	0. 0373
Disaster Planning	0. 0365
External Cooperation	0. 0262
Problem-solving Channels	0. 0205
Community Resource Seeking	0. 0201
Community Expectations	0. 0197
Community Fairness	0. 0194
Mutual Aid among Residents	0. 0185
Information Supply	0. 0179
Resident-Leader Communication	0. 0143
Community Collaboration	0. 0122
Community Trust	0. 0113
Experience Summary	0. 0049

Specifically, Table 2 illustrates emergency preparedness holds the highest weight at 0. 1999, indicating that disaster and emergency-related preparations are considered the most critical factor in community resilience. Following closely are emergency services and disaster resource reserve, with weights of 0. 0942 and 0. 0916, respectively. This underscores the significance of the availability of emergency services and disaster resources in enhancing community resilience during disasters. Additionally, indicators such as community leadership, sense of belonging, post-disaster services, and access to services also have substantial weights, highlighting the importance of community management, social cohesion, and service assurance in improving community resilience. Conversely, softer indicators such as community collaboration, community trust, and experiential learning have relatively lower weights but remain essential components of community resilience. These weight results

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provide crucial reference points for communities in formulating disaster prevention and mitigation strategies and enhancing resilience.

Scoring Communities

To develop the predictive model, the research team selected 33 communities from the capital of China, provincial capitals, typical cities, towns, and rural areas as study samples. These communities were chosen based on specific selection criteria, including their geographic location, population density, socio-economic diversity, and historical exposure to natural disasters. The selection criteria were based on several considerations. First, the sample ensured broad geographic representation to reflect the differences and commonalities in community resilience across China. Second, it included communities of varying sizes and structures, from densely populated urban communities to relatively dispersed rural communities, to comprehensively understand how different types of communities respond to disasters. Finally, communities with different levels of disaster risk were chosen to capture the diversity of community resilience in facing various natural disasters such as earthquakes, floods, and typhoons. This diverse selection aimed to ensure that the model could generalize well across different community contexts and provide robust insights into resilience strategies.

During data collection, the research team conducted field surveys to gather detailed data from these 33 communities. The surveys were completed by community members, local officials, and representatives from relevant agencies, with a total of approximately 500 respondents participating across all communities. After completing the surveys, eight experts from fields such as community planning, disaster management, and public policy were invited to score the community data. These experts used the indicator weights previously determined through the Analytic Hierarchy Process (AHP) to comprehensively score each community, resulting in a total score for each community. The scores in Figure 2 reflect the varying levels of community resilience, with higher scores indicating stronger resilience. For example, Provincial Capital Community 4 achieved the highest score of 4.1235, signifying robust resilience, likely due to well-developed infrastructure and effective disaster management systems. In contrast, Rural Community 2 received the lowest score of 1.5755, highlighting vulnerabilities possibly related to limited resources and weaker infrastructure. This approach not only allowed the research team to assess the resilience levels of the communities but also provided a reliable data foundation for subsequent model training.

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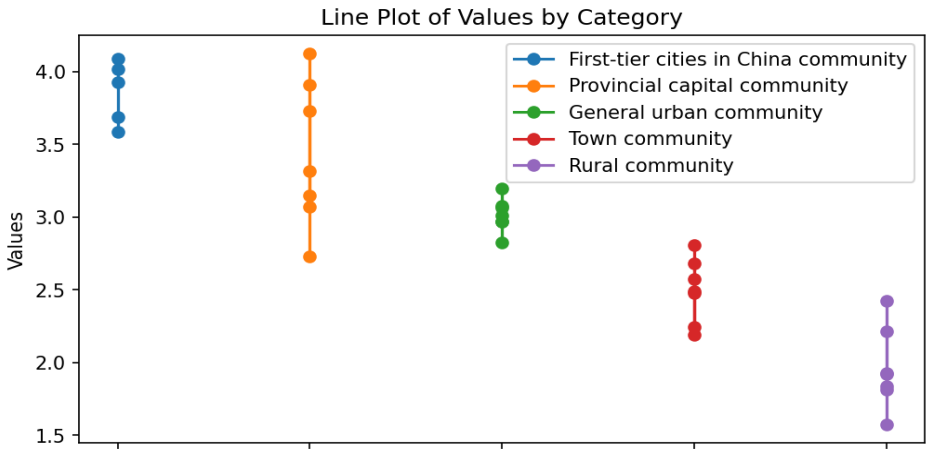


Figure 2: Community Resilience Scores by Community Type (Author's Creation)

Model Training and Results

The random forest regression algorithm was employed to train the model, with preliminary results indicating a Mean Squared Error (MSE) of 0. 09 and a coefficient of determination (R^2) of 0. 81. These results suggest that the model can explain a substantial portion of the data variance, though its interpretability and predictive accuracy are still limited. Specifically, an R^2 score of 0. 81 indicates that while the model has a good fit, approximately 19% of the variance remains unexplained.

The primary reason for this limitation is the small sample size, with only 33 community samples, which restricts the model's generalization ability and predictive accuracy. Furthermore, the diversity and complexity of community data add to the challenges of model training, limiting the model's performance in capturing the intricate relationships among different dimensions of community resilience. However, the detailed analysis of these 33 diverse communities provides valuable insights into the key factors influencing community resilience, making the presented data a useful reference for future studies. While the model's generalizability may be limited, the methodological framework and findings can guide larger-scale studies and inform the development of more robust models as additional data becomes available. Therefore, increasing the sample size and enhancing data diversity will contribute to improving the model's interpretability and predictive accuracy (Dimitriadis et al., 2018).

To address the issue of insufficient community sample size, this study incorporated Generative Adversarial Networks (GANs) for deep learning(Joshi et al., 2022). By training on the original data from 33 communities, GANs successfully generated 300 virtual samples. Through the adversarial training of the generator and discriminator, GANs produced virtual samples that closely matched the feature distribution of the actual data, effectively mitigating the

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problem of limited sample size. These virtual samples are considered representative of real-world conditions because GANs are designed to replicate the feature distribution of actual data. Through the adversarial training of the generator and discriminator, GANs produced virtual samples that closely matched the characteristics and variability observed in the real communities. This process ensures that the virtual samples reflect the diversity and complexity of the real-world environments, effectively mitigating the problem of limited sample size and enhancing the robustness of the model's predictions.

These virtual samples not only increased the quantity of training data but also enhanced the model's generalization capability and predictive accuracy (Salimans et al., 2016). Consequently, they provided a robust data foundation for subsequent training of the random forest regression model, significantly improving its performance in assessing community resilience.

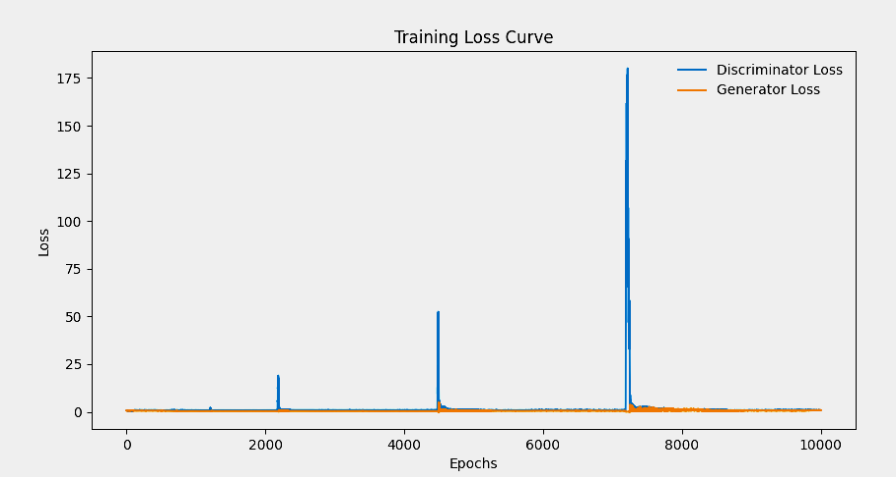


Figure 3: Training Loss Curve for GAN Model (Author's Creation)

The training loss curve in Figure 3 illustrates the changes in generator loss and discriminator loss during GANs training (Pan et al., 2020). The X-axis represents the number of epochs, while the Y-axis represents the loss values. The figure shows that the discriminator loss (blue curve) experiences some noticeable fluctuations in the early stages of training but generally stabilizes over time. In contrast, the generator loss (orange curve) remains relatively stable throughout the training process. This indicates that as training progresses, the generator and discriminator gradually reach a dynamic balance, with the generator producing realistic samples and the discriminator effectively distinguishing between real and generated samples. These training results demonstrate that the GANs model successfully generated virtual community data with realistic features, thereby

enhancing the training effectiveness and predictive accuracy of the subsequent model.

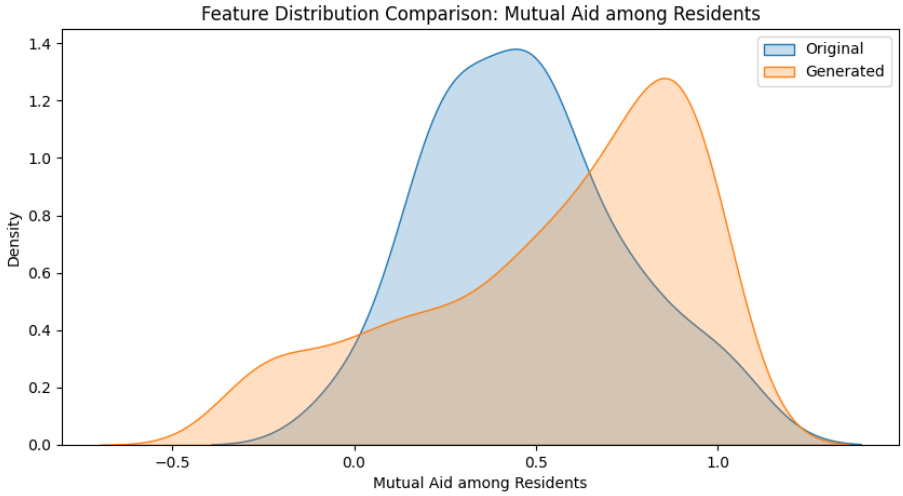


Figure 4: Feature Distribution Comparison for 'Mutual Aid among Residents' (Author's Creation)

As shown in Figure 4, the feature distribution comparison plot in the figure illustrates the distribution of the "Mutual Assistance among Residents" indicator in both the original sample data and the virtual sample data generated by GANs. The X-axis represents the values of "Mutual Assistance among Residents," and the Y-axis represents density. The blue curve represents the distribution of the original data, while the orange curve represents the distribution of the generated data. It can be observed that the distribution of the generated data closely aligns with the overall shape of the original data distribution, indicating that GANs successfully generated virtual samples with characteristics similar to the actual data.

This consistency validates the reasonableness and authenticity of the feature distribution in the GANs-generated virtual samples, thereby enhancing the data foundation for subsequent model training (Pan et al., 2020). Introducing these virtual samples enables the model to better understand the complex relationships within community resilience, providing more accurate assessment and prediction results in practical applications. This outcome demonstrates the effectiveness of using GANs technology to generate data, offering a feasible solution to the problem of insufficient actual data and providing a solid foundation for constructing community resilience assessment models.

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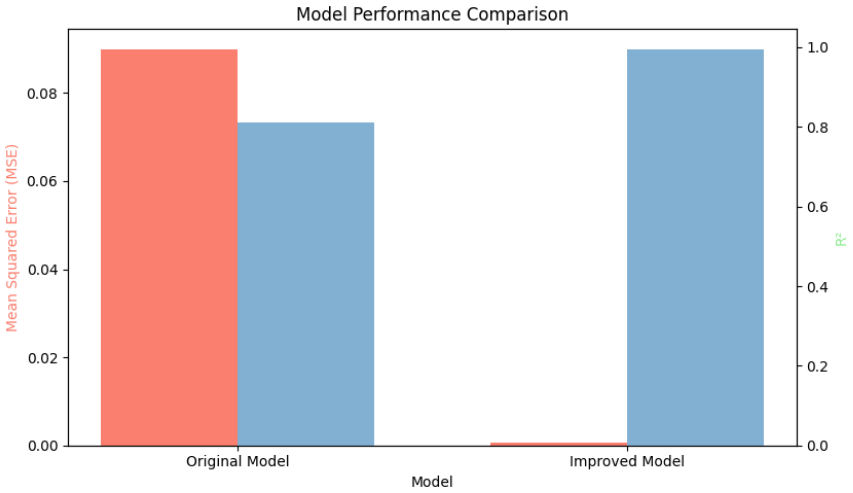


Figure 5: Model Performance Comparison (Author's Creation)

Combining the 300 virtual samples generated by GANs with the original 33 community data samples, the random forest algorithm was used for model training. The final results shown in Figure 5 illustrates that the Mean Squared Error (MSE) significantly decreased to 0. 00055, and the coefficient of determination (R^2) increased to 0. 99578. This indicates that the use of GANs-generated virtual samples substantially improved the model's predictive accuracy and explanatory power, allowing the model to more accurately reflect the actual conditions in community resilience assessment. This result proves the effectiveness and feasibility of GANs in enhancing datasets and improving model performance.

CONCLUSION

This study aims to address the issues of insufficient data and inaccurate predictions in traditional methods by constructing a community resilience assessment and prediction model based on Generative Adversarial Networks (GANs) and random forest regression. In the context of China, the world's most populous country, evaluating community resilience is crucial for safeguarding residents' lives and property and enhancing urban governance. As urbanization accelerates, communities face increasing risks and challenges, including frequent natural disasters and changes in socio-economic structures, making the development of a scientific and reasonable community resilience assessment model imperative.

The innovation of this study lies in the use of GANs to generate a large number of virtual samples, combined with the random forest regression algorithm for quantitative assessment and prediction of community resilience. The evaluation

indicator weights determined by the Analytic Hierarchy Process (AHP) ensure the model's scientific validity and accuracy. The research results indicate that models using all features for evaluation performed poorly on the test set, whereas the inclusion of GANs-generated virtual samples significantly improved the model's predictive accuracy and generalization capability. Specifically, the model with GANs-generated samples achieved a Mean Squared Error (MSE) of 0. 00054 and a coefficient of determination (R^2) of 0. 99578, demonstrating high explanatory power and predictive accuracy.

The findings of this study are directly relevant to the 33 communities analyzed, as they provide a data-driven foundation for enhancing disaster preparedness and resilience at the local level. By improving the accuracy of resilience assessments, the model contributes to safeguarding lives and property in these communities, helping local authorities to make informed decisions on resource allocation and disaster mitigation strategies. Furthermore, the model supports urban governance by offering a tool that can be adapted to other rapidly urbanizing regions, thereby addressing the broader challenges of urbanization and increasing disaster risk.

The findings show that GANs technology has significant advantages in generating virtual samples and enhancing datasets, effectively addressing the issue of insufficient data. When combined with the random forest regression algorithm, the model excels in handling high-dimensional data and noise resistance, significantly improving the predictive accuracy and interpretability of community resilience assessments. This method not only provides a better understanding of the complex relationships within community resilience but also offers more accurate assessment and prediction results in practical applications.
Future research should aim to further expand the sample size and increase data diversity to enhance the model's generalization capability and predictive accuracy. Additionally, exploring other deep learning algorithms and ensemble learning methods could help develop more precise and robust community resilience assessment models. Collaboration with experts in related fields to optimize and refine the evaluation indicator system will ensure the model's operability and effectiveness in practical applications. This study provides new methods and tools for community resilience assessment, offering a scientific basis for the formulation and implementation of disaster prevention and mitigation policies, and holds significant theoretical and practical value.

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VALUE ENGINEERING PLANNING CONCEPT FOR STREET LIGHTING (MYSINAR+) THROUGH THE PUBLIC-PRIVATE PARTNERSHIP (PPP) SCHEME

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Abstract

Urban environments face complex challenges, including security concerns, rising energy costs, and environmental degradation, while cities are simultaneously required to modernize infrastructure within budgetary constraints and ambitious climate commitments. Weak value creation in municipal governance, coupled with inadequate street lighting infrastructure, further exacerbates these problems. Addressing such challenges requires innovative and cost-effective solutions that enhance urban safety and sustainability. This study examines MYSinar+, a sustainable street lighting solution developed using a value engineering approach. The research evaluates its impact on urban safety and sustainability by identifying the key functions of street lighting systems and optimizing their design to improve performance. The findings demonstrate that MYSinar+ supports climate action objectives, strengthens urban resilience, and enhances public safety. By integrating advanced technology and innovative financing within the framework of Public-Private Partnerships and leveraging carbon trading mechanisms, MYSinar+ provides a scalable solution to urban infrastructure challenges. Focusing on the initial conceptual phase, this study highlights the need for further research on prototype development and investment cost estimation, offering valuable insights for policymakers.

Keywords: Climate Action; Innovation; PPP; Street Lighting; Value Engineering

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INTRODUCTION

Urbanization is rapidly accelerating worldwide, placing significant pressure on cities to provide adequate infrastructure and public services (Ahmed et al., 2018; Mangal et al., 2024). Governments are expected to enhance the quality of life for their citizens while managing constrained budgets and fulfilling global environmental obligations (Ekardt & Bärenwaldt, 2023; Ekardt et al., 2018). As urban areas expand, the challenges they face also intensify, including outdated infrastructure, rising energy costs, insufficient public safety measures, and increasing demand for sustainable development (Mangal et al., 2024). In this context, inadequate street lighting plays a critical role, as insufficient lighting not only compromises road safety but also contributes to higher crime rates and a diminished sense of security among residents (Qin et al., 2024; Steinbach et al., 2015). Enhancing urban security is therefore closely linked to improving city infrastructure, particularly through street lighting, which has been shown to increase safety and reduce crime (Erturk et al., 2024). Simultaneously, cities are expected to play a central role in addressing climate change by reducing carbon emissions. Commitments under the Paris Agreement require the adoption of greener technologies and more sustainable practices (Ekardt & Bärenwaldt, 2023; Ekardt et al., 2018). However, many cities lack the financial resources, technical expertise, and innovative solutions necessary to achieve these ambitious targets. This challenge is further compounded by weak value creation within municipal governance, where infrastructure projects often fail to deliver optimal economic, social, and environmental benefits, resulting in underutilized resources and missed opportunities for growth (Erk et al., 2023; Alghamdi et al., 2022).

Value Engineering (VE) provides a systematic approach to maximizing functionality while minimizing costs (Almarri, 2023); however, its application within urban planning and Public-Private Partnership (PPP) frameworks for street lighting remains limited. This study addresses this gap by applying VE principles to the conceptual design of a multifunctional PPP-based street lighting system, termed MYSinar+. The contribution of this research lies in linking VE methodology with urban infrastructure planning and PPP models, demonstrating how innovative procurement and design can generate social, environmental, and economic benefits. The novelty of this study lies in operationalizing VE within a PPP context to reconceptualize street lighting as a multifunctional system, offering transferable insights for policymakers, practitioners, and scholars engaged in sustainable urban development.

LITERATURE REVIEW

Value Engineering (VE)

According to The Value Society (2007), VE is a structured and cost-effective method for evaluating project value. It is widely applied to achieve key benefits,

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including value addition, time efficiency, quality improvement, and the identification of design deficiencies. VE operates as a structured decision-making process that employs a systematic and multidisciplinary approach, assessed through functional analysis to optimize project outcomes. Optimal value is achieved by identifying the functions necessary to meet the desired target value (Arumsari & Tanachi, 2018). Moreover, VE investigates potential alternatives and design options to fulfill project objectives by integrating the client's value criteria, refining functions, enhancing quality, addressing needs and requirements, and developing technical solutions to achieve optimized designs (CIDB Malaysia, 2022).

Public-Private Partnership (PPP)

In the provision of public infrastructure, governments frequently encounter challenges such as budget constraints, limited innovation and technological capacity, and inadequate operational and maintenance practices (Sunandar & Indiyati, 2023; Sunandar, et al., 2025a). The involvement of private entities or investors with the necessary expertise and resources can therefore provide a breakthrough in infrastructure development. Such collaboration, conducted under specified requirements, is referred to as a PPP (Sunandar et al., 2024; Sunandar, et al., 2025b). The advantages of PPPs have been widely documented in the literature, particularly regarding improvements in efficiency (Mat Aron et al., 2024), value for money (Izebhor, 2022), generation of social benefits (Qingbiao et al., 2024), enhancement of time and cost performance (Verweij & van Meerkerk, 2021), and increased investment (Chen, 2021).

RESEARCH METHODOLOGY

This study employed a qualitative research design and adopted a VE methodological approach. The framework was adapted from Arumsari and Tanachi (2018); CIDB Malaysia (2022); The Value Society (2007). The methodology comprised four sequential phases: the information phase, the function analysis phase, the creative phase, and the evaluation or validation phase. The process began with the information phase, which established a shared understanding of the relevant issues. During this stage, qualitative insights were primarily gathered from secondary sources and policy documents, with the objective of consolidating existing knowledge and ensuring alignment among stakeholders.

The function analysis phase was subsequently undertaken using the Function Analysis System Technique (FAST). This approach enabled a systematic examination of both core and supporting functions, clarifying how each function contributes to addressing infrastructure challenges. The outcome was a structured understanding of functional relationships, providing the

analytical foundation for the subsequent phase. The creative phase focused on generating innovative solutions. In this study, the PPP mechanism was integrated into the VE process to stimulate creative and strategic alternatives. This phase emphasized the development of conceptual strategies that illustrate how PPPs can enhance value creation in infrastructure projects, rather than producing numerical outputs.

The final stage, the evaluation or validation phase, aimed to assess the robustness of the proposed framework. This was operationalized through participation in the Petronas Innovation Challenge 2024, which offered an external platform for independent critique and validation of the conceptual outcomes. To ensure methodological rigor, established criteria for qualitative validity and reliability were applied. Credibility was reinforced through reference to authoritative VE and PPP literature and the systematic application of the FAST technique. Transferability was supported by providing detailed descriptions of the methodological process, enabling replication in other contexts. Dependability was achieved through transparent documentation of all phases, while confirmability was maintained by grounding interpretations in documented evidence and securing external validation through the competition platform.

ANALYSIS AND DISCUSSION

Information Phase

The challenges facing contemporary urban environments are complex and multifaceted, encompassing issues such as public safety, rising energy costs, and environmental impacts. Cities are under increasing pressure to modernize their systems while simultaneously operating within constrained budgets and striving to meet ambitious environmental targets, including Nationally Determined Contributions (NDCs). Limited value creation within municipal governance and insufficient infrastructure, particularly in the provision of street lighting, further exacerbate these challenges.

Addressing these interconnected issues is essential to ensure the safety, sustainability, and economic vitality of urban areas. Effective solutions are required to enhance public safety through improved street lighting, reduce energy consumption and associated costs, and support cities in achieving their climate action commitments. By harnessing innovative technologies and financing mechanisms, such as MYSinar+, cities can respond more effectively to these pressing concerns and create more resilient, secure, and sustainable urban environments for their residents. A summary of the MYSinar+ information issues is presented in Table 1.

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Table 1: Recapitulation of MYSinar+ Information Issues Phase

No	Issue	Description
1	Inadequate Urban Lighting	Many cities face challenges arising from inadequate street lighting, which heightens safety risks for both pedestrians and motorists. Insufficiently illuminated areas are associated with increased crime rates and diminished perceptions of security, thereby reducing the accessibility and usability of public spaces, particularly during nighttime (Erturk et al., 2024; Steinbach et al., 2015)
2	Urban Security and Crime Prevention	Insufficiently illuminated streets elevate the risk of accidents and increase the vulnerability of certain areas to criminal activities, including theft, vandalism, and assault. Enhancing street lighting is therefore essential for improving public safety and mitigating crime rates, particularly in areas with high traffic volumes or elevated crime incidence (Erturk et al., 2024; Qin et al., 2024)
3	High Energy Costs	Traditional street lighting systems frequently depend on non-renewable energy sources, which impose substantial operational costs on local governments. This financial burden constrains their capacity to allocate resources toward other essential public services and infrastructure development (Kaminsky, 2022; Velásquez et al., 2024)
4	Environmental Impact	Reliance on fossil fuels for energy generation contributes substantially to carbon emissions, thereby intensifying the impacts of climate change. Cities are therefore required to adopt measures that reduce their carbon footprint to fulfil both national and international climate commitments (Ahamer, 2019; Facchini et al., 2021)
5	Pressure to Meet NDC Targets	As part of the global commitment to addressing climate change, countries have established NDCs aimed at reducing carbon emissions. However, many cities encounter substantial challenges in meeting these targets, including limited adoption of sustainable energy solutions and inadequate financial resources (Ekardt & Bärenwaldt, 2023; Ekardt et al., 2018)
6	Limited Budget and Funding Constraints	Governments often encounter budgetary constraints that limit their capacity to finance essential infrastructure projects. With the continuous growth of urban populations, the demand for improved public services intensifies, thereby exerting additional pressure on already scarce financial resources (Sunandar & Indiyati, 2023; Zulu et al., 2023).
7	Weak Value Creation in City Governments	Many municipal governments struggle to generate substantial value from their investments in infrastructure projects. Inefficient resource allocation and reliance on outdated operational models often lead to missed opportunities for economic development and the enhancement of public services (Erk et al., 2023; Li & Love, 2022)
8	Need for Innovation in Urban Infrastructure	There is an urgent need for modern and smart solutions that can adapt to the evolving demands of urban environments. Traditional infrastructure models are frequently inadequate to address contemporary challenges, particularly those related to technological integration and sustainability (Asumadu et al., 2023; De Paula et al., 2023).
9	Challenges in Public-Private Collaboration	Although PPPs offer significant potential to alleviate funding pressures, they are frequently constrained by challenges related to stakeholder alignment, risk-sharing, and accountability (Sunandar et al., 2024; Sunandar & Indiyati, 2023).

Source: Author's Own Creation (2024)

Function Analysis Phase

The VE methodology was applied to maximize the efficiency and functionality of the MYSinar+ street lighting system using the FAST diagram. This structured approach facilitated the systematic breakdown of core and value-added functions of the street lighting system, ensuring that it addresses urban needs such as energy efficiency, environmental sustainability, and public safety, while simultaneously providing additional value to the city. The primary role of street lighting is to illuminate urban spaces, including roads, parks, and public areas. MYSinar+, however, advances this core function by integrating energy-efficient and environmentally sustainable technologies that contribute to citywide objectives, such as reducing energy consumption, promoting renewable energy adoption, and minimizing the overall environmental footprint. The core functions of the MYSinar+ street lighting system are summarized in Table 2.

Table 2: Core Street Lighting Functions

No	Core Street Lighting Functions	Description
1	Decrease Energy Consumption: Use LED Technology	● Objective: Traditional street lighting systems, which frequently rely on incandescent or high-intensity discharge lamps, consume substantial amounts of electricity. ● Solution: MYSinar+ adopts LED technology, which provides higher luminous efficiency (producing more light per watt) and significantly reduces energy consumption compared with conventional lighting technologies.
2	Decrease Environmental Impact: Use Solid Plastic Recycle	● Objective: Cities produce substantial amounts of plastic waste, while traditional lighting poles made of metal contribute to environmental degradation. ● Solution: MYSinar+ utilizes streetlight poles constructed from recycled solid plastic materials, thereby reducing the environmental footprint of street lighting infrastructure.
3	Increase Renewable Energy: Use Solar Panel	● Objective: Street lighting systems powered by conventional electricity grids contribute to the reliance on non-renewable energy sources. ● Solution: MYSinar+ incorporates solar panels into the street lighting system, enabling it to operate using renewable solar energy.

Source: Author's Own Creation (2024)

Beyond its basic lighting function, MYSinar+ provides a wide range of value-added features that deliver benefits across multiple urban domains, including public safety and revenue generation. These enhancements extend the utility of the street lighting system, transforming it into a multifunctional asset that supports the broader objectives of smart city development. The value-added functions of the MYSinar+ street lighting system are summarized in Table 3.

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Table 3: Value-Added Street Lighting Functions

No	Value Added Street Lighting Functions	Description
1	Increase Telecommunication: Create Wi-Fi Spots	● Objective: Cities are increasingly adopting smart infrastructure to enhance service delivery, including the expansion of public access to the internet. ● Solution: MYSinar+ streetlights can be equipped with Wi-Fi hotspots, enabling the establishment of public Wi-Fi zones in strategic urban locations.
2	Increase City Tax Revenue: Create Advertising Business	● Objective: Cities are continually seeking innovative approaches to generate revenue, particularly from non-tax sources such as advertising. ● Solution: MYSinar+ streetlights can be equipped with digital advertising panels, enabling municipalities to monetize strategic urban locations through the display of advertisements.
3	Increase Other City Revenue: Create Carbon Trade Mechanism	● Objective: As cities work toward achieving their climate action goals, opportunities arise for generating financial returns through participation in carbon markets. ● Solution: By reducing carbon emissions through the use of solar energy and energy-efficient LED technology, MYSinar+ supports the city's overall carbon reduction targets, thereby creating opportunities to engage in carbon trading schemes.
4	Increase Security Monitoring: Create Safety Cameras	● Objective: Urban security remains a critical concern, with increasing demand for enhanced surveillance in public spaces to prevent crime and facilitate timely emergency responses. ● Solution: MYSinar+ can be equipped with safety cameras, enabling continuous monitoring of public spaces and supporting improved security management.
5	Increase City Beautification: Create Street Furniture	● Objective: Public spaces must be both functional and aesthetically appealing to attract residents and tourists, thereby fostering a vibrant urban environment. ● Solution: MYSinar+ poles can be designed to integrate street furniture such as seating areas, planters, and decorative elements, enhancing the visual quality and usability of urban spaces.
6	Increase Traffic Management: Create Traffic Cameras	● Objective: Effective traffic management is essential for reducing congestion, preventing accidents, and ensuring the smooth flow of vehicles in urban environments. ● Solution: MYSinar+ streetlights can be equipped with traffic cameras that enable real-time monitoring and management of traffic conditions.

Source: Author's Own Creation (2024)

The functions of the MYSinar+ street lighting system, analyzed using the FAST diagram, are summarized in Figure 1.

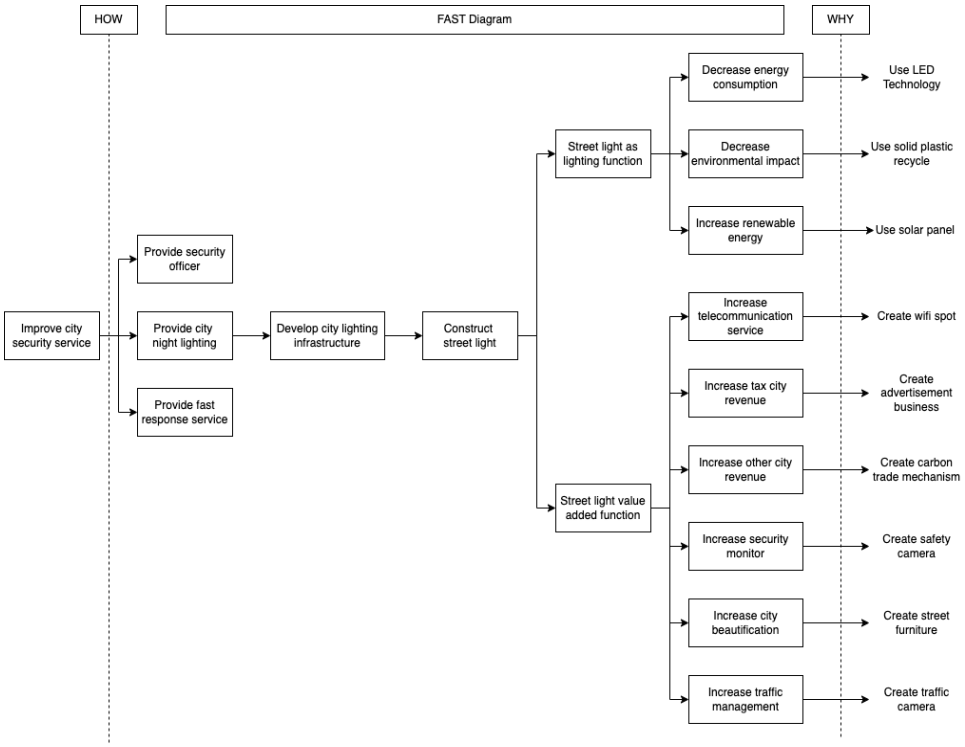


Figure 1: MYSinar+ Function Analysis System Technique (FAST) Diagram
Source: Author's Own Creation (2024)

Creative Phase

The PPP mechanism offers an innovative and strategic approach within this value engineering analysis, enabling city governments to implement the MYSinar+ street lighting system without imposing excessive pressure on public budgets. This financing arrangement is particularly beneficial for cities experiencing funding constraints, as it allows them to leverage private sector investment to address public safety and infrastructure needs. The stakeholders involved in the MYSinar+ PPP scheme are summarized in Table 4.

Table 4: Stakeholders involved in the MYSinar+ PPP

No	Stakeholder	Description
1	City or Central Government	Role: Government Contracting Agency (GCA) Responsibilities: Approve projects and provide necessary permits and monitor compliance with regulations.
2	Investors/ Sponsor/ SPV (Special Purpose Vehicle)	Role: Provide equity funding for the project. Responsibilities: Financial backing and risk management and ensure project viability and return on investment.

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No	Stakeholder	Description
3	Lenders (Financier)	Role: Provide debt funding for the project. Responsibilities: Loan disbursement and setting loan terms
4	Residents	Role: End-users benefiting from improved urban lighting and safety. Responsibilities: Provide feedback on lighting needs and safety concerns and participate in community engagement initiatives.
5	Local Business non-core	Role: Local businesses that may benefit from enhanced lighting and business non-core opportunities. Responsibilities: Engage in local business non-core.
6	Carbon Trading Exchange	Role: Facilitate the trading of carbon credits generated through MYSinar+'s sustainability initiatives. Responsibilities: ● Provide a marketplace for the buying and selling of carbon credits. ● Promote market participation by connecting buyers and sellers of carbon credits
7	REC Issuers	Role: Certify and facilitate the trading of renewable energy attributes associated with MYSinar+'s solar-powered lighting solutions. Responsibilities: ● Verify and issue Renewable Energy Certificates (RECs) for energy generated from renewable sources. ● Ensure compliance with national and international renewable energy standards.

Source: Author's Own Creation (2024)

Drawing on the explanation of the stakeholders outlined in Table 4, the MYSinar+ PPP conceptual framework is constructed as illustrated in Figure 2.

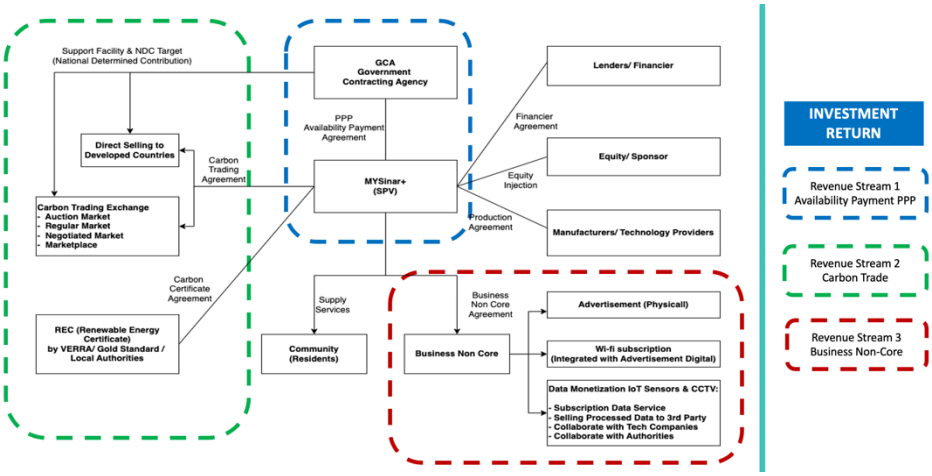


Figure 2: MYSinar+ PPP Conceptual Framework
Source: Author's Own Creation (2024)

The conceptual framework presents an integrated financial and operational model for the MYSinar+ street lighting value engineering initiative within the PPP scheme. The government, through a contracting agency, ensures financial sustainability via a PPP agreement with a SPV, which receives equity contributions from sponsors and loans from lenders. The carbon trading mechanism functions through various market platforms, including auctions and negotiated transactions, with direct sales to developed countries supporting national climate commitments. Additionally, the inclusion of RECs enhances market credibility and ensures compliance with international sustainability standards.

Beyond the core PPP operations, the model incorporates non-core revenue streams to improve financial viability. These include the monetization of Internet of Things (IoT) sensor data, subscription-based Wi-Fi services, and integrated physical and digital advertising. The diversified revenue structure, categorized into availability payments, carbon trading revenues, and non-core business income, mitigates financial risks and reinforces the long-term sustainability of the project.

Evaluation or Validation Phase

The evaluation and validation phase involved assessing the MYSinar+ street lighting value engineering conceptual framework at the PETRONAS CHESS Innovation Challenge 2024, a competition among university participants across Malaysia. The conceptual framework was selected for presentation in the grand finale at the Kuala Lumpur Convention Center after successfully passing two preceding rounds. In the grand finale, it was awarded Second Runner-up in the Sustainability category. Feedback on the conceptual framework was provided by three expert judges during the grand finale, as summarized in Table 5.

Table 5: Summary Feedback Evaluation

No	Expert	Summary Feedback
1	Senior Leader Petronas 1 in Sustainability	This conceptual framework is highly robust and comprehensive; however, further analysis is required to provide a more detailed calculation of the investment, particularly regarding the market-accepted rate of return.
2	Senior Leader Petronas 2 in Technology & Commercialization	The PPP approach employed in this study is highly commendable; however, it could be further enhanced by incorporating commercialization aspects for the retail market. This addition would make the framework more comprehensive.
3	Chief Amazon Web Service Malaysia & Cambodia	This conceptual framework is highly commendable, as it integrates revenue commercialization from the digital and IT sectors with carbon trading, which is particularly noteworthy.

Source: Author's Own Creation (2024)

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MYSinar+ Prototype Development

After undergoing a value engineering study, followed by evaluation and validation in an innovation challenge forum with three relevant experts, the MYSinar+ product concept, encompassing both core and value-added functions, is presented in Figure 3. This process demonstrates the systematic integration of expert judgment and structured analysis to refine the proposed solution. Future research should extend beyond the innovation contest by conducting technical piloting and feasibility assessments. Such efforts are essential for evaluating implementation readiness in real-world contexts, including operational performance, cost efficiency, and scalability. These steps will facilitate the transition of the MYSinar+ prototype from a conceptual model to a practical solution that contributes to sustainable urban infrastructure development.

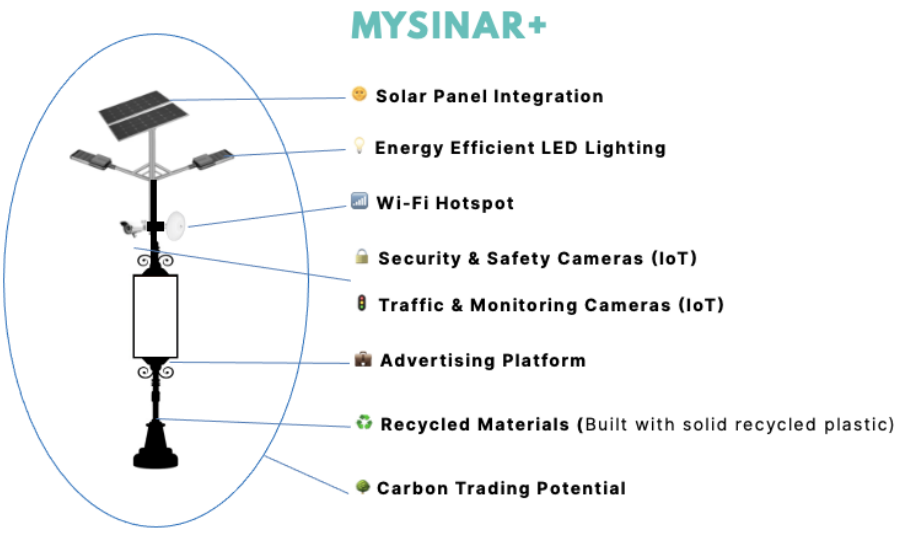


Figure 3: MYSinar+ Prototype Development
Source: Author's Own Creation (2024)

CONCLUSION

Through the application of value engineering, the MYSinar+ street lighting system extends beyond its core function of illumination to provide a range of value-added services that address critical urban challenges, including energy efficiency, environmental sustainability, public safety, and revenue generation. By integrating advanced technologies such as solar power, LED lighting, Wi-Fi hotspots, safety cameras, and traffic management systems, MYSinar+ becomes an essential component of smart, sustainable, and secure urban infrastructure. Furthermore, features such as carbon trading, advertising opportunities, and street

beautification create new avenues for municipal revenue while enhancing residents' quality of life. Ultimately, MYSinar+ represents a forward-looking solution that not only improves urban lighting but also supports broader objectives, including climate action, economic development, and public safety.

This study primarily focuses on the conceptual planning phase. Further research is required to advance prototype development and conduct detailed investment cost analyses, providing critical insights for municipal stakeholders and investors. Although the current model was developed within a specific local context, many of its components—including renewable energy integration, multifunctional infrastructure design, and revenue diversification—are transferable to other jurisdictions facing similar urban challenges. However, contextual variations in governance structures, financing mechanisms, and regulatory frameworks may influence implementation, limiting the model's immediate applicability across all settings. Addressing these limitations will require comparative studies, cross-regional pilot projects, and structured stakeholder engagement to adapt the model to diverse urban environments. In this way, the study lays the groundwork for a comprehensive multifunctional street lighting system with international relevance and offers policymakers valuable guidance in designing sustainable and socially responsible infrastructure strategies.

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DISCLOSURE

The authors declare that there is no conflict of interest associated with this research.

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EMPIRICAL ANALYSIS OF SOLID WASTE MANAGEMENT: A CASE STUDY APPROACH IN MALAYSIA

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Abstract

This study investigates Malaysia's solid waste management (SWM) system through a comparative case study of Shah Alam and Johor Bahru. The analysis focuses on governance, public participation, management mechanisms, and stakeholder integration. A mixed-methods design triangulates data from semi-structured expert interviews, household surveys, and archival reviews. Findings indicate that while governance weaknesses are evident in Shah Alam due to federal–state tensions, strong partnerships and community participation compensate for these shortcomings, ensuring overall system performance. This research contributes new empirical insights by integrating expert and resident perspectives, advancing theory by framing SWM effectiveness as multidimensional rather than governance-dependent, and offering policy recommendations for Malaysia's ongoing SWM reforms.

Keywords: Solid Waste Management, Governance, Partnerships, Policy, Malaysia

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INTRODUCTION

Malaysia's rapid urbanization, population growth, and changing consumption patterns have placed increasing pressure on its SWM system. Government reforms such as the Solid Waste and Public Cleansing Management Act 2007 (Act 672) were introduced to harmonize waste practices nationwide. However, challenges in recycling rates, landfill dependency, and uneven service quality persist. Earlier works (Manaf et al., 2009; Moh & Abd Manaf, 2017) highlighted these issues but did not empirically examine the interplay of governance structures, partnerships, and community participation across different governance models.

This study addresses this gap by comparing centralized (Johor Bahru under SWCorp) and decentralized (Shah Alam under KDEB) systems. It uniquely integrates expert and resident perspectives using mixed methods to assess how governance, management mechanisms, partnerships, and participation shape SWM outcomes.

***Research questions**:*

1. How do governance, management mechanisms, public participation, and partnerships influence SWM outcomes in Shah Alam and Johor Bahru?
2. What are the key differences between centralized and state-led approaches in practice?
3. What policy lessons can be drawn to improve Malaysia's SWM system?

LITERATURE REVIEW

Solid Waste Governance in Malaysia

Foundational studies (Manaf et al., 2009; Moh & Abd Manaf, 2017) documented inefficiencies in collection, recycling, and infrastructure. These works serve as baseline references but have become dated in addressing Malaysia's evolving challenges. More recent contributions (Zainal & Abas, 2019; Salleh et al., 2022; Chuah et al., 2023) highlight the emergence of circular economy models, digitalization of waste monitoring, and localized innovations. Official reports (MITI, 2025; KPKT, 2025) emphasize integration with sustainable development goals, yet gaps remain in empirical validation of policy outcomes.

Centralized vs. Decentralized Models

SWCorp's centralized system offers standardization, economies of scale, and federal oversight but often faces criticism for inflexibility and bureaucratic delays. In contrast, KDEB's decentralized approach enables state-level customization, but performance depends heavily on financial capacity, managerial expertise, and coordination with local governments. Comparative studies in other developing nations (Massoud et al., 2019; Rodić & Wilson, 2017) suggest hybrid governance models may balance accountability with adaptability.

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However, in Malaysia, systematic evaluations comparing these models empirically are scarce.

Community Participation and Partnerships
Literature stresses the importance of community engagement and partnerships in shaping sustainable outcomes. Guerrero et al. (2013) and Sharholy et al. (2007) show that resident involvement, when institutionalized, improves recycling rates and waste separation practices. In Malaysia, while campaigns exist, few studies evaluate long-term behavioral change or the institutionalization of community roles. Similarly, public–private partnerships (PPPs) are discussed widely but without detailed empirical assessment of accountability frameworks.

Identified Gaps:

1. Heavy reliance on descriptive overviews rather than empirical validation.
2. Insufficient attention to Malaysia's dual governance system and its implications for policy.
3. Lack of integration of community participation and partnership analysis into governance studies.
4. Limited focus on recent innovations such as smart waste technologies and circular economy practices.

This study directly addresses these gaps by providing comparative empirical analysis of two governance systems, integrating resident and expert perspectives, and offering policy recommendations rooted in multidimensional performance indicators.

METHODOLOGY

Research Design
This study adopts a convergent mixed-methods approach, integrating qualitative and quantitative evidence to generate a holistic understanding of SWM in two Malaysian cities. The rationale for this design is to overcome the limitations of single-method studies and ensure triangulation of findings across multiple sources.

Sampling Strategy

- Expert Interviews: 15 experts were purposively selected based on professional experience in waste governance, policy-making, concessionaire management, and academic research. This ensured representation of diverse institutional perspectives.
- Household Surveys: A total of 389 residents were surveyed across Shah Alam and Johor Bahru. Stratified random sampling was used to ensure diversity in household income, education level, and residential zones.

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The sample size was determined using Krejcie & Morgan's (1970) formula, providing representativeness for large urban populations.

- Archival Review: Municipal reports, national policies, and SWM concessionaire records were analyzed to validate interview and survey data.

Instrument Design and Validation

The household survey included four sections: governance, management mechanisms, partnerships, and participation. Each construct was operationalized into 1-5 Likert scale items (1 = Strongly Disagree, 5 = Strongly Agree). Pilot testing with 30 respondents produced Cronbach's alpha scores above 0.70 for all constructs, confirming internal consistency. Interview protocols included semi-structured questions tailored to elicit insights on institutional roles, challenges, and innovation opportunities.

Data Analysis

- Quantitative Analysis: Descriptive statistics (means, SDs), Pearson correlations, and regression models were run using SPSS. These analyses identified the strength and direction of relationships between the four constructs.
- Qualitative Analysis: Thematic coding of interview transcripts was conducted. Emergent codes were grouped into broader themes that informed Tables 5–8.
- Triangulation: Findings from surveys, interviews, and documents were systematically compared to identify convergences and contradictions, thereby strengthening validity.

ANALYSIS

The study consists of three main parts in data analysis and findings: (1) Qualitative analysis (content analysis), through the archival and document as well as based on semi-structured interviews with key informants from relevant organizations, agencies, and institutions; (2) Quantitative analysis, derived from questionnaire surveys reflecting the perspectives of urban residents; and (3) In-depth triangulation analysis, combining insights from both qualitative and quantitative data.

Qualitative Analysis

Archival and Document

Table 1 and Table 2 compares the solid waste management and public cleansing policies in Malaysia prior to Act 672 and Act 673 as well as the policies implemented by the two different states in Peninsular Malaysia since the introduction of both acts. The Tables consist of the policies, practices, programs

and initiatives before and once Acts 672 and 673 were enforced. The introduction of Act 672 and Act 673 transferred all operational aspects of urban solid waste management and public cleansing services in participating states to the Solid Waste and Public Cleansing Corporation (SWCorp). This corporation oversees waste management through concession agreements with Alam Flora Sdn. Bhd., SWM Environment Sdn. Bhd., and Environmental Idaman Sdn. Bhd., ensuring a coordinated and efficient system across Peninsular Malaysia.

However, due to the involvement of multiple administrative levels and actors, achieving uniform service delivery remains a challenge. Larger municipalities with greater resources can effectively manage waste, while smaller municipalities struggle with budget, staffing, and technological constraints. Waste separation initiatives, such as 3R programs, help address landfill overcapacity and environmental concerns. Reducing waste at the source minimizes reliance on landfills, mitigating pollution and disease risks (Moh & Abd Manaf, 2017).

To standardize solid waste and public cleansing management, the government introduced Act 672 in 2007, enforced in 2011, to ensure all municipalities operate under a common system with equitable budgets, policies, and technical support. This approach allows municipalities to allocate resources more efficiently. In Selangor, particularly in Shah Alam, the waste management system follows federal practices under SWCorp. The KDEB Waste Management (KDEBWM) structure closely mirrors SWCorp's, with programs aimed at improving efficiency and service delivery. Despite Selangor rejecting the implementation of Act 672 and Act 673 due to state-federal disputes, KDEBWM has maintained commendable service standards.

Both SWCorp and KDEBWM have developed various strategies and initiatives to manage solid waste effectively. While decentralization is often seen as a way to encourage community involvement (Konteh, 2009), both organizations have proven their competence in delivering reliable waste management services in Malaysia. Their efforts demonstrate strong capabilities in achieving an efficient and sustainable solid waste management system.

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Table 1: Comparison of Solid Waste Management and Public Cleansing Acts, Policies, Enactments, Guidelines and By-Laws Implemented in the State of Selangor (MBSA) and State of Johor (MBJB) prior to Act 672 and 673 and the Gazetted Act 672 & 673

Item	Malaysia WM Prior Act 672 & 673	Introduction of Act 672 & 673	
		Selangor (MBSA)	Johor (MBJB)
Policy	- ABCM (1988) - NSPSWM (2005) - MWMP (2006) - NSWMP (2006)	- DPSPN(P) 2016 - DPN 2, (2016-2025) - Free Plastic & Polystyrene Campaign (2017) - RMK 10 & RMK 11	- DPSPN(P) 2016 - DPN 2, (2016-2025) - RMK 10 & RMK 11 - Waste Separation at Source Strategies (2015)
By-Laws	State Government & Local Authority	- Undang-undang Kecil (MBSA) (2017)	- UBBL (MBJB) 2010
Guidelines	State Government & Local Authority	- Waste Separation & Bulky Waste Disposal Guideline	- SEHAP 2018

Source: JPSPN (2020), MHLG (2018); BPEN, Johor (2019); SUK Johor (2019); MBJB (2019); MBSA (2020); SUK Selangor (2020); KDEBWM, (2019); Hebat Abadi Sdn. Bhd (2019

Table 1: Comparison of Solid Waste Management and Public Cleansing Acts, Policies, Enactments, Guidelines and By-Laws Implemented in the State of Selangor (MBSA) and State of Johor (MBJB) prior to Act 672 and 673 and the Gazetted Act 672 & 673 (Cont.)

Item	Malaysia WM Prior Act 672 & 673	Introduction of Act 672 & 673	
		Selangor (MBSA)	Johor (MBJB)
Operation	State Government & Local Authority	- KDEB - KDEB WM	- SWCorp - Concessionaires
Outsourcing Operation	State Government & Local Authority	Hebat Abadi Sdn. Bhd/Concessionaires	NA
Funding	State Government & LA, Concessionaires	State Government, KDEB and LA	JPSPN, SWCorp, LA, Concessionaires
Human Resources	LA / Concessionaires Workers	KDEBWM Contractors	Concessionaires Workers

Source: JPSPN (2020), MHLG (2018); BPEN, Johor (2019); SUK Johor (2019); MBJB (2019); MBSA (2020); SUK Selangor (2020); KDEBWM, (2019); Hebat Abadi Sdn. Bhd (2019)

Table 2: Comparison of Solid Waste Management and Public Cleansing Strategies and Initiatives in the State of Selangor (MBSA) and State of Johor (MBJB)

Item	Malaysia WM Prior Act 672 & 673	Introduction of Act 672 & 673	
		Selangor (MBSA)	Johor (MBJB)
Waste Separation	/	/	/
Deterrence Option	/	/	/
Enforcement	/	/	/
Distinction between types of waste	/	/	/
Education & Awareness	/	/	/
3R Issues Addressed	/	/	/
Waste Treatment Options	Recycling, Landfills	Recycling, Landfills	Recycling, Landfills
Waste generators responsibility	*x*	/	/
Scavenger's issues addressed	*x*	/	/

Source: JPSPN (2020), MHLG (2018); BPEN, Johor (2019); SUK Johor (2019); MBJB (2019); MBSA (2020); SUK Selangor (2020); KDEBWM, (2019); Hebat Abadi Sdn. Bhd (2019)

Semi-Structured Interviews (The Expert)

This study highlights the importance of a structured and well-defined institutional framework for enhancing the effectiveness of urban solid waste management (SWM) in Malaysia. Based on consultations with key stakeholders, the research identifies four main themes essential to understanding and evaluating the current system: governance structure, integration and partnership management, mechanisms and management structures, and public involvement and participation.

In terms of governance structure, the study finds that clearly defined roles and responsibilities are critical for ensuring efficient service delivery. Various stakeholders, including federal agencies, state-level departments, and local authorities, contribute differently to the management process. Their ability to coordinate policies, planning, and implementation efforts significantly impacts the overall success of the SWM system. When roles are not clearly defined or executed, the governance structure becomes fragmented, affecting operational efficiency. The integration and partnership management theme emphasizes the importance of collaboration between public and private sector actors. The study observes that regular meetings and coordinated efforts between local authorities, federal agencies such as SWCorp, and private concessionaires create a platform for shared decision-making. This coordinated approach not only improves communication but also ensures that waste management operations are responsive and consistent across administrative levels.

Mechanisms and management structures, such as the formation of environmental standing committees and inter-agency working groups, provide a formal structure for problem-solving and coordination. These mechanisms allow stakeholders to actively participate in planning, implementation, and monitoring processes. The existence of such structures enhances transparency, accountability, and the ability to respond to evolving environmental challenges.

Lastly, public involvement and participation play a significant role in the success of SWM. Platforms such as the Resident Representative Councils (MPP) and local Complaints Committees enable community members to voice their concerns and contribute to local governance. These participatory structures help bridge the gap between authorities and residents, encouraging shared responsibility and minimizing resistance, such as the commonly observed “Not in My Backyard” (NIMBY) attitude.

In essence, interviewees stressed the importance of clear role definitions, effective concessionaire oversight, and community platforms such as Resident Representative Councils. Experts agreed that decentralized systems can perform well if adequately resourced, but federal support remains critical for smaller municipalities. On different notes, document analysis has revealed uneven adoption of Act 672, with some states resisting federal intervention. Despite structural differences, both SWCorp and KDEB have demonstrated

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capacity to deliver services when partnerships and community involvement are emphasized.

Quantitative Analysis

Questionnaires Survey

The quantitative analysis examined respondents' views on urban solid waste and public cleansing practices in Malaysia. The analysis was organized around four key themes: governance structure, public involvement and participation, management mechanisms and structures, and integration and partnership management. A summary of the findings is presented in the following section.

Table 3: Summary of Descriptive Analysis

Theme	Variables	Study Area	Mean	Std. Error	Std. Dev.
Governance Structure	LA's role important in WM	Johor Bahru	4.15	.046	.548
		Shah Alam	4.35	.058	.657
	Workers doing their job well	Johor Bahru	3.72	.051	.815
		Shah Alam	3.61	.072	.813
Mechanisms & Management Structure	Clean and comfortable Neighbourhood	Johor Bahru	3.67	.051	.823
		Shah Alam	3.64	.073	.829
	Effectiveness SWMPC services	Johor Bahru	3.81	.049	.790
		Shah Alam	3.61	.074	.841
Integration & Partnerships Management	Government, Community & individual important in WM	Johor Bahru	4.13	.047	.752
		Shah Alam	4.40	.054	.619
	Organisation needed in WM Services	Johor Bahru	4.08	.045	.518
		Shah Alam	4.36	.054	.610
Public Involvement & Participation	Community organisation important in WM	Johor Bahru	4.12	.045	.725
		Shah Alam	4.38	.059	.657
	Resident's ideas & opinions considered	Johor Bahru	3.89	.052	.831
		Shah Alam	3.83	.072	.821
Total Average			**3.98**	**.056**	**.728**

Source: Author's Calculation

Table 4: Summaries of Pearson's Correlation Analysis for Shah Alam and Johor Bahru

Themes	Variables	Study Area	
		Sig.	
		Shah Alam	Johor Bahru
Governance Structure	LA's role important in WM	.519	.000
	Workers doing their job well		
Mechanisms & Management Structure	Clean and comfortable Neighbourhood	.000	.000
	Effectiveness SWMPC services		
Integration & Partnerships Management	Government, Community & individual important in WM	.000	.000
	Organisation needed in WM Services		
Public Involvement & Participation	Community organisation important in WM	.004	.000
	Resident's ideas & opinions considered		

Source: Author's Calculation

Table 3 shows that overall perceptions of SWM services were favourable (mean scores 3.6–4.4). Governance scored lower in Shah Alam (mean 3.6) compared to Johor Bahru (mean 4.1), reflecting institutional fragmentation under state-led systems. Standard deviations were consistently below 1.0, demonstrating consensus among respondents rather than polarized opinions.

Table 4 presents correlations among governance, mechanisms, participation, and partnerships. Governance in Shah Alam was statistically non-significant ($p > .05$), underscoring institutional weakness. However, partnerships and participation had strong, significant correlations with mechanisms and overall performance ($p < .001$). Regression results further confirmed that while governance was not a predictor in Shah Alam, the integrated effect of all variables remained significant

FINDINGS AND TRIANGULATIONS

Qualitative Analysis

Before Act 672 and Act 673 were introduced, local authorities managed solid waste and public cleansing in Malaysia, under state supervision and guidance from the Ministry of Housing and Local Government (SWCorp, 2007). These responsibilities later shifted to the Solid Waste and Public Cleansing Corporation (SWCorp) to streamline and centralize operations under federal control. The document analysis revealed four key elements in urban waste management: governance, public involvement, operational mechanisms, and institutional coordination. With many stakeholders involved, understanding political relationships and power dynamics is crucial (Marshall & Farahbakhsh, 2013).

Governance issues include accountability, transparency, system efficiency, and stakeholder coordination. These factors shape how well services are delivered. Although Acts 171 and 172 allow public participation in urban

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management, involvement in waste services is still limited (Local Government Act 1976; Town and Country Planning Act 1976). People tend to rely on local authorities for urban services, as they are the most accessible level of government. Both public and private institutions are expected to deliver good services, and their internal systems play a major role in making that happen.

Malaysia's top-down, centralized approach is common, but often lacks input from informal sectors and the public. This can cause bureaucratic and technical issues (Medina, 2005; Afrizal, 2012). However, SWCorp and KDEB Waste Management show that centralized systems can still work well when properly managed. Private companies also contribute by providing expertise, funding, and technology, helping reduce government costs and improve service delivery (Medina, 2010). While concerns about monopolies and power abuse exist, effective regulation can ensure centralized systems remain efficient.

Selangor chose not to adopt Acts 672 and 673 but formed KDEB Waste Management to run its waste services. Though operating separately, it uses a similar structure to SWCorp. Both focus on policy execution, while private contractors like SWM Environment and Hebat Abadi handle actual waste collection. The World Bank introduced the concept of governance to highlight the importance of links between governments and civil society. In this case, transparency, accountability, cooperation, and power balance are still key concerns. Despite some challenges, cooperation among all stakeholders has led to successful waste management practices in both cases.

Quantitative Analysis

This section presents the views of 389 respondents on solid waste and public cleansing services in Malaysian cities. The participants had diverse backgrounds. Most (75.1%) said these services exist in their neighbourhoods, while 86.1% confirmed they are regularly provided. These services are important for public health and environmental cleanliness (Abas & Wee, 2014a; Memon, 2010). Waste management is a shared duty between the government, the public, and private companies. Global initiatives like Local Agenda 21, the Rio Summit, and the Sustainable Development Goals (SDGs) reflect this shared commitment to sustainability.

Although local governments are mainly responsible for these services, their performance is often uneven (Wilson et al., 2013). However, 69.4% of respondents said the services in their area were effective. This success is due to the efforts of agencies like SWCorp and KDEB Waste Management, supported by contractors and the community. Collaboration among residents, authorities, and private firms is crucial (Wilson et al., 2013; Abas & Wee, 2014b; Moh & Abd Manaf, 2017). Better communication between the public and local councils helps improve service quality. Environmental problems in cities are often linked to poor waste services. As urban populations grow, so does the amount of waste

(Fauziah & Agamuthu, 2012; Moh & Abd Manaf, 2017), leading to overfilled landfills and pollution (Abas & Wee, 2014b; Fauziah & Agamuthu, 2012). Waste management includes several steps like collection, transport, treatment, and disposal. If done poorly, it can harm people and the environment.

Triangulation

Tables 5 to 8 were derived from thematic content analysis of interview transcripts and triangulated with document reviews. Sub-themes were identified by coding recurring concepts raised by experts and residents. The categorization process was validated through inter-coder agreement, ensuring reliability of the qualitative findings (Sharholy, Ahmad, Mahmood, & Trivedi, 2007; Chuah et al., 2023).

Table 5 summarizes findings related to governance structure in solid waste and public cleansing management in the two case study areas. The results highlight key issues such as roles, responsibilities, power dynamics, and management challenges. They also show that socio-political factors influence how urban services are delivered, and these elements were clearly observed in both case studies.

Table 5: Table of Themes, Sub-Themes and Findings of Qualitative Data - Governance Structure

Theme	Sub-Theme	Findings
Governance Structure	Roles	Exercise of power and management issue
	Responsibility	

Table 6 highlights the importance of having proper organizational structures to deliver urban services efficiently and effectively. These structures show that a system is in place, and with them, better management mechanisms can be developed.

Table 6: Table of Themes, Sub-Themes and Findings of Qualitative Data - Mechanisms and Management Structures

Theme	Sub-Theme	Findings
Mechanisms and Management Structure	Delegation of Power	Organisational Framework
	System effectiveness and efficiency	
	Process and practices	

Table 7 shows that integration is an important part of managing urban services like solid waste and public cleansing. The findings highlight the need for strong collaboration between all stakeholders to ensure services are delivered efficiently and effectively.

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Table 7: Table of Themes, Sub-Themes and Findings of Qualitative Data - Integration and Partnerships Management

Theme	Sub-Theme	Findings
Integration and Partnership Management	Cooperation	Stakeholders Relationships
	Coordination	

Table 8 outlines elements of public participation in urban solid waste and public cleansing management. Based on respondents' answers and expert interviews, community involvement is made stronger through platforms like residents' or community organizations.

Table 8: Table of Themes, Sub-Themes and Findings of Qualitative Data - Public Involvement and Participation

Theme	Sub-Theme	Findings
Public Involvement and Participation	Involvement	Community Empowerment
	Platform of participation	

DISCUSSION

The results highlight that governance is a necessary but insufficient condition for effective SWM. In Shah Alam, weak governance did not collapse the system because partnerships and public participation compensated for institutional gaps. This finding aligns with the concept of polycentric governance (Marshall & Farahbakhsh, 2013), which emphasizes the role of overlapping actors in sustaining essential services.

Comparing Shah Alam and Johor Bahru demonstrates that centralized systems may achieve greater consistency but at the cost of bureaucratic rigidity, while decentralized systems allow innovation but face uneven institutional strength. This comparative evidence extends Moh & Abd Manaf (2017) by empirically demonstrating how governance models shape outcomes differently in Malaysia.

Policy Implications:

1. Strengthen PPP frameworks with clear accountability metrics and transparent performance audits.
2. Enhance community engagement by institutionalizing resident councils and participatory recycling programs.
3. Invest in digital monitoring platforms (IoT bins, GIS-based collection tracking) to mitigate governance fragmentation.
4. Develop tailored governance models that balance federal oversight with state autonomy.

CONCLUSION

This study contributes to Malaysia's SWM discourse by empirically showing that governance, partnerships, mechanisms, and participation must work in synergy to deliver effective outcomes. The mixed-method triangulation and case comparison provide new knowledge beyond prior descriptive accounts. Policy reforms should focus on strengthening partnerships, institutional clarity, and public participation while addressing federal–state tensions in governance. Future research could expand to comparative studies across more states and explore circular economy adoption.

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DISCLOSURE STATEMENT

The authors declare that there are no potential conflicts of interest, financial or otherwise, that could have influenced the research, analysis, or conclusions presented in this paper. This study was conducted independently and did not receive specific external funding. The authors alone are responsible for the content and writing of this article.

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GIS ANALYSIS OF FLOOD EVACUATION CENTRE PLACEMENT: IDENTIFYING SPATIAL GAPS IN KUANTAN, MALAYSIA

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Abstract

Kuantan, Malaysia, faces recurrent flooding that displaces thousands annually, underscoring the need for strategically located evacuation centres (ECs). This study employs a GIS-based spatial analysis, framed by concepts of spatial equity, resilience planning, and disaster risk governance, to assess the distribution, accessibility, and capacity of ECs relative to flood-prone residential areas and vulnerable populations. Results reveal significant spatial inequities: 41% of flood-prone residential land and 66% of at-risk residents are located beyond the recommended 1-km EC coverage radius. Capacity analysis indicates that existing shelters can accommodate only 25% of the population within the covered zones. A suitability analysis integrating proximity to existing ECs, flood risk, and population density identified 14% of flood-prone residential land as "extremely suitable" and 21% as "very suitable" for new ECs. These priority zones are concentrated in peripheral areas with high flood exposure, high population density, and limited current shelter access. Comparative insights from the Philippines, Indonesia, and Bangladesh highlight that such urban–rural disparities in EC access are common in Southeast Asia, often due to centralised infrastructure planning. The study's findings and GIS-based suitability mapping provide a replicable approach for planners and policymakers, enabling targeted, equitable, and resilience-focused evacuation infrastructure development in flood-prone regions.

Keywords: GIS, Flood, Evacuation Centre, Spatial, Hazard

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INTRODUCTION

Climate change has intensified the frequency and severity of hydrometeorological disasters worldwide, causing extreme weather events to become increasingly unpredictable. Rising global temperatures have altered precipitation patterns, resulting in prolonged and intense rainfall events, particularly affecting regions such as Southeast Asia (Singh & Qin, 2020). Malaysia, located within the tropical monsoon climate zone, is notably vulnerable to these climate-induced disasters, with flooding being the most recurrent and impactful hazard (Md Saad et al., 2023). Seasonal monsoons frequently lead to severe flooding, causing widespread socio-economic disruption and environmental damage. The East Coast region of Malaysia, particularly states such as Kelantan, Terengganu, and Pahang, consistently experiences substantial flood-related impacts including significant infrastructure damage, disruption to economic activities, increased government expenditure on recovery efforts, and prolonged impacts on local economies.

Kuantan, the capital city of Pahang, stands out as especially vulnerable to recurrent flooding due to its geographical characteristics, monsoonal influence, and insufficient flood management infrastructure (Mabahwi & Nakamura, 2024). The city's proximity to significant river systems, ongoing rapid urbanisation, and changes in land use have intensified flooding impacts, regularly displacing thousands of residents. Factors such as heavy rainfall, river overflow, ineffective drainage systems, and proximity to coastal areas amplify flood severity, necessitating large-scale evacuations (Suzuki et al., 2019). Effective disaster preparedness, therefore, is crucial for protecting lives and mitigating flood impacts, highlighting the importance of strategically placed evacuation centres (ECs) to serve as immediate shelters for affected populations.

The spatial distribution of evacuation centres critically affects their capacity to provide timely and effective shelter during flood emergencies (Alam et al., 2021). Poorly positioned shelters lead to accessibility challenges, overcrowding, and increased vulnerabilities for displaced individuals. Strategic location planning, incorporating population distribution, flood risk zones, and geographic accessibility, is essential to ensure that ECs effectively mitigate the impacts of flooding (Mabahwi & Nakamura, 2024). Geographic Information Systems (GIS) serve as a robust methodological framework for assessing these spatial factors, providing valuable insights into gaps and inadequacies in existing shelter networks (Rahman et al., 2021).

This study employs GIS-based spatial analysis to evaluate the spatial distribution and adequacy of evacuation centres in Kuantan’s flood-prone areas. By assessing shelter locations relative to residential zones, flood-risk areas, and population density, the research aims to identify spatial mismatches and deficiencies in the current evacuation infrastructure. The study's outcomes will inform strategic recommendations to optimise shelter placement, enhance

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disaster preparedness, and ultimately improve resilience among communities vulnerable to flooding in Kuantan.

LITERATURE REVIEW

The spatial distribution of evacuation centres (ECs) significantly influences the efficiency and effectiveness of evacuation operations during disasters (Mabahwi et al., 2021). GIS-based spatial analysis provides a systematic approach for assessing EC locations, considering critical factors such as flood risk, population density, and shelter accessibility. Effective evacuation management necessitates precise identification and strategic placement of ECs within optimal distances to at-risk populations. GIS technologies, including buffer analysis and intersect overlays, have become crucial tools for spatial planning in disaster management by highlighting accessibility issues, shelter coverage gaps, and mismatches between EC capacities and population demands (Mabahwi et al., 2021; Sanyal & Lu, 2009).

Buffer analysis is a widely applied GIS technique to evaluate the spatial accessibility of evacuation centres, generally recommending EC placement within a 1-kilometre radius of residential settlements (Lee & Sung, 2013; Mabahwi et al., 2021; Mabahwi & Nakamura, 2024; Sanyal & Lu, 2009; Sritart et al., 2020). Strategic placement within this radius significantly reduces evacuation time and maximises shelter coverage, particularly benefiting populations residing in high-risk zones (Batur et al., 2025; Kusumo, 2016; Sanyal & Lu, 2009). Nevertheless, practical constraints such as uneven spatial distribution and limited infrastructure often challenge effective EC placement. Peripheral and rural communities commonly face insufficient shelter coverage, increasing their vulnerability during flood events (Chen et al., 2020; Mabahwi et al., 2021).

Research in Metro Manila, Philippines, highlighted the challenges resulting from spatial planning inadequacies. GIS-based analysis revealed substantial disparities in ECs coverage, with overcrowding in urban centres and inadequate coverage in peripheral areas. Similarly, studies in Tubay, Agusan del Norte, Philippines, identified significant shelter gaps due to inappropriate or insufficient spatial planning and a lack of comprehensive spatial data (Chen et al., 2020; Muller et al., 2024). Such examples underline the critical importance of incorporating detailed spatial analysis into evacuation planning.

Accurate spatial data is essential for effective EC planning. However, limitations related to data accuracy, reliability, and availability pose substantial challenges in disaster management research. Spatial heterogeneity in population density and variations in infrastructure quality further complicate the planning and effectiveness of evacuation infrastructures. Consequently, advanced spatial analysis, including GIS overlays and buffer techniques, are vital to identify and mitigate these issues (Muller et al., 2024; Sanyal & Lu, 2009).

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Additionally, integrating GIS technologies into existing emergency management systems is frequently hampered by resource constraints and technological barriers, especially in developing regions. Addressing these barriers requires concerted efforts, including the development of clear policy frameworks, adequate resource allocation, and capacity building to ensure long-term sustainability and effectiveness of EC planning (Ahmadi et al., 2022; Muller et al., 2024). By addressing these challenges, researchers and policymakers can improve the spatial distribution of evacuation centres, enhancing disaster resilience and reducing risks for affected populations.

Conceptual Framework

This study adopts an integrated framework combining spatial equity, resilience planning theory, and disaster risk governance to guide the spatial analysis of evacuation centres (ECs) in Kuantan.

Spatial equity refers to the fair distribution of public resources, facilities, and opportunities across geographic areas, ensuring that all segments of the population regardless of socio-economic status or location have equitable access to essential services (Soja, 2010). In the context of flood evacuation, spatial equity requires that shelters be located in a manner that minimises travel time, reduces exposure to hazards, and prioritises vulnerable populations.

Resilience planning theory emphasises building the adaptive capacity of communities to absorb, recover, and adapt to shocks such as extreme flooding (Davoudi et al., 2012). Applying resilience principles to evacuation centre planning involves anticipating hazard impacts, safeguarding critical infrastructure, and enhancing redundancy in shelter networks.

Disaster risk governance, as framed by the United Nations Office for Disaster Risk Reduction (UNDRR, 2019), highlights the importance of coordinated policies, participatory decision-making, and transparent allocation of resources in managing disaster risks. This governance lens underscores that spatial planning for ECs should be embedded within broader institutional frameworks, ensuring accountability and sustainability.

By integrating these three perspectives, the present study not only evaluates the geographic distribution of ECs but also interprets the results through lenses of fairness, adaptability, and institutional effectiveness, enabling recommendations that are both spatially targeted and policy relevant.

MATERIALS & METHOD

Kuantan, the capital of Pahang, has been selected as the study area due to its recurrent flooding. The district is highly susceptible to seasonal floods, which pose significant challenges to residential, commercial, and rural areas alike. Recognising the severity of flood risks, the National Physical Plan 3 has classified Kuantan District as a high-risk flood zone, with the city itself identified as

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particularly vulnerable to inundation (PLANMalaysia, 2018). Furthermore, the Kuantan Local Plan 2035 highlights that a substantial portion of the district's residential areas remains at risk of flooding (Majlis Perbandaran Kuantan, 2019).



Figure 1: Location Plan of Kuantan
Source: Majlis Perbandaran Kuantan, 2019

DATA COLLECTION

A site visit to Kuantan, Pahang, was conducted in February 2025 to identify and verify the spatial locations of evacuation centres (ECs). This field survey aimed to complement and validate GIS-based spatial data (land use layer) on ECs provided by PLANMalaysia. Additionally, population data for this study were obtained from an open-source platform (WorldPop), in TIFF format. The integration of field data, official spatial datasets, and population distribution information enhances the reliability and accuracy of the study's geospatial analysis. Data on the capacity of evacuation centres were also obtained from the Civil Defence Department, enhancing the assessment of shelter adequacy in relation to the at-risk population.

GIS-based Analysis

This study utilised ArcGIS to analyse the spatial distribution of evacuation centres relative to residential areas, employing geospatial techniques to assess population demand and evacuation capacity. Key GIS processes included spatial

data integration, overlay analysis, and zonal statistics, buffer analysis and site suitability analysis.

1. **Mapping and Plotting EC Locations**: The study began with geocoding and mapping of EC locations in GIS. Spatial data provided by PLANMalaysia were used to generate a point layer representing ECs in Kuantan. This served as the base map for further spatial analysis.

2. **GIS Buffer Analysis**: A GIS buffer analysis using ArcGIS software was conducted to evaluate the spatial coverage of evacuation centres. A buffer zone of a 1-kilometre radius was generated around each EC to represent the standard acceptable walking distance for residents during emergencies. The buffer tool in ArcGIS was employed for this step, creating circular polygons surrounding EC points to illustrate coverage areas visually. Following buffer generation, an overlay analysis was performed by intersecting the buffer zones with the residential land-use layer. This intersection allowed the researchers to calculate precisely how much residential land falls within and outside these 1-km buffers. Additionally, this buffer overlay was intersected with flood-prone residential areas and the population grid dataset to quantify the total residential land area and population effectively served by existing ECs. This approach clearly highlighted spatial disparities and identified locations lacking adequate shelter coverage.

3. **Population Grid Intersection Analysis**: Population data obtained in raster format from WorldPop (2013) were first georeferenced and clipped to match the Kuantan District boundary. Using ArcGIS, the raster data were converted to vector polygons representing grid cells. The intersect overlay analysis was then conducted by combining the population grid data layer with flood-prone residential zones and EC buffer layers. This intersection provided precise quantification of populations residing within flood-prone zones and within the 1-km buffer radius of ECs. The Zonal Statistics tool in ArcGIS further facilitated summarising and extracting demographic information from these intersections, providing detailed insights into the spatial relationship between the population at risk and shelter locations.

4. **Flood-Prone Zone and Residential Overlay Analysis:** An intersect overlay analysis was performed using ArcGIS by overlaying the flood-prone area layers with residential land-use layer. This overlay analysis involved the following technical GIS steps: (1) flood-prone area layers were prepared and validated for spatial accuracy; (2) residential land-use polygon were spatially referenced within ArcGIS; (3) the Intersect tool in ArcGIS was applied to merge the two layers into a single new layer, thereby enabling the precise

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quantification of residential land at risk of flooding; (4) EC buffer zones (1-kilometre radius polygons) were subsequently overlaid onto the intersected layers to further quantify the proportion of flood-prone residential areas effectively covered by existing evacuation shelters. This comprehensive multi-layered overlay analysis enabled the identification and quantification of spatial gaps in shelter distribution relative to areas exposed to flooding, providing detailed insights into the effectiveness of current EC placement strategies.

5. **EC Capacity vs. Population Demand Analysis:** To perform this analysis, a spatial join was conducted in ArcGIS between EC locations (point vector data) and the intersected population grid dataset. This involved combining evacuation centre points with corresponding polygon grid cells representing population data derived from WorldPop. The spatial join operation in ArcGIS linked each evacuation centre to nearby population grid cells within the previously generated 1-km buffer zones. Attribute calculations were then carried out within ArcGIS to sum the population counts from grid cells intersecting each EC buffer, thus quantifying the potential demand for each evacuation centre. Subsequently, this calculated demand was compared to the capacity data collected from field.

6. **Suitability Analysis:** To complement the spatial gap assessment, a GIS-based site suitability analysis was conducted to identify optimal areas for future evacuation centre (EC) development in Kuantan. The analysis integrated three spatial criteria:

    - Proximity to existing ECs – areas beyond the 1-km coverage buffer were prioritised, as they represent underserved zones.
    - Flood-prone residential areas – polygons overlapping high flood-risk zones were assigned higher suitability scores.
    - Population density – areas with higher concentrations of at-risk residents received greater weights.

    Each criterion was standardised to a uniform scale and assigned a weight according to its relative importance: distance from existing ECs (40%), flood-prone residential areas (35%), and population density (25%). The Weighted Sum tool in ArcGIS was used to combine these layers, generating a continuous suitability surface. The resulting suitability map (Figure 6) was classified into five categories using natural breaks (Jenks) classification (Less suitable; Moderately suitable; More suitable; Very suitable; Extremely suitable). This classification allows for fine-grained prioritisation, enabling decision makers to focus first on “extremely suitable”

and "very suitable" zones where EC coverage gaps overlap with high flood vulnerability and population density.

Sensitivity Analysis were conducted to assess the robustness of the GIS-based suitability analysis, a weight sensitivity test was conducted within the ArcGIS environment. A one-at-a-time variation of each criterion weight (±10%) was applied while keeping the others constant. The recalculated suitability surfaces were then compared with the baseline using ArcGIS overlay and zonal statistics. Across scenarios, the extent of the top-two suitability classes ("extremely suitable" and "very suitable") changed by less than 5%, and priority zones exhibited more than 80% spatial overlap with the baseline map. These results confirm that the suitability surface generated through the GIS weighted overlay method is stable under reasonable perturbations of criterion weights, thereby increasing confidence in its reliability for planning decisions.

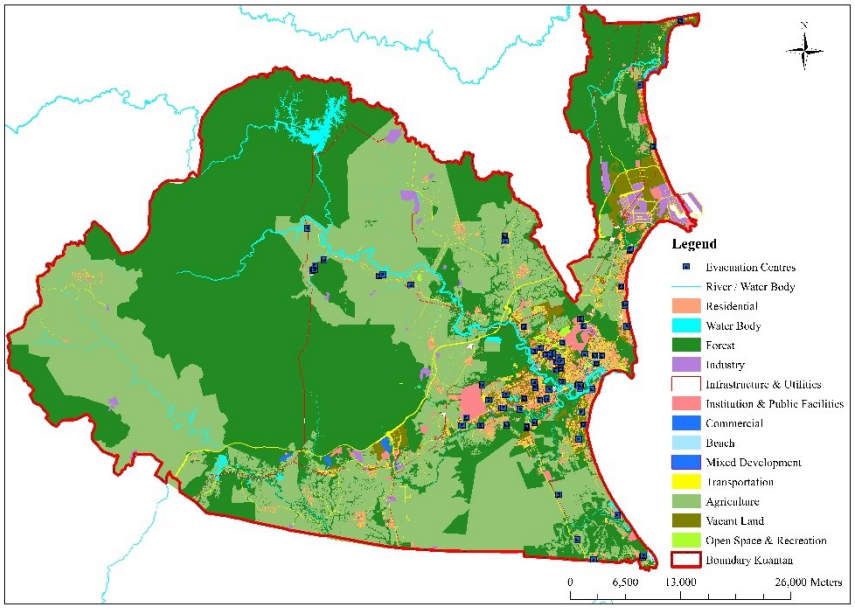


Figure 2: Spatial Distribution of Evacuation Centres

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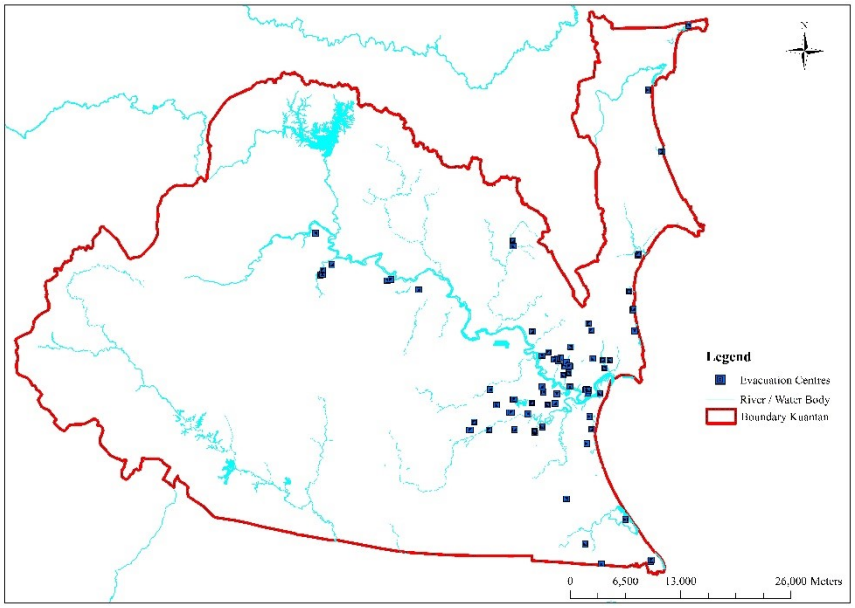


Figure 3: GIS Mapping of Sporadic and Scattered Evacuation Centres

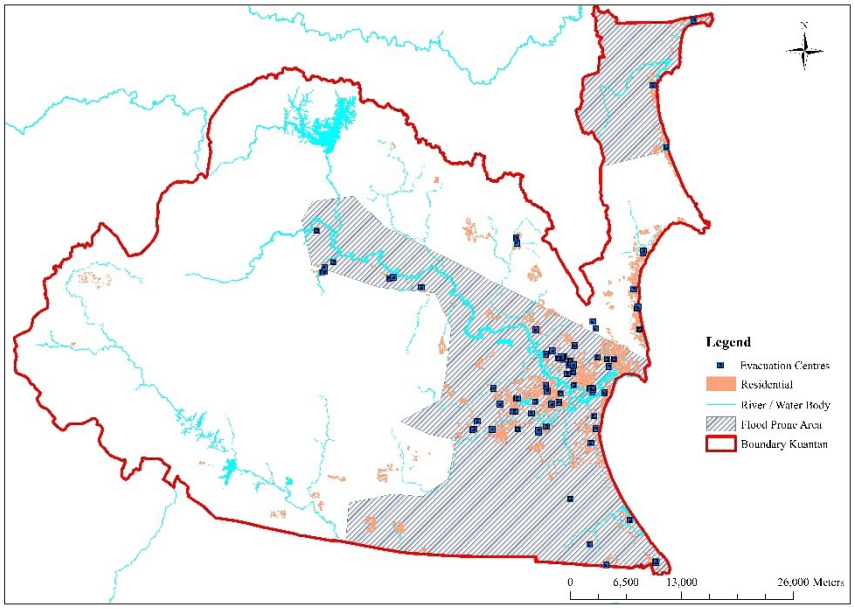


Figure 4: GIS-Based Overlay of Flood-Prone and Residential Area

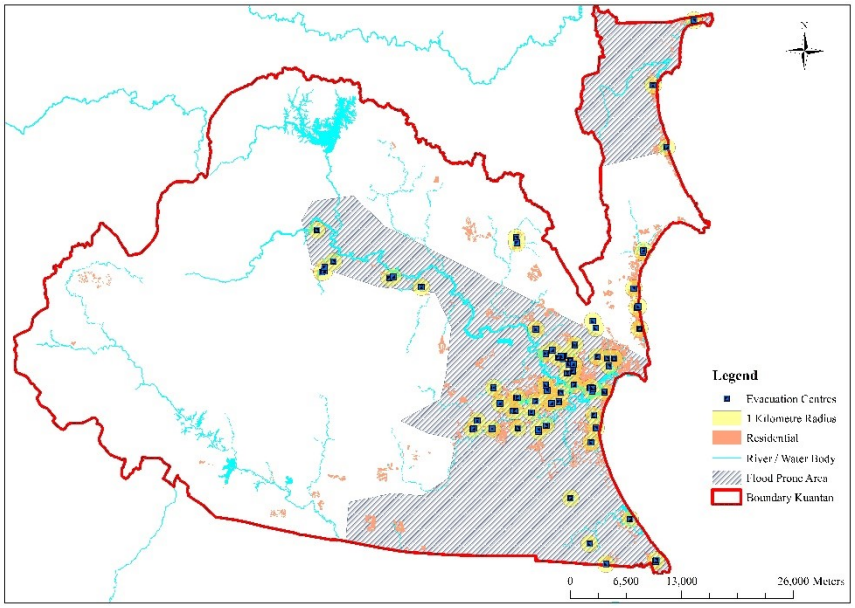


Figure 5: 1-km Evacuation Centre Radius Overlay with Residential and Flood Areas

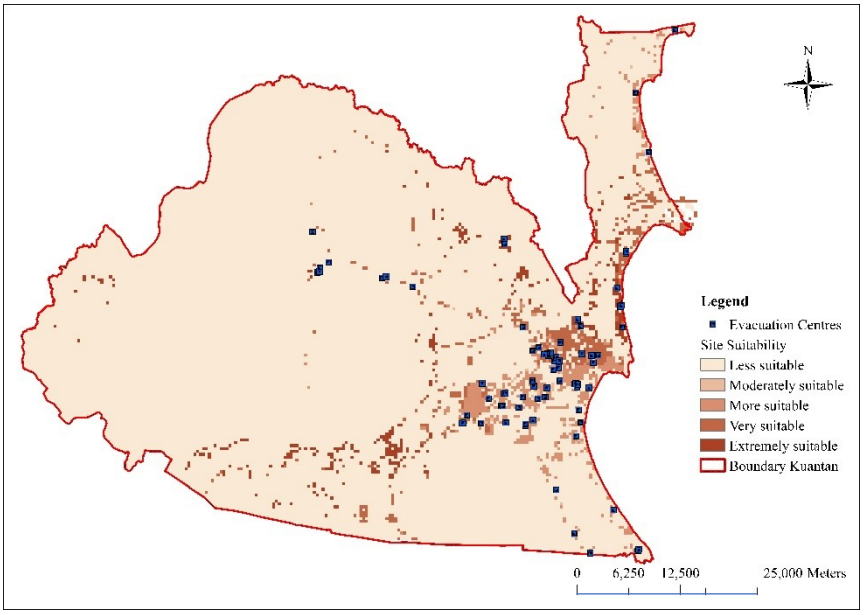


Figure 6: GIS-based Suitability Map

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FINDINGS

A total of 85 evacuation centres (ECs) were identified from the collected data. The spatial distribution of ECs was found to be sporadic and scattered, lacking a clearly definable pattern (refer Figure 2 and refer Figure 3). Most ECs were concentrated in Kuantan City, with fewer centres located in peripheral areas, indicating a pattern where the availability of ECs diminishes with increased distance from the city centre. This uneven distribution highlights the challenge in providing equitable shelter access to all residents during flood emergencies.

Sanyal and Lu (2009) emphasise that emergency shelters should be strategically located to serve the maximum number of vulnerable residents, ideally within a 1 km radius of affected settlement areas. Using GIS-based intersect overlay analysis, this study quantified flood vulnerability by identifying that 4,226 hectares (73.51%) of Kuantan's 5,748 hectares of residential land are flood-prone (refer to Figure). The intersect overlay in ArcGIS combined the residential land-use layer with the flood-prone layer to precisely delineate residential areas exposed to flooding.

Buffer analysis further refined this assessment by creating a 1-km radius around each EC to evaluate direct shelter coverage. Results revealed that only 2,476 hectares (59%) of flood-prone residential land falls within this ideal accessibility range (refer to Figure), while the remaining 41% is outside, indicating significant shelter coverage gaps. This detailed GIS analysis indicated that a significant portion of the vulnerable population lacks adequate spatial coverage by existing ECs, highlighting a notable gap in shelter accessibility during flooding events and underscoring the need for strategic shelter placement improvement.

To assess shelter demand, the GIS intersect overlay technique was employed to combine residential areas, population grid cells, flood-prone zones, and buffer areas around ECs. This intersection facilitated precise quantification of residents residing within flood-prone areas that also fall within the 1-km radius of an EC. GIS intersection analysis demonstrated that 119,548 out of 355,140 residents in flood-prone areas live within accessible distances to shelters.

However, the total shelter capacity data from the Civil Defence Agency Kuantan indicated that all 85 ECs combined could accommodate only 29,700 people at one time. Consequently, current evacuation infrastructure is sufficient for approximately 25% of residents within the ideal 1-km buffer zone during large-scale flood events. This finding points to a substantial gap in evacuation centre provision compared to potential evacuation demand, highlighting critical deficiencies in the current emergency planning and management framework.

The suitability analysis (Figure 6) reveals a clear spatial pattern in potential sites for new EC development. Approximately 14% of Kuantan's flood-prone residential areas fall within the "extremely suitable" category. These zones are predominantly located in the northern and eastern peripheries, where current

EC coverage is sparse and travel distances exceed the recommended 1 km evacuation radius.

The "very suitable" category accounts for an additional 21% of the flood-prone residential land. These areas often exhibit moderate-to-high population densities combined with insufficient proximity to existing shelters. Together, the "extremely" and "very suitable" zones comprise 35% of at-risk residential land, representing the highest priority for infrastructure investment.

The "more suitable" category covers 26% of flood-prone residential areas, generally located in semi-urban zones where shelter capacity may still be inadequate during large-scale events. The "moderately suitable" and "less suitable" categories account for 39% combined, largely overlapping with zones already served by ECs within walking distance.

Sensitivity results confirmed robustness: the combined 'extremely' + 'very suitable' area varied within ±5% across weight scenarios, and the priority polygons exhibited >80% overlap with the baseline, supporting their reliability for planning. This classification provides a nuanced spatial prioritisation, allowing local authorities to sequence EC development in phases beginning with "extremely suitable" and "very suitable" areas to maximise coverage for underserved populations most vulnerable to flooding.

DISCUSSION

The findings of this study highlight critical spatial and capacity-related challenges in Kuantan's evacuation centre (EC) network. The GIS-based spatial analysis confirmed that ECs are unevenly distributed, with a high concentration in Kuantan City and a notable scarcity in peripheral and rural areas. This pattern directly raises concerns of spatial inequity, as a significant proportion of flood-prone residents in outlying zones remain beyond the recommended 1-km evacuation radius.

The buffer analysis showed that only 59% of flood-prone residential land falls within optimal accessibility to ECs, leaving 41% underserved. Population-overlay analysis further revealed that just 34% of the vulnerable population resides within the recommended walking distance, and existing shelters collectively meet only 25% of the capacity needs for those in the covered zone. From a resilience planning perspective, these figures indicate a limited ability to absorb and respond effectively to large-scale flooding events.

The suitability analysis offers a more nuanced view of future planning priorities. Approximately 14% of flood-prone residential land is classified as "extremely suitable" for new EC placement, concentrated in the northern and eastern peripheries of Kuantan. These areas combine high flood risk, high population density, and lack of current EC coverage representing the most urgent locations for intervention. An additional 21% falls under the "very suitable" category, also underserved but with slightly lower flood exposure or population

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concentration. In total, 35% of at-risk residential land ranks in the top two suitability classes, providing a clear, evidence-based foundation for phased infrastructure expansion. The weight-sensitivity check indicates the priority zones are stable to reasonable changes in criteria weighting, strengthening confidence in using the map for staged investments.

Comparable challenges have been reported in other flood-prone contexts. In Metro Manila, Philippines, Chen et al. (2020) found severe overcrowding in centrally located shelters and lack of access in peripheral barangays, echoing Kuantan's urban–rural disparity. In Jakarta, Indonesia, (Kusumo, 2016) documented a similar concentration of shelters in urban cores, forcing residents in suburban communities to travel beyond recommended evacuation distances. In Bangladesh, Alam et al. (2021) reported that over half of rural households in flood-prone regions were located more than 1.5 km from designated shelters, significantly increasing evacuation delays. These international parallels suggest that the concentration of ECs in urban cores is a recurring issue in many Southeast Asian flood contexts, often linked to centralised infrastructure planning and inadequate integration of hazard exposure data into site selection.

From a disaster risk governance perspective, the results underscore the need for coordinated, multi-level planning involving local government, community stakeholders, and technical experts. Integrating the suitability map into municipal development plans could ensure that resource allocation is both data-driven and socially equitable. Such integration would also support Malaysia's commitments under the Sendai Framework for Disaster Risk Reduction, which calls for strengthening disaster preparedness and building resilience at all levels.

In sum, applying the combined lenses of spatial equity, resilience planning, and risk governance reveals that Kuantan's current EC network not only lacks spatial balance but also risks leaving its most vulnerable populations underserved during future flood events. Targeted expansion into "extremely suitable" and "very suitable" zones offers the most effective pathway to improving equitable access, reducing evacuation times, and strengthening the district's overall flood resilience.

CONCLUSION

Using GIS-based spatial analysis within the frameworks of spatial equity, resilience planning, and disaster risk governance, this study identified major gaps in Kuantan's evacuation centre network. Forty-one per cent of flood-prone residential land and 66% of vulnerable residents lie beyond the recommended 1-km coverage, while existing shelters can serve only 25% of those within reach. The suitability analysis highlights 14% of land as "extremely suitable" and 21% as "very suitable" for new ECs, concentrated in underserved, flood-prone

peripheral areas. Addressing these priority zones through targeted expansion and capacity upgrades can significantly improve equitable access and reduce evacuation times. The findings and approach are applicable to other flood-prone cities, offering a replicable, data-driven method to guide fairer and more resilient disaster preparedness planning.

The research contributes by providing a detailed, spatially explicit analysis that identifies specific areas needing improved evacuation infrastructure, thus guiding strategic planning decisions. Future studies should integrate real-time population dynamics and detailed accessibility analyses to further enhance flood preparedness and community resilience.

ACKNOWLEDGEMENT

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ASSESSING PADDY GRANARIES DEGRADATION: INTEGRATING SPATIAL ANALYSIS WITH FIELD VERIFICATION

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Abstract

This study aims to explores the extent of granaries degradation to assess the development pressures from surrounding area, primarily from the Greater Kota Bharu area while also take account of existing land development control mechanism. The scope is granaries under the Kemubu Agriculture Development Authority (KADA). Employing a comprehensive methodology that incorporates spatial analysis and field verification which includes document review and stakeholder interviews. Analysis identified a significant rate of 8% decline in paddy granaries between 2020 and 2021, corresponding to an annual reduction of 3,342 tons in rice production. The research pinpointed physical degradation, socio-economic factors, and climate uncertainties as the key contributing factors to the degradation, decline was corroborated through field verification involving stakeholders. Analysis of policy documents revealed discrepancies in policy interpretation and implementation between federal and state levels. Socio-economic plays a major role in driving farmers motivation to stay in the activity and its ability to replenish human capital. Understanding of degradation is key as it reflect the ability of policy to address the issue and farmers motivation on the ground influencing paddy production thus effecting national rice security.

Keywords: Paddy Granaries, Degradation, Spatial Analysis, Urban Planning, Rice Security

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INTRODUCTION

Malaysians rely heavily on rice as a staple food, with rice being a staple food (Hill, 2012). Despite the critical importance of rice, Malaysia has only achieved a 56.2% self-sufficiency level necessitating the importation of 43.8% of its rice from countries such as India, Indonesia, Thailand and Vietnam (Department of Statistic Malaysia, 2023).

The rice industry is a cornerstone of Malaysia's socio-economic activity, particularly in the northern and eastern regions of Peninsular Malaysia. The price and availability of rice significantly impact the livelihoods of Malaysians as the annual consumption per person averaging 73.9 kilograms (Ho et al., 2023) emphasizing the necessity for effective coordination between rural production areas and urban consumption zones (Rahim et al., 2017). Peninsular Malaysia is home to ten primary rice granaries, each managed by institutions such as the Muda Agricultural Development Authority (MADA), the Kemubu Agricultural Development Authority (KADA), and the Integrated Agricultural Development Authority (IADA) (PLANMalaysia, 2023). These institutions play a crucial role in ensuring the sufficiency of domestically produced rice.

This study focuses on KADA, which manages a substantial land area of 23,199 hectares which currently exposed to the degradation, despite the trend is apparent among officials and locals a comprehensive study is yet to be conducted.

Malaysia's long-standing policy, originating from the New Economic Policy era, aims to achieve national rice security by reducing dependency on rice imports with the goals of 80% self-sufficiency level in the year 2030 (PLANMalaysia, 2023). However, recent data indicates an increasing trend in rice imports, with 1.24 million tonnes imported in 2022 compared to 1.16 million tonnes in 2021 (DOSM, 2023) the import value reflect the land degradation situation however there is a lack of spatial understanding for that matters

Therefore, the aim of this study is to identify the rate of granaries land degradation to understand ground situation of farmers perspective on granary condition. Degradation reflects farmers disinterest to stay in the activity and ineffectiveness of the policy deployed. Understanding it, is imperative as this will then contribute to the productivity in ensuring to alleviate the rice security situation in the country.

DATA & METHODS

Study Area

KADA granaries located at eastern corridor of Peninsular Malaysia, in the state of Kelantan Darul Naim. The site is located in proximity to the Kota Bharu which is the main conurbation area for the state of Kelantan and is receiving the development pressure from it (PLANMalaysia@Kelantan, 2023).

It is situated at Kelantan lowland area in the north of state which the region is the most fertile with highest number of populations amounting to

293,420 people within the state of Kelantan (DOSM, 2023). The granaries are in the district of Tumpat and Pasir Mas (see figure 1).

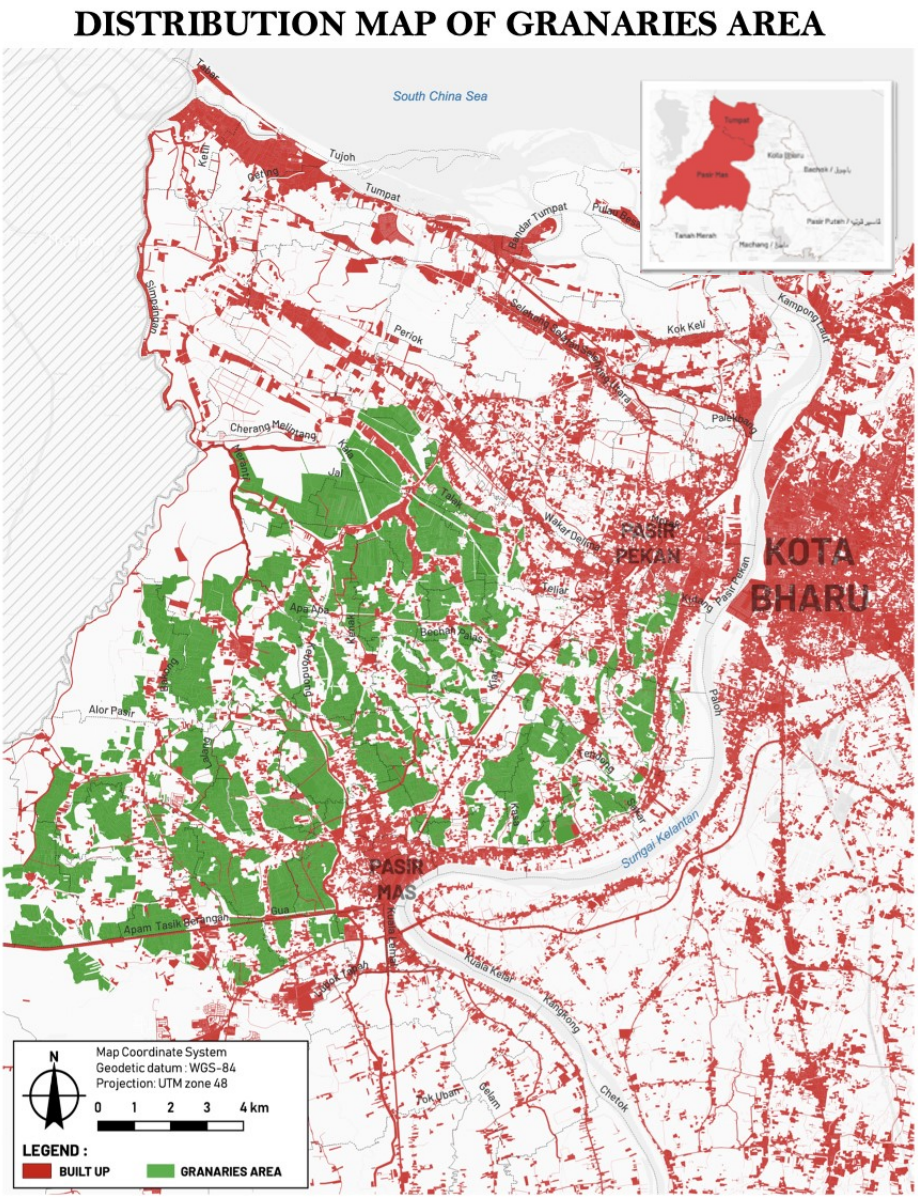


Figure 12: Kota Bharu Urbanisation and granaries position.

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Stakeholders

For reliability of the study multiple stakeholder that has relevancy to the granaries is considered, stakeholders identified are as below (table 1).

Table 11: List of stakeholders.

Stakeholder	Branch	Commentary
Industry Players	Farmers	Refers to the person which are doing or involved directly to the activity within the boundary of KADA granaries.
	KADA	Refers to the management authority which are responsible to distribute the infrastructure, fertilizers, and farming schedule.
Federal Government Agency	PlanMalaysia @Putrajaya	The department responsible to coordinate national development through the establishment of National Physical Development Council (MPFN).
	Ministry of Agriculture	The department is directly responsible in the performance of the granaries by distributing the yearly allocation, policy shaping, technology sharing and human capital development.
State Government Agency	PlanMalaysia @Kelantan	Refers to the authority to advise state policy through the State Planning Council (SPC) that determine the priority of the land matters.
	Office of Agricultural EXCO	Refers to the authority responsible in managing, driving and allocating involving agricultural capabilities in Kelantan state.
Local Authority	Pasir Mas Local Council	Respectfully, both authority holds the planning and development policy according to local plan.
	Tumpat Local Council	
	Penggawa	It's the branch of authority that are visible in Kelantan State only. The appointment is made by the kingship monitoring local social development for the district which hold influence toward the local farmers through distribution of the welfare allocation.

Datasets

This study involves transition of land from agricultural (He et al., 2011) in which for this study is Class 3 (predominantly paddy fields) to various non-granary land use categories (Chughtai, 2021). The list of datasets is as below (table 2).

Table 12: Datasets used to track degradation area

Datasets	Source	Format	Year	Commentary
Granaries Area	Department of Physical Planning (BRFN) @ PM Putrajaya	.shp (Shapefile)	2020	The area of granaries is verified and confirmed through the NPP 4 (National Physical Plan)
Land Use	Department of Physical Planning			Relevant data provided has been cross check within the both of

Datasets	Source	Format	Year	Commentary
	(BRFN) @ PM Putrajaya		2021 & 2022	agency and in-align and verified for the use of studies
	Office of Deputy Director@ PM Kelantan			

Datasets are then methodologically process (Eidsvik et al., 2018) as outlined below (figure 2) ensuring a systematic and accurate approach.

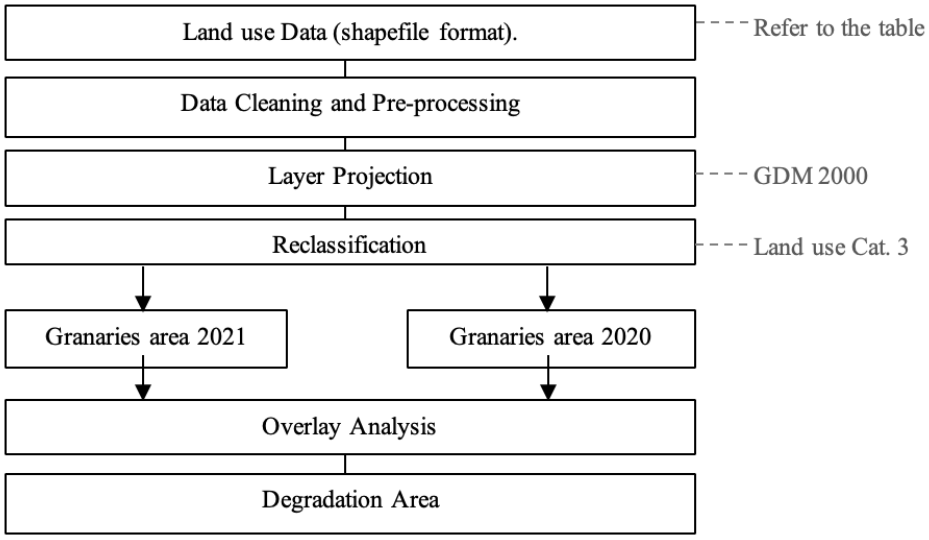


Figure 13: Data framework and studies flow.

Sampling Method

The sampling technique employed was the purposive method, targeting both agency representatives and farmers (Tongco, 2007). This approach was selected to encompass a broad spectrum of perspectives, thereby reducing potential bias in the conducted interviews and enhancing the reliability of the subsequent analysis (Campbell et al., 2020) while referring to spatial analysis to determine the study area in which the land degraded the most in its context to better address the issue and establish coherent understanding of the material based the structured interview question which will outline main concern and input for study purposes.

Data Integration

As the study involve multiple analysis, an integration the finding from spatial analysis and verification using structured interview as indicated below (figure 3).

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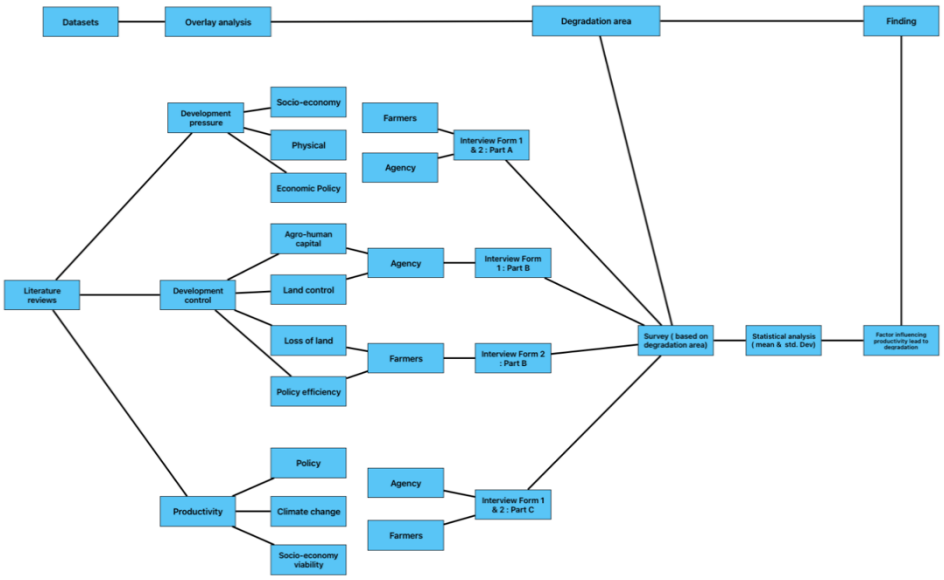


Figure 14: Integration of data for land degradation.

RESULTS AND DISCUSSION

Rate of Degradation

Based on the analysis, this study found that KADA paddy fields lost approximately 8% of their total land area between the periods of 2020 and 2021. This number is significant because the loss of each hectare of land can adversely affect rice production. To further understand, the 8% loss of that area is equivalent to 2,297.44 hectares, as shown in Table 3.

Table 13: Comparison of KADA granaries size between 2021 and 2020

Year	Size (Hectare)	Commentary
2020	9,553.43	Reduction of 2,297.44 hectares according to the land use categorically agriculture class 3 paddy.
2021	7,256.00	

The potential loss of approximately 2,297.44 hectares of paddy fields poses severe implications for rice production in Malaysia, a staple food for its population. KADA field productivity, averages at 4.52 tons per hectare (PLANMalaysia, 2023), this reduction could lead to a decrease in rice production by approximately 10,384.43 tonnes annually. Assuming rice prices range between RM 1,200 and RM 1,300 per tonnes (DOSM, 2023), the potential annual income loss from these fields estimated range from RM 12,461,314 to RM 13,499,757. This estimation assumes that the fields operate at optimal levels

without being impacted by socio-economic and climatic factors, which significantly affect productivity.

The largest proportion of KADA paddy field degradation occurs in the northwest area, adjacent to the Golok River (as shown in figure 4), where substantial and collective degradation is evident highlighting the conversion of paddy land to non-paddy land. Furthermore, a significant trend identified is the loss of paddy field areas to infrastructure development. Plans indicate that areas adjacent to main roads are particularly affected, showing linear losses parallel to these routes. Approximately 13% of the paddy field area, or 1,923 hectares, is transformed due to its high accessibility, resulting in rapid changes compared to other regions.

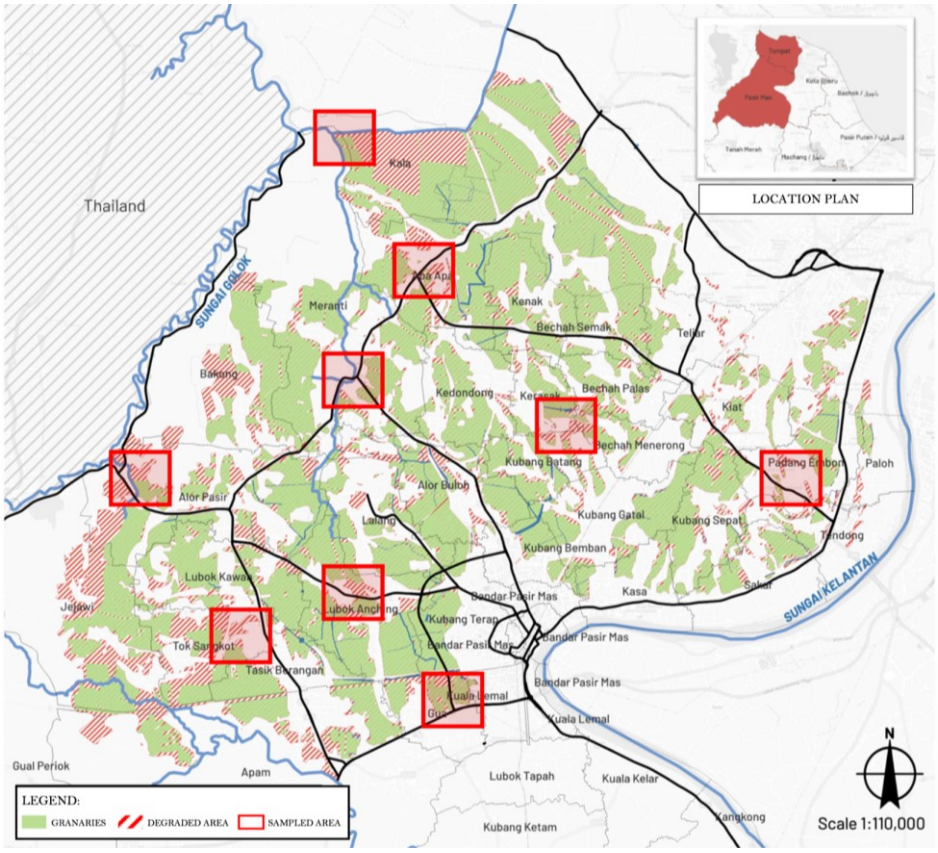


Figure 15: Integration of data for land degradation.

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Respondent Demography

Based on the demographic profile presented in Table 5, the majority of the farmers surveyed are aged above 25 years, with a substantial proportion (60%) being over 41 years old, consistent with findings from previous studies. The farming sector remains male-dominated (65%), suggesting that physical attributes still influence labour-intensive activities and productivity outcomes. In terms of field experience, most farmers have been involved in rice cultivation for more than 10 years, reinforcing the generational continuity and strong field knowledge among respondent despite that there is a loop in human capital from youndger generation indicating a generational drawback from the activity.

Farmers predominantly manage small to medium-sized plots, with 95% cultivating areas below 20 acres, implying limitations in the adoption of heavy mechanization thus hindering economies of scale resulting in lesser economical gain per plot driving the fragmentation further. All respondents possess land ownership and self-finance their operations, indicating relatively high autonomy. Additionally, 95% of the respondents are full-time farmers, highlighting strong commitment levels, which are critical for sustaining granary productivity. Most farming households comprise 3–5 members, enabling reliance on family labor and reducing operational costs. Collectively, these demographic characteristics suggest a resilient but aging farming population operating under moderate resource constraints and has a lengthy exposure to the changes of fields in the cultivation area.

Table 14: Farmers respondent demography

Respondent	Citation	Criteria	Percentage	Commentary
Age	Nguyen et al., 2021; Hermawan et al., 2021; Chandio et al., 2018; Tauer, 1994	<25 years old	5	Majority of the farmers is people above 25 above. The findings in align with other literature document.
		26-33 years old	10	
		34-40 years old	25	
		>41 years old	60	
Gender	Kinkingninhoun-Mêdagbé et al., 2010; Addison et al., 2016; Mishra et al., 2017	Male	65	Male dominated field, physical attribute play role in higher productivity.
		Female	35	
Field Experience	Chandio et al., 2018; Khan et al., 2022; Nakano et al., 2018; Erythrina et al., 2021	<5 years	0	Most of the farmers are generational, meaning their involvement start at young age. Showing good understanding to the field.
		5-10 years	20	
		10-15 years	40	
		>15 years	40	
Area of Activity	Rahman, 2003; Rahman et al., 2009b; Tu et al., 2021	<5 acres	30	Most of the area tended by farmers or group is under 20 acres. Meaning utilization of heavy machinery is limited and
		5-10 acres	35	
		10-20 acres	30	
		>20 acres	5	

Respondent	Citation	Criteria	Percentage	Commentary
				unimpactful toward planting cost reduction.
Holdings	Bello et al., 2020; Koirala et al., 2016	Capital and Land	100	All of the farmers interviewed claim to hold the title and using own capital to stay in the activity.
		Capital	0	
Time of Activity	Munton et al., 1989; Bateman et al., 1974; Conway et al., 2002; Mohd Rashid Rabu & Mohd Dainuri Mohd Shah, 2013	Full Time	95	Most of the farmers involved in full time, the productivity is hugely affected by farmer commitment to the field.
		Part Time	5	
Number of Household	Panta, 2018; Emran et al., 2021	3-5 person	65	For farmer that use traditional, or hybrid approach higher number of households means significant reduction on labour cost which will lower the overall production cost.
		>5 person	35	

Stakeholder Verification

In term of stakeholders, analysis indicates a consensus among both agencies and farmers, acknowledging the presence of development pressures on the KADA territories aligning with the finding of the study.

Table 15: Farmers respondent demography

Respondent	Criteria	Percentage	Commentary
Agency	Agree	100	There is a high level of agreement among stakeholders regarding land degradation, aligning closely with the findings from the spatial analysis.
	Disagree	0	
Farmers	Agree	90	
	Disagree	10	

This study supported by literature review and previous analyses confirmed that socio-economic play a crucial role in influencing fragmentation of the paddy field. It acts as a catalyse that drive development of physical while at the same time provide a continuance of sustainability in the activity in time of natural disaster. This is then amplified by policy introduce to the region and its enforcement in orchestrating the paddy fields fragmentation.

Further analysis reveals that the physical aspect is also perceived as significant, with 36% and 45% of agency and farmers respectively citing impacts from land use changes and infrastructure developments. Followed by the third, 5% of respondents from the farmers' side identified climate as a significant factor.

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Table 16: Factors of Land Degradation

Factors	Agency (%)	Farmers (%)	Commentary
Physical (Land Use)	36	50	
Socio-Economy	64	45	
Natural Disaster	0	5	

Land Degradation Impact on Productivity

The findings from Table 7, which identify key factors affecting granary productivity, gain deeper contextual meaning when triangulated with the farmer demographic profile presented in Table 5. The high agreement on "small and isolated plots" as a significant constraint (Mean = 4.87) directly correlates with the reality that 95% of surveyed farmers operate on land areas below 20 acres, limiting the feasibility of mechanization and scale-driven cost reduction.

Table 17: Factors effecting granaries productivity

Factors	Citation	Mean Score	Level of Agreement	Std.	Rank of Influence
Small and isolated plot reduce its productivity	Rahman, 2003; Rahman et al., 2009a; Tu et al., 2021; Das et al., 2021; Key, 2019; Sheng et al., 2019; Muyanga et al., 2019; Wu et al., 2005; Nilsson, 2018; Du et al., 2018; Jiang et al., 2017; Hiironen et al., 2016; Zeng et al., 2018; Nguyen et al., 2020; Fan et al., 2018	4.87	Prominent	0.72	Significant
Stable and competent rice price catalyze productivity	Rosegrant et al., 1994; Jones, 1995; Dawe, 2001; Nghiem et al., 2002; Kajisa et al., 2005; Rahman et al., 2009b; Dawe et al., 2012; Kompas et al., 2012; Rakotoarisoa, 2011; Prihtanti et al., 2020	4.94	Prominent	0.25	Highly Significant
Adequate paddy field operation infrastructure has influence on productivity	Antle, 1984; Tuong et al., 2005; Rahman et al., 2009b; Mariyono, 2018; Jimi et al., 2019; Devkota et al., 2020	4.84	Prominent	0.73	Significant
Climate change and rate of natural disaster event has influence productivity	Knox et al., 2012; Weerasekara et al., 2021; Saud, 2022	4.94	Prominent	0.25	Highly Significant

This fragmentation, compounded by the aging nature of the farming population—60% of whom are above 41 years old—reinforces generational drawback related to key factor of limited socioeconomic opportunity to stay in the activity. Similarly, the highest-rated factor, "stable and competent rice pricing" (Mean = 4.94), must be interpreted through the lens of a farming community entirely reliant on self-capital.

The role of infrastructure, another prominent factor (Mean = 4.84), is also shaped by demographic limitations—small household sizes (65% with 3–5 members) and fragmented landholdings hinder collective action for irrigation upgrades or drainage maintenance and further marginalize farmers from benefiting from government support or large-scale interventions. Additionally, while farmers are committed—95% being full-time—the lack of youth involvement (only 15% are under 33 years) poses a risk to future innovation and adaptive capacity, especially in response to increasingly frequent climate-related disruptions, which are also rated highly significant (Mean = 4.94) with climate change and natural disasters accelerating soil erosion, salinity intrusion, and crop failure, the combination of demographic rigidity, economic constraints, and infrastructural inadequacies forms a feedback loop that intensifies land degradation and undermines granary resilience.

CONCLUSION

In conclusion study has confirmed that there is apparent degradation of granaries area on the KADA granaries through spatial analysis and field verification, demonstrating that 8% of the fields experienced degradation between 2020 and 2021. This degradation led to a reduction in rice production by 3,342 tonnes and had financial implications amounting to RM 4,689,048 annually.

Evidently supported by a high level of consensus among respondents concerning the impact of development pressures. Which align with findings from literature reviews. Among the three factors of pressure discussed, the socio-economic aspect is found to have the most substantial impact for degradation of paddy fields, as indicated by both agency and farmer respondents. This is followed by the physical aspect, where concerns about its lasting effects are prominent. The study also notes that the consequence impact is attributed to climate and natural disasters. Lastly, study would suggest a nationwide analysis for the degradation of paddy fields in order to cast a holistic understanding.

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BRIDGING INTEREST AND POTENTIAL OF ASTROTOURISM IN MALAYSIA: BARRIERS, OPPORTUNITIES, AND STRATEGIES

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Abstract

This study examines the emerging astrotourist behavior, perceptions, and expectations by focusing on their interest in astronomy, awareness of astrotourism, amenities, accessibility, activities, and its value chain contributions. Using a cross-sectional design and purposive sampling, 117 responses were collected via face-to-face interviews and online surveys and analyzed descriptively. The study reveals a significant gap between interest (61.5%) and participation (13.7%) in astronomy tourism in Malaysia, driven by barriers like accessibility and awareness. Most respondents stressed the importance of basic astrotourism activities like stargazing and astrophotography. Findings highlight astrotourism's economic, educational, and spiritual value, emphasizing its untapped potential. The study emphasizes targeted marketing, infrastructure, and community engagement to bridge gaps between the products, operators and astrotourists for sustainable astrotourism growth in Malaysia. While demand for astrotourism is emerging in Malaysia, broader engagement requires targeted marketing, enhanced amenities, and competitive offerings.

Keywords: Astrotourism; Barriers; Opportunities; Strategies; Malaysia

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INTRODUCTION

Astrotourism, a rapidly growing niche within special interest tourism, offers travelers opportunities to explore celestial phenomena, connect with the cosmos, and experience the beauty of dark skies. Activities such as stargazing, observing celestial events, visiting observatories, and exploring astronomical heritage sites merge recreational and educational elements, appealing to diverse audiences from amateur enthusiasts to seasoned astronomers (Tapada et al., 2021). Advancements in astronomical knowledge and heightened awareness of light pollution's impact on natural nightscapes have supported the development of astrotourism (Falchi et al., 2016; Ruggles & Cotte, 2010). Recognizing astrotourism's potential to attract high-value, environmentally conscious visitors, destinations increasingly focus on preserving dark skies and promoting astronomical experiences.

However, challenges persist. Light pollution, driven by urban expansion and inadequate policies, significantly compromises dark skies and celestial visibility (Cinzano et al., 2001; Kyba et al., 2015). Additionally, limited infrastructure and accessibility in remote stargazing locations hinder development, as do low awareness levels about astrotourism's economic and educational benefits (Jacobs et al., 2020). These challenges restrict tourist experiences and the contributions of astrotourism to sustainable tourism and community development.

Despite growing interest, research gaps remain. Few studies have deeply examined tourist behavior, perceptions, and expectations related to astrotourism, including their interest in astronomy (Weaver, 2011; Soleimani et al., 2019). Further investigation is needed into the role of awareness campaigns and interpretive programs in enhancing public understanding and the accessibility and amenities required for astrotourism destinations (Ramdlani et al., 2025). Additionally, limited attention has been given to astrotourism's value chain contributions, including its economic impact on rural areas and integration into sustainable tourism strategies (Pašková et al., 2021; van Wyk-Jacobs, 2018).

Malaysia's equatorial position allows visibility of constellations from both hemispheres, enhancing its appeal to astronomy enthusiasts (The Star, 2024a). Certified stargazing sites in Kota Belud, Sabah, and Mersing, Johor, reflect efforts to provide safe and comfortable experiences for astrotourists (New Straits Times, 2019; The Star, 2024a). The Ministry of Tourism, Arts, and Culture has identified astrotourism as a strategic focus, supported by initiatives like Dark Sky Malaysia, which promote sustainable development and train guides (Astro Awani, 2022; The Star, 2024b).

This study examines astrotourist perceptions and expectations, focusing on their astronomy interest, awareness, activities, and value chain contributions to identify astrotourism barriers, opportunities, and strategies. It provides

actionable insights for policymakers and tourism stakeholders, offering a framework to promote sustainable tourism, enhance visitor experiences, and preserve dark sky heritage for future generations.

LITERATURE REVIEW

Astrotourism

Astrotourism, a niche within special interest tourism, focuses on observing celestial phenomena, engaging in astronomy-related activities, and exploring dark sky environments. This form of tourism has led to the creation of Dark Sky Parks and Reserves, where light pollution is minimized to preserve natural nightscapes (Jacobs et al., 2020). Astrotourism combines recreational, educational, and scientific elements, catering to diverse interests while contributing to societal and environmental goals (Ruggles & Cotte, 2010; Weaver, 2011).

Culturally, astrotourism connects human fascination with the cosmos to the preservation of astronomical heritage sites, such as ancient observatories, which reflect the historical and spiritual connections between astronomy and civilization (Soleimani et al., 2019). Astrotourism fosters cultural appreciation and heritage conservation (Rodrigues et al., 2023; Tapada et al., 2021). Environmentally, astrotourism advocates for dark sky conservation, addressing the growing issue of light pollution that threatens pristine nightscapes vital for celestial observation. Studies emphasize light pollution's harmful effects on ecosystems and well-being (Falchi et al., 2016; Kyba et al., 2015). Astrotourism contributes to sustainable tourism by mitigating light pollution and raising awareness about dark skies' ecological importance (Mitchell et al., 2019).

Critical variables influencing astrotourism's appeal include interest in astronomy, which drives tourists' motivations for stargazing, astrophotography, and celestial events (Cinzano et al., 2001; Weaver, 2011). Awareness of astrotourism's cultural, recreational, and educational benefits shapes tourist decisions (Collison & Poe, 2013). Location amenities and accessibility, including transport, accommodation, and services, are also essential for a successful visitor experience (Jacobs et al., 2020; Ramdlani et al., 2025). Additionally, astrotourism activities, such as guided tours and workshops, cater to various expertise levels, enhancing the inclusivity and value of the experience (Cater, 2010). The sector also contributes economically, socially, and culturally, supporting job creation and local heritage preservation (Pašková et al., 2021).

Past Studies on Astrotourism

Astrotourism, a niche tourism industry sector, has received limited research attention, though various facets of its development have been explored. Weaver (2011) highlighted that people's innate curiosity about celestial phenomena drives

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participation in astrotourism, particularly during unique astronomical events like eclipses or meteor showers. These events often act as strong motivators for travel (Soleimani et al., 2019), and public outreach programs and amateur astronomy groups have played key roles in nurturing interest, especially among younger audiences.

Awareness and understanding of astrotourism remain crucial for the sector's growth. Collison and Poe (2013) emphasized the importance of awareness campaigns, especially in national parks and heritage sites, where educational programs about dark sky preservation and the cultural significance of astronomy are promoted. However, widespread understanding of the potential of astrotourism is still lacking, limiting participation and exposing gaps in the sector (Jacobs et al., 2020). Furthermore, Jacobs et al. (2020) and Azwar et al. (2023) identified challenges faced by rural communities in developing infrastructure, such as transport networks and visitor facilities, which hinder tourism potential. In contrast, as seen in Portugal's Alqueva Dark Sky Reserve, well-planned infrastructure enhances visitor experiences and attracts more tourists (Rodrigues et al., 2015).

The diversity of activities available in astrotourism, such as night sky photography workshops and storytelling about constellations, significantly enhances tourist engagement (Cater, 2010). Observatories and planetariums provide educational opportunities, appealing to both casual tourists and astronomy enthusiasts (Ruggles & Cotte, 2010). Additionally, studies on the value chain contributions of astrotourism highlight its role in supporting sustainable tourism and local economies. Pašková et al. (2021) found that it fosters job creation, community empowerment, and the preservation of cultural heritage. Similarly, Mitchell et al. (2019) demonstrated its economic impact on local businesses in the Colorado Plateau, driven by dark sky tourism.

Despite valuable insights, further research on tourist perceptions, behaviors, and expectations is needed to inform more effective marketing and destination management strategies. Weaver (2011) emphasized the importance of aligning tourist expectations with actual experiences, especially when environmental factors, such as weather, impact the visibility and enjoyment of celestial events. Astrotourist behavior is influenced by demographic factors, cultural backgrounds, and prior exposure to astronomy (Soleimani et al., 2019). However, limited research exists on specific behavioral patterns and their implications for destination planning. Understanding these aspects could help tailor offerings to meet the needs of different tourist segments, enhancing satisfaction and repeat visitation (Jacobs et al., 2020).

Addressing barriers to participation is also crucial. Collison and Poe (2013) found that many potential tourists are unaware of dark sky reserves or available astrotourism experiences. Expanding awareness through targeted

campaigns can help overcome these challenges. Additionally, the availability of location amenities and accessibility is critical, especially in remote areas (Ramdlani et al., 2025; Rodrigues et al., 2015). Managing tourist expectations, particularly in relation to uncontrollable environmental factors like weather, is essential for ensuring satisfaction and positive word-of-mouth promotion (Falchi et al., 2016).

Rodrigues et al. (2023) emphasized the need for purpose-built infrastructure, such as observatories and designated stargazing areas, to enhance tourist experiences and promote education. While infrastructure development faces challenges, such as funding limitations and balancing accessibility with environmental preservation, successful examples like the Aoraki Mackenzie Reserve in New Zealand show how strategic investments can foster tourism growth (Jacobs et al., 2020). As seen in Bryce Canyon's dark sky program, multi-stakeholder collaboration is also vital for aligning scientific goals with local interests (Collison & Poe, 2013).

Finally, addressing artificial light pollution, as Falchi et al. (2016) documented, is critical for supporting astrotourism. Implementing stricter policies to reduce light pollution can enhance astrotourism experiences, benefiting biodiversity and human health. Despite growing awareness, enforcement gaps persist, particularly in urban-adjacent areas (Mitchell et al., 2019). Integrating cultural and archaeoastronomical heritage into astrotourism, as Ruggles and Cotte (2010) explored, can enrich visitor experiences while promoting cultural preservation. However, researchers have posited that it requires careful stakeholder' management to avoid cultural appropriation (Mitchell et al., 2019).

RESEARCH METHODOLOGY

This study employed a cross-sectional research design, suitable for descriptive investigations and allows for data collection at a single point in time (Babbie, 2020). This design was chosen to efficiently capture astrotourist perceptions and expectations while providing insights into current barriers, opportunites and strategies of astrotourism product. Cross-sectional studies are particularly effective for exploring relationships between variables without requiring prolonged timeframes, making them ideal for the objectives of this research (Creswell & Creswell, 2017).

The study population was comprised of experienced astrotourists in Malaysia, who were defined as individuals who participated in tourism-related activities such as stargazing, visiting observatories, or exploring dark sky destinations. Study participants were recruited using purposive sampling due to the niche nature of the population and the absence of a formal sampling frame. Inclusion criteria required participants to have prior experience with astrotourism

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activities or a demonstrated interest in astronomy-related travel. This approach ensured that the data collected was relevant to the study's objectives.

The study used a structured questionnaire, administered through an online survey form during face-to-face interviews. The instrument was adapted from validated scales by multiple authors and covered four key study variables: -

i. Interest and Inclination toward Astronomy (BA) – Questions measured tourists' intrinsic motivation and engagement with astronomy-related activities (Weaver, 2011).
ii. Astrotourism Awareness and Understanding (BB) – Items evaluated participants' knowledge about astrotourism's offerings and benefits (Collison & Poe, 2013).
iii. Astrotourism Activities (CB) – Respondents rated their participation and preferences for astrotourism-related activities (Cater, 2010).
iv. Astrotourism Value Chain Contributions (E) – Items measured economic and social impacts, such as community benefits and cultural heritage preservation (Pašková et al., 2021).

The questionnaire was reviewed by a panel of tourism experts for cultural relevance and content validity. It was also pilot-tested with a small sample (n = 30) to ensure clarity and reliability. Feedback from the pilot study was incorporated into the final instrument. The study was conducted in accordance with ethical research standards. Approval was obtained from Universiti Kebangsaan Malaysia ethics review board. Participants were informed about the study's objectives, the voluntary nature of their participation, and their right to withdraw at any time. Informed consent was obtained prior to participation, and responses were kept confidential.

Data collection occurred from October to December 2024 through face-to-face interviews using an online survey form. The hybrid approach allowed the researchers to clarify questions and ensure accurate responses while leveraging digital tools for efficient data recording. Recruitment and interviews were conducted at public astrotourism events and astronomy-related community gatherings across Malaysia. A total of 117 valid responses were recorded during the three months, meeting the sample size requirements for a descriptive analysis. The data were analyzed descriptively using SPSS version 29 software. Descriptive statistics were used to summarise the data, understanding the data distribution and identifying potential patterns or trends within the sample

ANALYSIS AND DISCUSSION

Interest and Inclination toward Astronomy

Table 1 highlights respondents' interest levels, knowledge, skills, and participation in astronomy-related activities.

Table 1: Interest and Inclination toward Astronomy

Item	Description	Strongly Disagree	Disagree	Agree	Strongly Agree
BA1	I am interested in astronomy	0%	7.7%	58.1%	34.2%
BA2	I have knowledge in the field of astronomy	0.9%	39.3%	51.3%	8.5%
BA3	I have skills in the field of astronomy	15.4%	64.1%	14.5%	6%
BA4	I am interested in activities related to astronomy	0.9%	12.0%	61.5%	25.6%
BA5	I have attended astronomy-related programs or courses	16.2%	43.6%	26.5%	13.7%

N=117

The findings reveal strong interest in astronomy, with 92.3% of respondents expressing enthusiasm for astronomy-related activities (BA1), and 61.5% agreeing or strongly agreeing to be interested in such activities (BA4). However, only 13.7% strongly agreed to having attended astronomy programs (BA5), indicating a gap between interest and active participation. Barriers like limited access, lack of awareness, or constraints such as time and cost may hinder participation. These results align with Ajzen (1991) Theory of Planned Behavior, which suggests that interest does not always translate into action due to perceived limitations on control.

Astrotourism Awareness and Understanding

Table 2 summarizes the findings, shedding light on the varying degrees of awareness and enthusiasm for astrotourism within the surveyed population.

Table 2: Astrotourism Awareness and Understanding

Item	Description	Strongly Disagree	Disagree	Agree	Strongly Agree
BB1	I have heard of the term astrotourism	9.4%	30.8%	40.2%	19.7%
BB2	I have attended astrotourism-related programs or courses	13.7%	63.2%	15.4%	7.7%
BB3	I am interested in participating in astrotourism packages	12.0%	61.5%	0%	26.5%

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The analysis shows varying levels of awareness and engagement with astronomy tourism. While 59.8% of respondents are familiar with the term "astronomy tourism" (BB1), only 23.1% have participated in related programs (BB2), indicating limited practical engagement despite recognition of the concept. However, 88% expressed willingness to engage if opportunities were available (BB3), highlighting significant untapped demand. This gap suggests potential barriers, such as limited access, insufficient marketing, or inadequate infrastructure. This latent demand aligns with Roger (2003) Diffusion of Innovation Theory, indicating early-stage diffusion of astrotourism.

Astrotourism Core Activities

Table 3 outlines participants' perceptions regarding the significance of each activity, including celestial observations, astrophotography, and interactive learning experiences.

Table 3: Astrotourism Core Activities

Item	Description	Strongly Disagree	Disagree	Agree	Strongly Agree
CB1	Observing celestial objects (stars, planets, the moon)	0%	0.9%	49.6%	49.6%
CB2	Observing celestial phenomena (eclipses, meteor showers)	0%	0.9%	42.7%	56.4%
CB3	Storytelling during celestial observations	0%	0.9%	44.4%	54.7%
CB4	Astrophotography (taking pictures of stars, constellations, etc.)	0%	0.9%	41.0%	58.1%
CB6	Learning activities (e.g., recognizing stars, planets, the moon, etc.)	0%	0.9%	37.6%	61.5%
CB8	Local traditions and beliefs about celestial objects (e.g., stars, clouds)	0%	4.3%	43.6%	52.1%

The study's findings reveal a significant level of interest among respondents in various astronomy-related activities, highlighting the diverse appeal of astrotourism. Observing celestial objects, such as stars, planets, and the moon, emerged as a universally popular activity, with equal proportions of respondents (49.6%) expressing agreement and strong agreement. This indicates a widespread fascination with the Observing celestial phenomena, including events like eclipses and meteor showers, generated even higher levels of enthusiasm. More than half of the respondents (56.4%) strongly agreed, while 42.7% agreed, underscoring the allure of dynamic and rare astronomical

occurrences. These findings suggest that such events could be key drivers of engagement in astrotourism.

Storytelling during celestial observations also garnered significant interest, with 54.7% of respondents strongly agreeing and 44.4% agreeing. This reflects the value of incorporating cultural narratives and historical context into stargazing experiences, enriching the activity beyond its scientific appeal. Similarly, astrophotography, which combines creativity with technical skill, resonated strongly with respondents. Over half (58.1%) expressed strong agreement, while 41.0% agreed, highlighting the potential of this activity to attract both amateur and professional photographers. Educational activities, such as learning to recognize celestial objects, were among the most highly valued aspects of astrotourism. A significant majority (61.5%) strongly agreed, and 37.6% agreed, indicating a strong desire for knowledge-based engagement with astronomy. This finding reinforces the importance of incorporating interactive and educational elements into tourism offerings to cater to the growing demand for meaningful and enriching experiences.

Interest in local traditions and beliefs about celestial objects was slightly lower but still notable, with 52.1% strongly agreeing and 43.6% agreeing. This suggests that while cultural interpretations of astronomy hold appeal, they may be more niche compared to other activities. Nonetheless, these traditions present an opportunity to create unique and authentic experiences that differentiate destinations. The findings highlight the potential for astrotourism to cater to diverse interests, from passive observation and cultural storytelling to active engagement through education and creative pursuits. These preferences underline the importance of designing tailored astrotourism packages that integrate both scientific and cultural elements, ensuring broad appeal and deeper visitor satisfaction. By addressing these interests, tourism operators can unlock the full potential of this emerging niche market.

The popularity of these activities can be attributed to their immersive and memorable nature. Astronomy tourism is a niche form of experiential tourism that satisfies the demand for meaningful, multisensory, and intellectually stimulating experiences. This aligns with Experiential Consumption Theory (Holbrook & Hirschman, 1982), which posits that consumers derive satisfaction from activities engaging their senses, emotions, and intellect. The high value placed on storytelling and astrophotography highlights the importance of personal connection and memory creation in tourism experiences.

Astrotourism Value Chain Contributions

Table 4 examines the value chain contributions of astrotourism, focusing on its impact on local economies, tourism product expansion, environmental awareness, and scientific education.

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Table 4: Astrotourism Value Chain Contributions

Item	Description	Strongly Disagree	Disagree	Agree	Strongly Agree
E1	Astrotourism creates local employment opportunities and generates income for local communities	0%	0.9%	47.9%	51.3%
E2	Astrotourism can contributes to national revenue	0%	0%	46.2%	53.8%
E3	Astrotourism can be packaged as an ecotourism product	0%	2.6%	43.6%	53.8%
E4	Tourism operators can expand existing products by offering astrotourism	0%	0%	47%	53.0%
E5	Astrotourism has the potential to be popularized in the current tourism industry	0%	0%	49.6%	50.4%
E6	Astrotourism has the potential to enhance domestic and international tourist numbers	0%	0%	48.7%	51.3%
E7	Astrotourism enhances awareness and education in science and technology	0%	0%	40.2%	59.8%
E8	Astrotourism incorporates educational elements through the concepts of conservation and environmental awareness	0%	2.6%	43.6%	53.8%
E9	Astrotourism raises awareness about the importance of protecting the environment from excessive development	0%	1.7%	42.7%	55.6%
E10	Astrotourism incorporates learning based on history and sharing about local cultural heritage	1.7%	8.5%	44.4%	45.3%
E11	Astrotourism introduces the local community's beliefs related to the sky	0.9%	2.6%	49.6%	47.0%
E12	Astrotourism can provide peace of mind	0%	0.9%	47%	52.1%
E13	Astrotourism can relax the mind	0%	0.9%	47%	52.1%
E14	Astrotourism can remind us of the greatness of God	0%	0%	23.9%	76.1%

The findings highlight astronomy tourism's significant economic, educational, and spiritual contributions. Respondents overwhelmingly agreed that it creates local employment (99.1%, E1), generates income (99.1%, E2), and boosts national revenue (99.1%, E2), while increasing tourist numbers (94%, E6).

It also raises awareness of science (99.8%, E7) and promotes environmental conservation (97.4%, E8). Spiritual benefits were emphasized, with 100% (E14) agreeing it inspires awe and reminds individuals of a higher power. These findings suggest astronomy tourism appeals to diverse motivations, blending tangible economic benefits with intangible educational and spiritual experiences. The economic potential aligns with Porter (1985) Value Chain Theory, which emphasizes the role of niche markets in driving community-level development. Similarly, the spiritual and educational dimensions connect to Positive Psychology (Seligman, 2002), as astronomy tourism fosters mindfulness, environmental stewardship, and personal growth.

Interpretation of Findings

The descriptive results across the four dimensions—interest and inclination toward astronomy, awareness of astrotourism, preferences for core activities, and value chain contributions—collectively present a paradoxical yet promising scenario for astrotourism development. Respondents expressed very high levels of interest in astronomy (92.3%, BA1) and in activities such as celestial observations, astrophotography, and educational learning (CB items). However, participation in structured programs or courses remains limited (13.7%, BA5; 23.1%, BB2). This reflects Ajzen (1991) Theory of Planned Behavior's "intention–action gap," whereby motivational interest does not consistently translate into actual behavior due to external constraints such as access, time, and cost.

This finding mirrors broader insights in astrotourism research, where Weaver (2011) and Soleimani et al. (2019) emphasized that while celestial events (eclipses, meteor showers) generate strong curiosity, actual participation is often constrained by inadequate awareness campaigns (Collison & Poe, 2013), weak infrastructure in rural areas (Jacobs et al., 2020), and limited program availability. Thus, the present results reinforce that Malaysia's astrotourism is still at an early stage of diffusion (Rogers, 2003), with untapped demand that requires systemic interventions.

A second critical insight is the multidimensionality of motivations. Respondents valued astrotourism for its educational (99.8% agreed on science awareness, E7), cultural (learning traditions and beliefs, E10–E11), recreational (relaxation and peace of mind, E12–E13), and spiritual (reminder of God's greatness, E14) contributions. This holistic profile resonates with Jacobs et al. (2020) and Rodrigues et al. (2023), who highlight how astrotourism merges recreational, cultural, and scientific interests while promoting heritage and environmental conservation. The combination of astrophotography, storytelling, and celestial observation also reflects the experiential nature of astrotourism, aligning with Holbrook and Hirschman's (1982) Experiential Consumption

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Theory. Such activities are multisensory, memorable, and meaning-laden, meeting the demand for deeper, transformative tourism experiences.

The results further underline the latent demand–limited engagement paradox. While 88% of respondents expressed willingness to join astrotourism packages (BB3), only a minority had prior exposure. This pattern is consistent with global studies showing that awareness campaigns and visitor education are critical for converting potential interest into real participation (Collison & Poe, 2013; Mitchell et al., 2019). For example, the success of Portugal's Alqueva Dark Sky Reserve demonstrates how strategic infrastructure and effective marketing can bridge this gap (Rodrigues et al., 2015).

From an economic perspective, respondents' recognition of astrotourism's potential to generate employment, diversify tourism products, and support community livelihoods (Azwar et al., 2023) (E1–E6) directly connects to Porter's (1985) Value Chain Theory. Previous work by Pašková et al. (2021) also showed how dark sky tourism initiatives empower rural communities while conserving cultural heritage. Importantly, the spiritual dimension observed here (E14) is less discussed in mainstream literature, suggesting that in Malaysia and other Muslim-majority contexts, astrotourism can uniquely intersect with faith-based tourism by fostering reflection on creation and divine majesty. This offers a culturally distinctive niche within the global astrotourism market.

STUDY IMPLICATIONS

This study contributes to the Theory of Planned Behavior (Ajzen, 1991) by highlighting the gap between interest and actual participation in astronomy tourism, revealing significant barriers limiting perceived behavioral control. Future research could expand the TPB framework by incorporating variables like accessibility, infrastructure, and awareness, enabling a more comprehensive understanding of how interest translates into behavior. The study also aligns with Rogers' (2003) Diffusion of Innovation Theory, positioning astrotourism in its early stages. Although early adopters are engaged, broader adoption is hindered by gaps in infrastructure and awareness. Expanding the application of Diffusion of Innovation Theory to niche tourism markets could provide strategies for accelerating adoption. Findings support Holbrook and Hirschman's (1982) Experiential Consumption Theory, demonstrating that astrotourism engages tourists' sensory, emotional, and intellectual faculties. Future theoretical models could integrate the multisensory dimensions of such experiences, emphasising storytelling as a tool for fostering long-term engagement. Lastly, the study supports Porter (1985) Value Chain Theory, illustrating how astrotourism adds value through local economic contributions, education, and cultural preservation, suggesting that value chain frameworks should also incorporate intangible benefits like educational and spiritual enrichment.

The findings emphasize the need for targeted awareness campaigns. Tourism boards and operators should utilize digital platforms and collaborate with influencers or astronomy clubs to enhance engagement with astronomy tourism. Policymakers could partner with educational institutions to align tourism with astronomy education. Infrastructure improvements are essential, particularly in remote areas. Investments in transport, accommodations, and facilities should prioritize accessibility and comfort, especially in rural dark-sky regions. Storytelling and astrophotography should be central to experiential tourism packages, with the integration of VR/AR tools for virtual experiences. Lastly, community-based approaches can foster authentic, sustainable tourism (Azwar et al., 2023). Local entrepreneurs, artisans, and guides should be incorporated into tourism programs, with governments offering capacity-building initiatives to ensure sustainable development aligned with local traditions.

Astrotourism in Malaysia presents significant potential but faces barriers such as limited public awareness, inadequate infrastructure in prime stargazing locations, and accessibility challenges in remote areas. Addressing these requires tailored, sustainable strategies. One primary barrier is the lack of public awareness, which can be mitigated through targeted campaigns and collaborations with schools, universities, and astronomy clubs. Public stargazing events that combine education and recreation can attract diverse participants, while digital platforms like augmented reality (AR) can simulate celestial phenomena, sparking interest among tech-savvy travellers.

Infrastructure development in rural areas, such as Kota Belud in Sabah and Mersing in Johor, is crucial. Establishing eco-friendly accommodations with observation decks and improving transport access, including shuttle services from urban centers, will enhance the visitor experience. Sustainable strategies should prioritize community involvement, with local guides and storytellers integrating cultural narratives with astronomy. Microfinancing can empower local entrepreneurs to create astronomy-themed businesses, supporting economic development. Policy advocacy and international collaborations are key. Implementing stricter light pollution regulations and partnering with the astronomy-related association to certify dark-sky reserves will enhance Malaysia's global astrotourism appeal. Integrating astrotourism with other niche markets, such as eco-tourism and cultural tourism, can attract diverse travellers seeking multidimensional experiences.

CONCLUSION

This study reveals that astronomy tourism holds significant potential as a niche tourism market, with strong interest but limited participation among respondents. The key findings highlight that while many individuals are fascinated by astronomy and desire to engage in astronomy tourism activities, factors such as

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limited awareness, accessibility, and the availability of programs hinder their active participation. Furthermore, astronomy tourism's educational and spiritual aspects were valued highly, with activities like stargazing, celestial phenomena observation, and astrophotography regarded as central attractions. The perceived economic benefits, such as local job creation and revenue generation, further underscore astronomy tourism's multidimensional value, contributing to economic development, environmental education, and spiritual enrichment.

This study, while offering valuable insights into astronomy tourism, is subject to several limitations. First, the use of non-probabilistic sampling restricts the generalizability of the findings. Although purposive sampling ensured relevance, the absence of a representative sampling frame limits the applicability of results to broader populations. Second, the study's cross-sectional design captures data at a single point, preventing the analysis of changes in tourist behaviors and perceptions over time. Longitudinal studies could provide a deeper understanding of evolving trends. Third, the reliance on self-reported data introduces potential biases, such as social desirability or recall bias, which may affect the accuracy of responses. Fourth, the study focuses solely on Malaysian astrotourists, potentially overlooking global cultural and regional differences that influence astrotourism. Future research could address these limitations by employing larger, representative samples, longitudinal designs, and cross-cultural comparisons to enhance the robustness of the findings.

Given the promising findings, future research should focus on exploring the barriers to participation in greater depth, such as the role of infrastructure development, targeted marketing strategies, and the impact of technological advancements in enhancing the accessibility of astronomy tourism. Additionally, more research is needed to investigate the long-term impacts of astronomy tourism on local communities, both economically and socially. Future studies could also explore how integrating astronomy tourism with other niche markets, such as ecotourism or wellness tourism, could further expand its appeal and sustainability. By addressing these areas, future research can provide deeper insights into how to foster growth in this burgeoning sector, ensuring its viability and success in the tourism industry.

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ETHICAL STATEMENT

According to the policy of Universiti Kebangsaan malaysia, ethical approval was not required for this study as it minimal risk. Nevertheless, informed consent was obtained from all participants prior to their inclusion in the study.

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PERSPECTIVE ON MODERN HERITAGE: IDENTIFICATION AND COMPARATIVE ASSESSMENT FOR THE HERITAGE VALUES OF THE LARGE HOUSING ESTATES OF ORAN 1950-1962, ALGERIA

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Abstract

Until now, no research has been carried out on how to develop criteria for assessing the heritage values of the built legacy that is the large housing estates, with the aim of launching reflections on heritage production. The aim of this document is to identify and assess the value of the architecture of large housing estates with a view to proposing its possible preservation. The article makes a comparative assessment of four large housing estates located in the city of Oran, chosen on the basis of relevant factors relating to the architect's fame, varied urban form and amalgamated destination between large housing estates for Muslims and large housing estates for Europeans. The study was based on the fusion of two empirical methods, qualitative and quantitative, also known as the mixed method (MMR). The first was based on semi-directive interviews, which offered the opportunity to identify new criteria in the field, and the second on 200 questionnaires distributed to two samples of the population, residents and professionals, whose data was analysed using Atlas.Ti software. The research also began with a review of the relevant literature to take stock of the values attributed to modern architecture included on the UNESCO World Heritage List and the Docomomo criteria. Finally, the results of this comparative study reveal that the values vary from one case to another according to the degree of the criteria, some of which are relevant in relation to others. This can trigger the choice of contextually relevant criteria which directly affect the score of each large ensemble and influence the heritage approach, since the criteria explored constitute important reference points in relation to the heritage production of domestic architecture in the second half of the twentieth century in Algeria.

Keywords: large housing estates, heritage values, assessment criteria, stakeholders, inhabitants, Oran (Algeria)

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INTRODUCTION

This is a spatial and social formation of urban forms built in the suburbs bordering Oran, constituting urban extension zones, as well as some implanted in the city center. These constructions developed significantly in the 1950s (Rezgui et al, 2020), a period marked by their establishment as symbols of modernity. Their current location lies at the very heart of the city of Oran, due to the city's constant eastward expansion. Some were built on the edge of the old city center or in nearby suburbs (Filali et al, 2023). Within a discourse of valorization and real estate classification, the large housing estates of the 1950s considered as modern colonial architectural heritage have been stigmatized, marginalized, and even forgotten in heritage practices. However, initiatives aiming to reveal their hidden beauty through rehabilitation, maintenance, as well as exhibitions and vernissages, are beginning to emerge. These gestures, however, remain timid due to a lack of awareness of this shared heritage (Volait, 2005). This heritage reflects the transition from an insalubrious way of life to a revolutionary one, transferred from the metropolis to the colony. It stands as an inescapable testimony to an architectural history that forms part of a broader chain of production, dating from 1831 with the arrival of the French in Oran, until their departure in 1962.

The backbone of this research consists in the contribution of a new approach to heritage evaluation, a model evaluation grid is proposed which goes beyond certain current values by emphasising the distinctive criteria for access to the heritage of this modern architectural heritage which requires recognition of the diversity of elements which will allow the identification of values (González Martínez,2023) for this reason three major series of questions on the future of large housing estates have been raised, on what relevant criteria can or should the heritage of large housing estates be based? What constitutes heritage in large housing estates? Are there any housing estates in Oran that require heritage protection? The hypothesis is that heritage value is assessed on the basis of the Criteria, which are a model that is constantly evolving over time as societies change (Carabelli et al., 2022), modelled according to the specific context that is different and varied in every country in the world, which is why the question of the heritage value of social housing is made possible by changing the heritage logic (Hadbi, 2020), and their effectiveness must be defined by a scientific method. This is precisely what this research sets out to do.

LITERATURE REVIEW

Modern heritage values

The expansion of the heritage concept has fostered extensive debate on the notion of value, now seen as central to conservation (Davallon, 2006; Polious, 2014). Value is approached as dynamic (Laurent, 2003), multidimensional economic, aesthetic, and ethical (Bos et al., 2023) and linked to criteria that determine

conservation (Salvo et al., 2018). Rooted in Riegl's seminal work (1902), value theory identifies monuments through a system of historical, contemporary, commemorative, use, artistic, and age-related values (Harrer, 2017). This original typology has continued its course to be revisited and even remodelled according to well-defined requirements by the various expert researchers, having compared different variables, a selection of sets of typologies of values linked to the built heritage has been summarised in the development of an explanatory table in the research carried out by Fredheim & Khalaf(2016) , this updating of values cannot be complete or lasting but rather perpetual in mutation over time and according to societies. It is impossible to draw up a set of complete and universally applicable typologies of values (Rudolff, 2006) because several elements come into play in the elaboration of a typology of value, despite several aspects such as the type of heritage object (habitat or building, monument), the context in which it is paid for, the nature of the actors (expert or non-expert (citizens, inhabitants).

The efficiency of DOCOMOMO AND UNESCO

Similarly, DOCOMOMO establishes classification criteria that are linked to innovation and to the cultural, social and economic changes that have altered the built environment of the twentieth century. Since 1999, DOCOMOMO has been working in collaboration with the UNESCO World Heritage Centre to establish criteria for selecting twentieth-century sites in order to guarantee their protection, and its capacity to evolve (Tiry-Ono et al., 2023) a distinct model of built heritage that emerged at the time of the modern movement, namely the large 'social heritage' ensembles, to which various researchers have contributed in order to identify values with a view to its inclusion on the heritage list , According to Gyurkovich(2021) , the large Polish estates resulting from the modern movement often present high urbanistic and architectural values and are currently the subject of revitalisation measures, in addition this specimen derived from the modern movement immerses a work of modelling value (Heinich,2017) , all depending on several factors, that said could not be defined outside any geographical, social, historical context (Courbebaisse et al., 2022).

Heritage Values of Large Housing Estates

Highlighting a body of work whose objectives are linked to the question of the heritage values of large housing estates, each researcher focusing on one or two values for the evaluation of large housing estates as much as heritage, this field so fragile and complex at the same time which has become a laboratory for a new way of thinking (Reichen, 2000), this research engine must not be limited to a few current architectural, aesthetic or historical values (Amougou, 2007). With the rehabilitation method for the Ancely housing estate in Toulouse, France, where the value of use is analysed as a potential approach in order to enhance

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practices, perceptions and appropriations as a strategy for understanding a changing space (Issot, 2023), among other things, the historical value of housing estates in Algeria is a radical break with rural architectural style, as for the artistic value, which refers to the topical value theorised by Riegl, which lies in a modernity that does not free itself from the local and from history(Smair, 2019) Notably (Tapie, 2014) other 'quality' values linked to large housing estates are introduced, namely spatial, urban, proximity and, finally, reputational value. That said, the values shared by the various researchers are no more than personal experiences in order to identify and determine an object to be given heritage status (Carabelli, 2022). This has made it possible to classify cold values into two categories, where the information is objective and the results are therefore the same for a specific case study, such as urban and architectural value, whereas warm value is approached in different ways by researchers, with divergent results, such as use value, which is based on the experience and stories of residents of large housing estates, expressed in terms of the degree of attachment to places, i.e. the contribution of residents to shaping their living environment, as seen in (Table 1).

Table 1: Modelling a typology of hot/cold values for large housing estates.

Cold heritage values	Warm heritage Values
1. historical	**6. Use**
2. Urban	**7. Memory**
3. Architectural	**8. Artistic**
4. Reputational	**9. Aesthetic**
5. Proximity	

Authors elaborated with information from Literature review.

RESEARCH METHODOLOGY

This study sought to define criteria for evaluating the 1950s large housing estates in Oran, key elements of twentieth-century urban structure (Gyurkovich, 2021). Using a mixed-methods approach (Shwani, 2021), qualitative data were gathered through ethno-architectural analysis, interviews (Robert, 2023), and photographs (Pinson, 2016), complemented by field investigations to test hypotheses (Baribeau, 2005). Interviews with institutional and professional actors in heritage and housing provided essential insights, supported by clarifying questions (Angers, 1996).

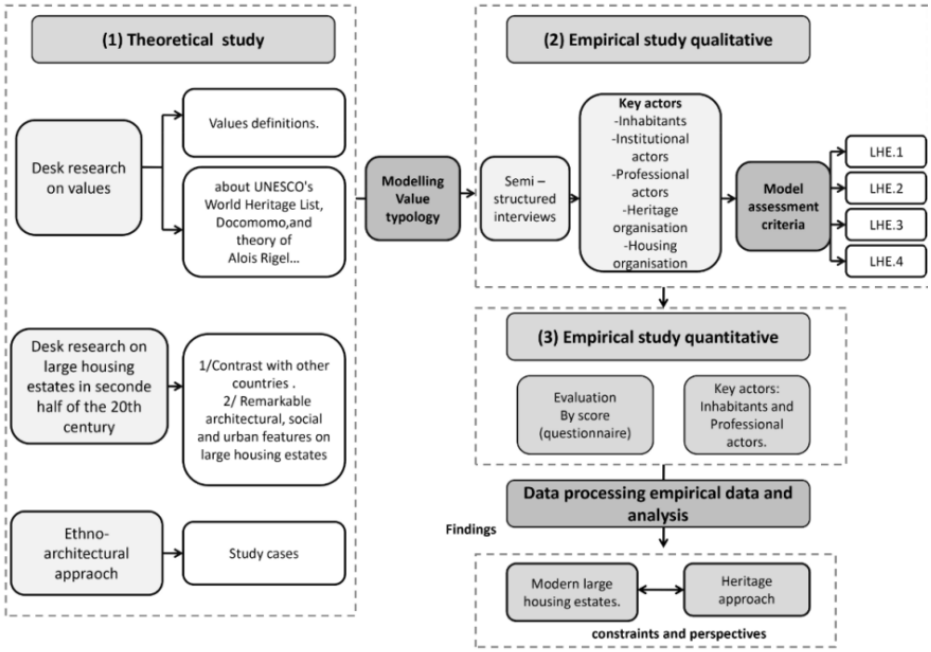


Figure 1: Research Diagram

Heritage values were assessed through a mixed-method approach. Semi-structured interviews helped refine criteria based on stakeholder input, while questionnaires with two population samples assigned scores to each predefined criterion (Table 2). On-site observations further validated the findings by highlighting consistencies and discrepancies between reported and observed data (Elizondo, 2024).

Table 2: Participants interviewed from large housing estates study cases in Oran

Interviewees group	Number of Interviewees stage one	Number of Interviewees stage two
Focus groupe « inhabitants of each large housing estate »	160=(4x4)	800=(200x4)
Institutional actors (architects teaching at various local and foreign universities, sociologists in the Department of Architecture, and others in the Department of Sociology of Architecture at the CRASC Oran research centre).	20	

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Interviewees group	Number of Interviewees stage one	Number of Interviewees stage two
Professional actors (architects from the Oran Department of Culture and the Arts, civil engineers working for the Construction Technical Control (CTC) body, architects from the Technical Design Office.	25	25
Heritage organisation: heritage associations, environmental protection associations, Bel Horizon, Sid el Houari health association (SDH).	15	
-Housing organization (employees of the administrative subdivision of the housing department of the wilaya of Oran, OPGI, Center for urban studies and planning, Housing Department (DL).	22	
Total	**242**	825

Source: Authors.

STUDY CASES

Oran has a strong identity, reflected in its rich and diverse architectural heritage. These traces of the past contribute to shaping Oran as a modern city. As Camus (1947) noted: "*Oran is, on the contrary, a city without suspicion*", in other words, a completely modern city. The 19th Mediterranean Games, held in 2022, have further established Oran as a place of exchange and encounter. Its public buildings and urban ensembles from earlier periods are generally subject to preservation and classification, with this form of heritage management particularly linked to the continuation of colonial approaches (Aouchal, 2023). This, however, is not the case for housing, particularly the large, unprotected housing estates dating from the 1950s, which by default are all considered "ordinary," even though this extensive corpus represents 20% of the city's collective housing stock (Filali et al., 2023). The large housing estates that were originally located outside the city walls and away from the city center are, relatively speaking, better positioned today, as the city has since expanded. They are generally well connected to the city center by public transport (Figure 2).

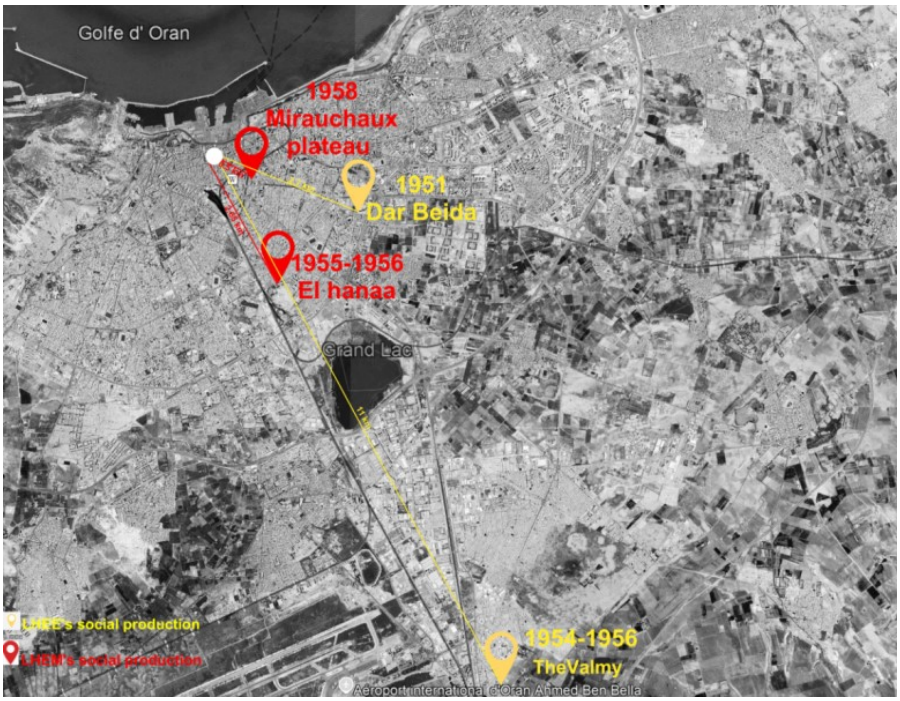


Figure 2: Map of the Oran metropolitan area and selected large housing estates with distance markers between the city centre and the neighbourhoods. Compiled by the Authors from a Google Earth © image.

Apart from two examples originally intended for the families of naval officers, civil servants, and workers from mainland France, the large housing estate of Dar Beida designed by Pierre Jean Guth, Grand Prix de Rome (1951), is exemplary. Comprising 580 units based on the *improved council housing* (*H.L.M. amélioré*) model from metropolitan France, it combined generous living spaces with an ambitious social vision. The north–south orientation of the main façades optimized winter sunlight and summer sea breezes, while the integration of district-scale facilities and public spaces underscored its role as both an architectural and social project (Kefif & Hendel, 2024).

Similarly, the Valmy estate, designed between 1954 and 1956 by Fernand Pouillon, a renowned specialist in social housing. Consisted of 614 dwellings strategically located for climatic advantages and connectivity with Oran. Its broad, open forms embodied the modern principles of urban planning while addressing the pressing demand for social housing. Overall, the housing capacity of LHEE exceeded that of LHEM by 60% highlighting its greater scale and urban significance (Figure 3).

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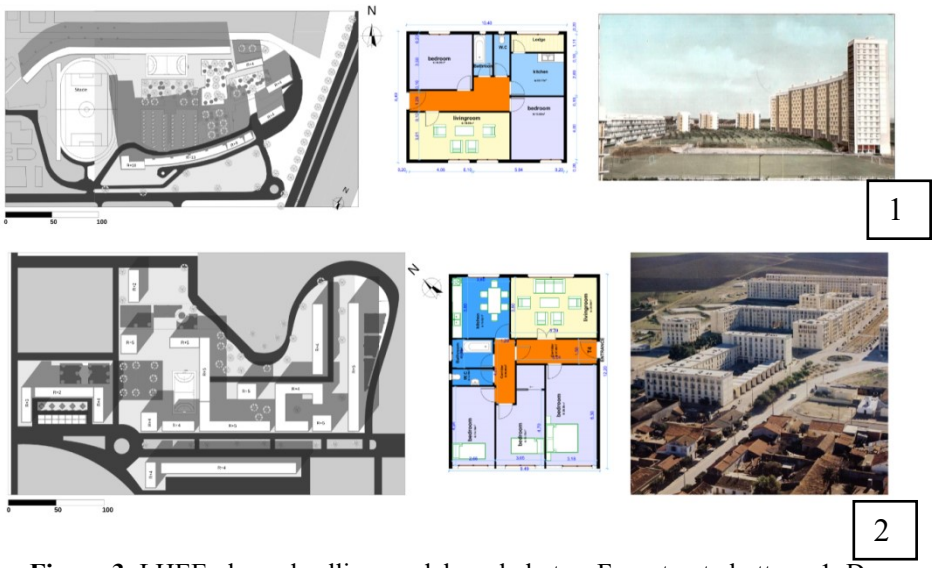


Figure 3: LHEE plans, dwelling models and photos. From top to bottom: 1. Dar Beida1951, 2. The Valmy 1954-1956. Mass lay-out and plans made by the Authors. Photos from Oran archive.

The housing of LHEM, financed by the Algerian Cooperative Society for Muslim Housing, introduced a new approach to modern architecture adapted to Algerian traditions, offering an alternative to the design of conventional traditional houses. The large housing estate of La Quietude (El Hanaa), built by the French architect Justin Marie between 1955 and 1956, relied on standardization and cost-efficiency. It comprised an average of 254 flats organized in four-storey blocks around a central courtyard, though without integrated facilities or essential services. The project offered three housing models arranged in a linear and monotonous layout.

By contrast, the co-owned housing complex on the Mirauchaux plateau, constructed in 1958 during the implementation of the Constantine Plan by Messrs. Mauri, Pons, and the Atbat group (which included architect Georges Candilis), provided 144 units in a variety of housing models. This ensemble was distinguished by a richer architectural vocabulary and greater attention to spatial diversity (Figure 4).

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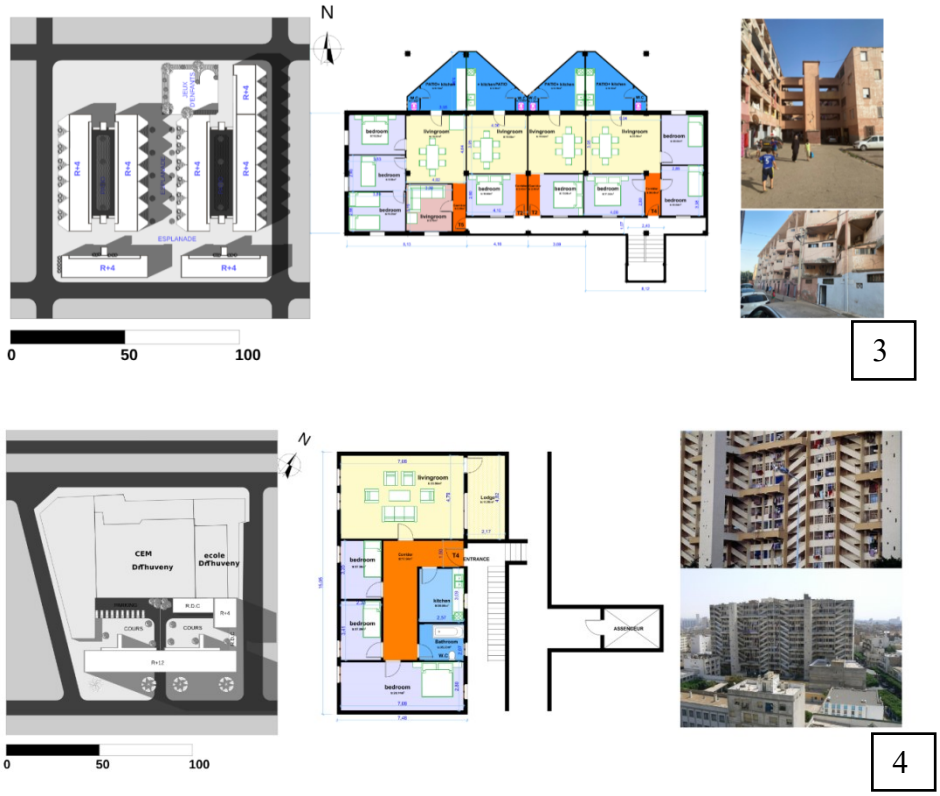


Figure 4: LHEM plans, dwelling models and photos. From top to bottom: 1. El hanaa1955.1956, 2. the Co-owned building on the Mirauchaux plateau 1958. Masse lay-out and photos of houses and plans made by the Authors.

ANALYSIS AND DISCUSSION

Construction of the assessment criteria in the field

Criteria provide an objective basis for assessing heritage values (Brunel, 2015), contributing to the promotion of twentieth-century architectural heritage (Kahrovic Handzic, 2024). For large housing estates, this fragile social heritage requires specific and consistent criteria, as outlined in (**Table 4)**.

The comparative assessment of heritage values

The following table summarizes the comparative assessment of values previously developed. It is composed of a set of criteria identified from a field survey and complemented by a questionnaire distributed to both populations, in order to determine the positioning of each large housing estate within the heritage approach. The results were processed using the Atlas.Ti tool and then transferred

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to Microsoft Excel to generate graphical series, with the objective of outlining the profile of the heritage approach. The first questionnaire, covering 5 out of 9 values, was completed by the inhabitants of each large complex, while the second questionnaire, relating to 4 out of 9 values, was completed by various stakeholders. To evaluate the state of each criterion, we applied our own weighting method to the results processed with Atlas.Ti, producing an overall score expressed in number of responses. We then established five scoring groups, each corresponding to a numerical rating (4, 3, 2, 1, and 0), structured as follows:

- 161 to 200: Exceptional = 4
- 121 to 160: Superior = 3
- 81 to 120: Strong = 2
- 41 to 80: Medium = 1
- 1 to 40: Weak = 0

Finally, all ratings were converted into numerical values (Table 4).

Table 4: Comparative assessment of the heritage values of the large housing estate in the case studies.

	Values **Assessment criteria**	**L.H.E.E 1**	**L.H.E.E 2**	**L.H.E.M 3**	**L.H.E.M 4**
Cold heritage values	**1. Historical value**	**1.66**	**2.66**	**0.33**	**1**
	1.1 Notable personalities.	0	2	0	0
	1.2 Significant events.	2	3	1	3
	1.3 Structure as historical evidence	3	3	0	0
	2. Architectural value	**2.33**	**3.16**	**2.33**	**2.66**
	2.1 Innovative techniques	2	2	4	4
	2.2 Unique materials.	1	3	1	2
	2.3 Renowned designer.	3	4	1	3
	2.4 Adequate lodging capacity.	3	4	1	1
	2.5 Adaptation to local needs	2	3	4	3
	2.6 Rarity & Integrity	3	3	3	3
	3. Urban value	**3.33**	**4.00**	**2.66**	**3.5**
	3.1 Optimum sunlight & Orientation.	3	4	3	3
	3.2 Wind protection. & Natural ventilation.	3	4	3	3.5
	3.3 Influence of architectural culture	4	4	2	4
	4. Proximity value	**2.50**	**2.50**	**3.00**	**2.00**
	4.1 Public facilities availability.	3	2	3	4
	4.2 Ecological/environmental sites	2	3	3	0
	5. Reputational value	**positive**	**positive**	**négative**	**négative**

	Values Assessment criteria	L.H.E.E 1	L.H.E.E 2	L.H.E.M 3	L.H.E.M 4
	5.1 Educated households (rate)	2	3	1	1
	5.2 Crime rate	0	0	2(0.06)	2(0.034)
Warm héritage valus	**6. Use value**	**1.66**	**3**	**2.33**	**3**
	6.1 Shared spaces (identity & security)	3	3	3	4
	6.2 Private units (identity & comfort)	1	4	2	2
	6.3Public facilities (attachment & affection)	1	2	2	3
	7. Memory Value	**2**	**2**	**2**	**2**
	7.1 Degree of ethnicity	0	0	2	2
	7.2 Positive personal representation	4	4	2	2
	8. Artistic value	**2.33**	**2**	**3**	**3.66**
	8.1 Original appearance	3	2	4	4
	8.2 Novel artistic expression	2	2	2	4
	8.3 Meaning interpretation	2	2	3	3
	9. Internal and external aesthetic value	**2.5**	**3.25**	**3**	**3.5**
	9.1 Visual/aural perception & enjoyment	3	2.5	3	4
	9.2 Cognition, creativity & sentiment	2	4	3	3

Source: Authors.

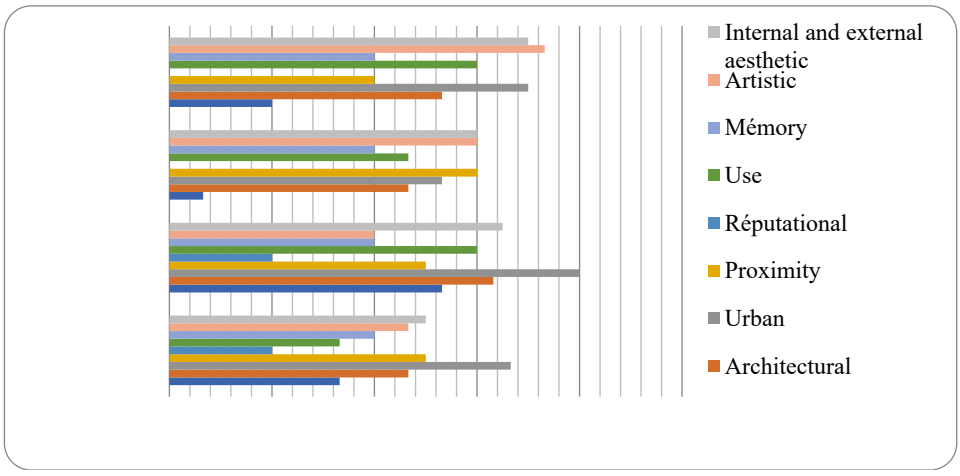


Figure 5: Profile of heritage values attributed to the large groups analysed. Source: Authors.

The evaluation of values revealed a strong connection between the heritage approach and the characteristics of the large housing estates. However, in order to understand the challenges and limitations of this approach, the values

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were assessed using specific criteria applied to the four large housing estates (Figure 6).

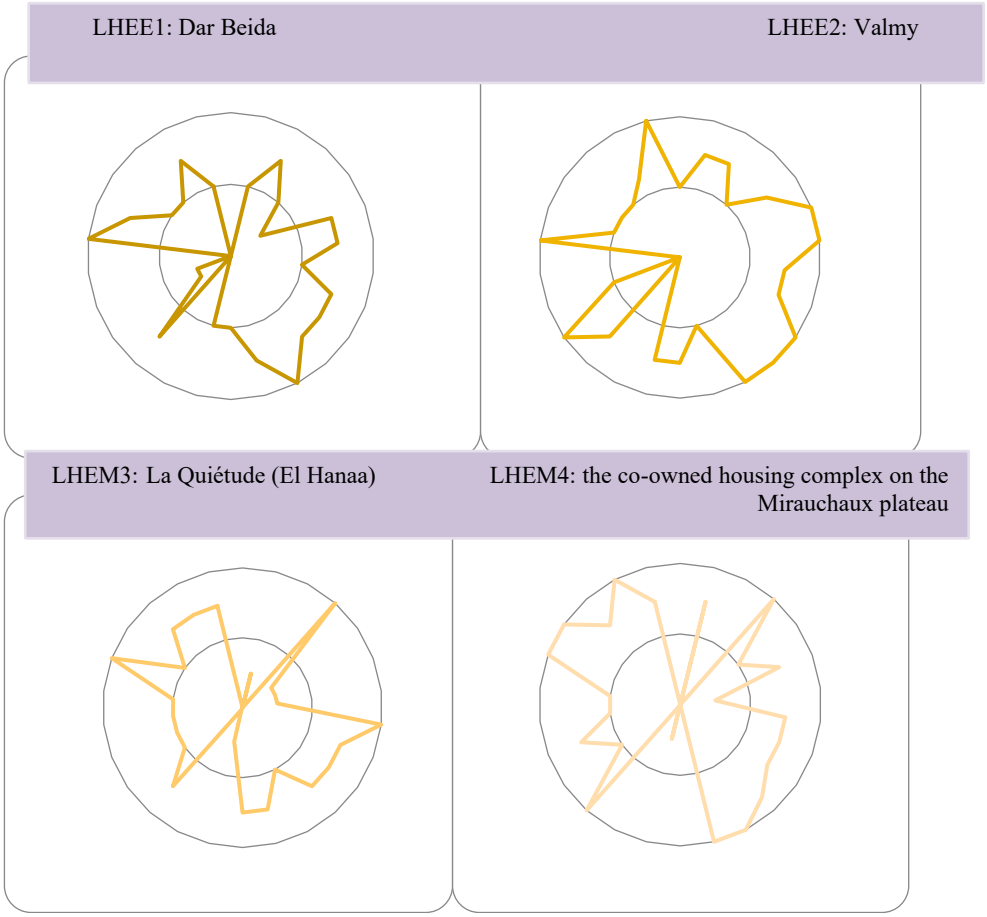


Figure 6: Heritage profiles for each large housing estate. Source: Authors.

Using the MMR methodology (Matović, 2023), the study highlights the Valmy estate and the co-owned housing complex on the Mirauchaux plateau as the most remarkable large housing complexes in Oran (Table 4; Figure 5). Valmy is recognized for its coherent layout, while Mirauchaux stands out as a unique artistic work (score 4), maintaining social identity (score 3) and authenticity through technical solidity and the absence of alterations (Figure 6). Both demonstrate rarity, local adaptation, and historical significance, confirming that heritage values are shaped by context and community expression (Courbebaisse, 2022).

As for the Dar Beida housing estate located near the co-owned building on the Mirauchaux plateau, it has a deficit (figure 6) in terms of the degree of autochthony and characters and idols worthy of remembrance score0 2 Authentic and singular appropriation at the level of the cell and facilities is low score1 and this is due to the perpetual departure and arrival of families given its military status, its curvilinear shape gives a visual pleasure whose two scores are identical by 3 a specificity and a principle that the architect pierre-Jean Guth uses for his projects who is considered to be a renowned architect (score3) (figure 6) its strategic location has favoured its visibility.

On the other hand, La Quietude (El Hanaa) represents a new artistic form (score3) that the architect has combined between the audacity of having a modern form adapted to local requirements (score4) and a remarkable technical demonstration by the individual and collective patio (score4) which has given an architectural rarity in the Oranese landscape (score4) (, figure 6), .However, this large housing estate has a high proportion of uneducated families originating from shantytowns, which has negatively influenced its reputational value and resulted in the absence of memory-related features or cultural activity (score 0). This considerable imbalance has led to behaviors that may harm the estate itself, as well as to its destruction and mismanagement.

CONCLUSION

This study aims to identify and evaluate the heritage values of two dominant forms of housing production that have shaped Oran as a modern city: the large housing estates for Muslims (LHEM) and the large housing estates for Europeans (LHEE), and their relationship with the "sense of place" (Rahil et al., 2020). To achieve this, a mixed-methods approach (MMR) was adopted, considering large housing estates as built heritage in which several key actors intervene, through semi-structured interviews and a questionnaire. The results of the systematic analysis of the state of the art made it possible to identify different strategies for determining heritage values, aligned with the evaluation criteria of the UNESCO World Heritage List and the Docomomo framework. Whether classified as "cold" or "warm," the results highlight that the heritage process functions as a flexible and dynamic approach based on an effective typology of values (Brunel, 2015). Cultural, social, and technical values are appreciated and debated by inhabitants who emerge as the key determinant in the effectiveness of heritage preservation efforts (Ariffin et al., 2023) as well as by other stakeholders. This complementarily helps simplify the complexity of the notion of values by breaking down the criteria and distinguishing architectural objects as remarkable, exceptional, or ordinary. According to the study, certain criteria appear to take precedence, whether tangible or intangible, such as the reputation of the architect, the consideration of local architectural traditions, and the sense of attachment.

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The findings show that heritage values vary from one housing estate to another, depending on their identity, the lived experiences of inhabitants reflected in use and appropriation the creator, and historical context, which all serve as resources with significant implications for their future as heritage in the making. Finally, the results support the attribution of an overall heritage status, given the diversity and richness of the values identified, while also taking into account the historical and social context of the property in question.

ACKNOWLEDGMENT

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AN INVESTIGATION OF STREET AFFORDANCES DURING SCHOOL-HOME JOURNEY IN HIGH-DENSITY NEIGHBORHOOD OF NANCHANG, CHINA

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Abstract

Affordance theory offers an effective approach to exploring how children perceive and engage with their everyday surroundings, providing important perspectives within the field of environmental psychology for research focused on children. This study examines the interaction between children's actions and the built environment through the lens of affordance theory, which emphasizes the direct perception of environmental functions. Using a taxonomy of affordances, the study investigates children's immediate actions (actualized affordances) during their homeward journeys, extending the application of affordance theory to Chinese street environments. Previous research often overlooks children's immediate interactions with their surroundings and fails to capture the dynamic transaction between children and the environment. This study addresses these gaps by examining street affordances in conjunction with children's perceptual responses to highlight the characteristics of street environments in high-density neighborhoods. The results aim to enhance the understanding of how daily landscapes affect children's behavior, which has significant implications for designing child-friendly urban environments.

Keywords: Affordance, School Journey, High-density Neighbourhood, Child-environment Transaction, City of Nanchang

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INTRODUCTION

Globally, more children are growing up in densely urban environments with limited access to nature and fewer opportunities for independent activity (Zhou et al., 2022). Children are naturally drawn to lively places filled with activity, such as streets, sidewalks, and commercial spaces (Guo et al., 2023; Loebach & Gilliland, 2022; No et al., 2023), which supports a variety of activities and interactions. However, many urban informal public spaces today lack functioning features to fail to support children's diversity activities. The term "third environment" refers to informal public spaces that exist on neutral ground and are characterized by openness, accessibility, and inclusivity (Oldenburg, 1997). These are in addition to the home and school, such as the street environment (Carroll et al., 2015). Therefore, the street environment is viewed as a pillar that supports resident interaction and the community's daily social activities (Tang & Long, 2019), particularly for children's daily school journeys. Furthermore, street environments are of great significance to the physical activity of school-age children. School travel and outdoor play serve as a key source of physical activity (PA) for school-age children (Helbich et al., 2016). Chinese children commute between home and school five days a week, and these daily journeys have become important opportunities for play and social interaction (Zacharias et al., 2017). This interaction could alter their perception and experiences of the various social and spatial characteristics of their surroundings.

In China, the urban planning policy places significant emphasis on the physical and mental health of children, recognizing them as a vulnerable group that deserves special attention. Hence, increasing attention has been given to the affordability of the built environment and the quality of public services for children. It includes quality educational and living environments, as well as safe spaces for leisure and recreation. Consequently, many municipal governments in China have incorporated the development of Child-Friendly Cities (CFCs) into their long-term strategic plans, aiming to enhance physical and social environment quality for children (Nan, 2020). Later, the State Council released the China National Program for Child Development (2011–2020), which identified the construction of a child-friendly environment as a key goal. This guidance highlights that the primary goal of building child-friendly cities and environments is to support and enhance children's physical and mental health (Nan, 2020). Nowadays, urban environment development in China has transitioned into a phase focused on renewing and optimizing existing built environments. Thus, Child-friendly neighborhood street environments should be promoted as a means to advance child-friendly cities and support high-quality urban development (Wei et al., 2024). Children constitute a significant demographic group in urban neighborhoods. Consequently, children should be

prioritized in neighborhood development to ensure their needs are fully met and their well-being safeguarded.

Since the 1980s, the concept of child-friendly environments has been explored from children's perspectives; however, much of the research remains limited in scope, particularly in overlooking the Chinese context (Guo et al., 2023). Additionally, research on the built environment and children's school journey is still scant. Hence, this study provides a foundational starting point for defining a child-friendly street environment to support children's independent school journey. Moreover, this study employed site observation, participatory observation, mapping, and drawing methods. Previous studies adopted child-centered methodologies to identify children's activities and play patterns during school commuting (Egli et al., 2020; Michail et al., 2021; Wilson et al., 2019). It is essential to recognize that children have the right to articulate their lived experiences and actively contribute to shaping their sense of place and belonging. This study reveals not only the complex interaction between material environmental factors and social factors in children's home-to-school journey experiences but also how this socio-material environment is engaged with, negotiated, and explored by them. From an ecological perspective, this study views affordances as a bridge between children's school travel behaviors and the concept of child-friendly environments. Consequently, this study is aimed to identify the properties and attributes of street environments. To that end, this study has been formulated to answer two main questions:

(1) What are street affordances within two high-density neighborhoods in Nanchang, China?
(2) What are the support factors for the children school-home journey?

LITERATURE REVIEW

Person–environment Relationship (P-E)

Affordances, as defined as functional properties of environments, offer children opportunities to interact actively with their surroundings (Heft, 1988). In other words, environmental affordances refer to the properties and attributes of a specific environment and are particularly relevant to the design and layout of constructed environments (Young and Cleveland, 2022). It also reveals the needs and preferences of receivers (Kyttä, 2004). The person-environment relationship elucidates how children's immediate performance (i.e., their activities) is afforded by the functionally significant properties of the environment (Kyttä, 2004). In turn, the children's immediate actions also shape the environment. This person-environment relationship is instant and grounded in functional interaction (Kyttä, 2004). Immediate actions and performances occurred during the journey, which actualized affordances in this context. Additionally, Kyttä (2003) proposed

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that the number of actualized affordances was positively correlated with the degree of child-friendliness within the environment (Kyttä, 2003). In other words, the higher availability of these environments indicates more frequent interactions between children and street environments. It reflects the degree of child-friendliness in these environments. Hence, children's play patterns are shaped by collective engagement. This paper identifies the activities, properties, and attributes of street environments that children engage in. Therefore, this study will contribute to the street planning of high-density neighborhoods in China, as well as to the development of child-friendly environments.

Affordances as an Approach in Assessing Child-friendly Environment

The concept of affordances, introduced by Gibson (1979), was intended to explain behavior through the lens of the reciprocal relationship between individuals and their surrounding environment. It is worth noting that affordances are dynamic, changing within the environment as they emerge from individuals' sustained reactions to the possibilities offered by relevant affordances (Gibson, 1966). In other words, environmental affordances offer opportunities and stimuli that encourage specific behaviors and interactions within that environment (Gibson, 1966). Therefore, the ecological psychology approach has been utilized to examine the relationship between children and their environment (Gibson, 1979). In this study, the theory of affordances serves as a primary framework for identifying street affordances and understanding children's play behavior.

Taxonomy of Affordances

Identifying children's actions through the lens of affordances helps researchers understand the reciprocal influence between the environment and children's performance. In this context, the taxonomy of affordances serves as a pillar to support the relationship between children and their environment. It is an important prerequisite for observing children's various activities during their school trips. This taxonomy reveals that environmental features can be characterized functionally based on the activities they enable or facilitate for an individual, adding psychological significance. Heft (1988) categorized the environmental features into ten functional categories: flat, relatively smooth surface; relatively smooth slope; graspable/detached object; attached object; non-rigid, attached object; climbable feature; aperture; shelter; mouldable material; and water. Later, Kyttä (2002) proposed the concept of affordances for sociality, emphasizing the opportunities for social interaction that the environment provides. Then, Yusof (2022) expanded the taxonomy of affordances by introducing categories such as soundable, ignitable, and edible, which reflect the sensory and functional possibilities offered by specific environments (Yusof et

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al., 2022). As Table 1 shows, this study used thirteen functional categories to identify the functional affordances.

Table 1: Functional taxonomy in this study

No	Author	Functional Taxonomy	Affordances
	Heft (1988)	Flat, relatively, smooth surface	Affords: running, walking, jumping, spinning, playing, relaxing
		Relatively smooth slope	Affords: jumping, rolling, throwing
		Shelter	Affords: manipulating, shading, taking, eating
		Attached object	Affords: observing, recognizing, sitting
		Climbable object	Affords: climbing, jumping, passaging
		Non-rigid attached object	Affords: spinning, sitting in, lying on, jumping, playing, holding
		Graspable/ detached object	Affords: giving, feeding, manipulating, collecting,
		Mouldable material	Affords: manipulating, shaping,digging
		Water	Affords: splashing, pouring, watching, fishing
	Yusof (2022)	Soundable	Affords: chirping (mimicking sound of animal)
		Ignitable	Affords: collecting, roasting, lighting up, igniting,
		Edible	Affords: eating, chewing, drinking, tasting
	Kytta (2002)	Affordance for sociality	Affords: talking, eating, greeting, waiting, lying, chasing, buying, chasing, catching

Source: Heft (1988), Kytta (2002), Yusof (2022), Lopes et al., (2018)

RESEARCH METHODOLOGY

The study gathered qualitative data from 80 students enrolled in grades 2 to 5 at two primary schools, following approval from Universiti Sains Malaysia (USM) and the two primary schools. Firstly, primary school teachers utilized existing school records to verify that the home addresses of participating children were situated within the specified residential areas. They capitalized on the pre-existing data gathered during the enrolment process, thereby obviating the necessity for the researcher to access sensitive personal details directly. To meet the ethical standard, I asked the parents and their children to sign the consent forms before observing the children's activities. When taking photos, I ensured that children's faces and other identifiable information would not be included, and I would delete any upon request from the children or their parents. To capture a broad range of home-school journey activities, the study first examined the

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affordances of each target street. Exploring how the physical and social aspects of target street environments influence children's activities. The selection process was guided by factors such as participant availability and the diversity of street environments, ensuring the study's feasibility and validity.

DATA COLLECTION

This study employed a field observation approach to identify the affordances of the street environment for school-to-home journeys. Therefore, the researchers determined the observation periods based on the children's school hours, once a day (after school), with each period lasting 60 minutes (determined by the absence of new activities during these sessions) on sunny days. Then, the participatory observation approach involves engaging directly with participants in group settings while simultaneously observing their behaviors and interactions (Uwamusi and Ajisebiyawo, 2023). In this study, participatory observation was employed to investigate children's perceptual responses in two high-density neighborhoods in Nanchang, China. The researcher accompanied the children on their school-to-home journey, participating in activities such as walking and socializing. The researcher carefully noted their behavior and perceptual responses, paying special attention to any challenges or opportunities they faced. Meanwhile, detailed insights into children's travel and play behaviors, such as school routes, duration, and destinations, were recorded. Data were gathered by accompanying the children on their journeys and capturing pertinent details in real-time using field notes, photographs, and video recordings. This approach facilitated a comprehensive understanding of the children's activity patterns and the environmental influences on their behavior and perception.

Furthermore, go-along interviews with children provide an in-depth understanding of the factors that influence the affordances they perceive in their street environments. In this session, ask children aged 8–11 to describe what they like or dislike about streets, landscapes, and elements. Hence, Researchers explore both the positive and negative behavioral and perceptual responses to the street environments from the children's perspective. Audio recordings were used, with the children's consent, to ensure accuracy and to support detailed analysis later. The go-along interview was intentionally selected because it allowed the researcher to step into an environment familiar to the children, one they had chosen at designated points during their journey (Alexander et al., 2022). This approach offered deep, situationally relevant insights into the children's experiences and their engagements with their environment.

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ANALYSIS AND DISCUSSION

The Affordances of Street Environment

As shown in Table 2, the findings reveal an activity pattern for the children's activities carried out in Case 1 and Case 2. As shown in Table 1, a total of 83 street activities were identified through direct observation. Of these, 79 activities (95%) were observed by researchers in Case 1, while 75 activities (90%) were observed in Case 2. The results indicated a slight variation in the number of activities observed in the two Cases. This finding suggests that the street environments of Case 1 are more child-friendly than those of Case 2. The frequent activities performed in both cases include crossing the road, engaging in commercial activities, cycling, running, and chasing (Figure 1). Meanwhile, activities such as homework, group games, and sports are more commonly found in both cases (Figure 1). Moreover, this study found that children run purposefully to cross the road quickly and safely. This behavior is more common among older children, who can better understand their location, manage time, and select safer and more convenient paths. The study identified the activities that children performed in two cases. Street affordance refers to the features of the street that either encourage or hinder children from engaging in activities. The evaluation of street affordances focused on the actualized affordances in each target street rather than the frequency of children's activities.

Table 2: Total activities performed by children during school journey

Target Site	Number of activities observed by researchers	Total
Case 1: Park Road Neighbourhood	79	95
Case 2: Hu Bin Neighbourhood	75	90
Total activities	**83**	**(100)**

As Figure 2 shows, children also engage in passive activities during the journey, such as observing their surroundings, waiting for friends, or even playing with digital devices while seated in shaded or semi-sheltered spaces (Clark and Uzzell, 2002; Woolley and Lowe, 2013). This finding aligns with Guo et al. (2023), who found that increased commercial area is associated with a greater number of affordances in urban environments. However, this finding contrasts with the conclusion of Michail et al. (2024), who found that children tend to avoid streets with a higher concentration of commercial activities (Michail et al., 2024). Evidence from a 10-year-old boy described, *"I do not like to walk on the left because there are too many people and it is too crowded."* A notable and novel finding was that children engaged in activities near shops and mixed-use spaces, such as areas combining shops and residential buildings, within high-density

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neighborhoods. This behavior in mixed-use neighborhood street spaces has not been previously reported in other studies.



Figure 1: Children crossing the road and running and chasing (left); children cycling and rope skipping (middle); children playing badminton (right)



Figure 2: Children observing and waiting on the benches (left); children playing digital devices on the pavilion (middle); children shopping in the stationery store (right)

Furthermore, as Figure 3 shows, cluttered objects and parked vehicles along the streets impeded the realization of affordances. This finding is consistent with Kyttä (2004), who emphasized that spatial mobility restrictions are associated with decreased actualized affordances (Kyttä, 2004). Apart from these, this study revealed that green elements integrated into the street environment create a supportive environment for a wide range of benefits and opportunities. This environment provides affordances such as running, playing facilities, waiting, observing, eating, and talking. An 8-year-old girl supports this, saying, *"We chase and play with my friends in a small park every day...there are a lot of tree planter boxes and lawn..."*These findings are consistent with those of Ortegon-Sanchez et al. (2022) and Zhang et al. (2024), which suggest that green space along streets has a positive significance in promoting children's play and their health. Moreover, public open spaces can foster a sense of belonging among children by providing familiar and accessible areas where they can play, socialize, and interact with their peers (Young, 2018). Children tend to prefer familiar areas for a sense of safety and security (Rastgo et al., 2024). For instance, as Figure 3 shows, areas like parklet parks, threshold spaces, or vacant spaces. Hence, small parks are effective child-friendly activity spaces in high-density residential areas, especially when they provide areas for supervision and observation (Krishnamurthy and Ataol, 2020).



Figure 3: Cluttered objects and parked vehicles along the sidewalks (left); children playing under guardian's observation from a distance in the threshold spaces (right)

Taxonomy of affordances during home-school journeys

The identified categories of this study are as follows: (1) flat, relatively smooth, (2) relatively smooth slope, (3) graspable and detached objects, (4) Attached objects, (5) non-rigid materials, (6) climbable surfaces, (7) shelter, (8) water, (9) mouldable materials, (10) soundable, (11) ignitable, (12) edible, and (13) affordances for sociality. The study found that each of these categories offers unique opportunities for children's after-school activities, particularly in Chinese high-density neighborhood street environments. The detailed results of the children's activities, categorized by these categories, are presented in Table 3.

Table 3: Taxonomy of affordances in 16 categories of Case 1 and Case 2

	Category	Case 1	Case 2	Total
1.	Flat, relatively rigid, smooth surfaces	17	19	36
2.	Relatively smooth slope	8	16	24
3.	Graspable/detached objects	31	35	66
4.	Attached objects	19	16	35
5.	Non-rigid attached objects	7	5	12
6.	Climbable features	5	5	10
7.	Shelter	11	16	27
8.	Water	2	11	13
9.	Mouldable material	4	7	11
10.	Soundable	3	4	7
11.	Ignitable	3	4	7
12.	Edible	3	4	7
13.	Sociality	21	20	41
	TOTAL	113	142	296

The most prominent category of affordances in both cases was graspable/detached objects, with 31 affordances identified in Case 1 and 35 in Case 2 (see Table 3). This finding demonstrates that graspable objects provided

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the highest number of affordances across both cases. Graspable/detachable objects on the street include plastic bottles, paper, stone, crayons, dogs, cats, chickens, food, disposable tableware, vegetation (i.e., flowers, leaves, branches, seeds, fruits), ball, soil, sand, stones, flyers, exercise books, stationery, toys, and screen devices. For example, students fold paper airplanes from flyers commonly found on the street and compete to see whose airplane can fly the farthest or tear the paper into pieces to create puzzles (n = 3). Additionally, snacks purchased from the grocery store are used to feed animals, such as dogs in supermarkets and cats in fruit stores, or to attract ants to observe their transportation routes. However, the use of graspable objects on the street was restricted by parents, who prohibited their children from picking up items from the ground due to concerns about cleanliness. Moreover, the loose materials of the built environment are more impactful than the loose elements of nature due to their versatility and relevance to the activities that occur in urban spaces (Herrington et al., 2022). Loose materials in the built environment, such as movable street furniture, construction debris, or everyday objects like cans or balls, often offer a wider range of affordances. They can be grasped, thrown, rearranged, or repurposed for creative play, sports, or informal construction activities. These materials are typically more accessible and varied in their functionality, directly aligning with the types of interactions that occur in the street environment. For instance, it affords seven affordances, namely, throwing, kicking, storing, digging a tool, building, shaking, and serving as a sword to fight.

Meanwhile, loose elements of nature, such as leaves, branches, or pebbles, while still interactive, tend to have more opportunities for younger children. For example, tree branches afforded seven affordances, namely digging, burning, writing, building something, and using them as weapons to fight. However, natural elements and available space on the street are often limited, which can constrain the actualized affordances in urban environments where activities such as running, cycling, and social play dominate. In parallel to Guo et al. (2023), the number of affordances was linked to the functional richness and the presence of activity opportunities in China (Guo et al., 2023).

Following this was the second-highest category, social affordances, where both Case 1 and Case 2 provided an almost equal number of affordances. Specifically, Case 1 offers 21 affordances, and Case 2 offers 20. Public open spaces are universally accessible environments that function as shared domains (Hantono et al., 2018), such as pocket parks and vacant areas, which also provide more social opportunities for street use (Chaudhury et al., 2019). These environments enabled a wide range of peer interactions, including talking, teasing, mocking, waiting for adults, doing homework, playing rule-based games, and engaging in commercial activity. For instance, in the “Thief Don’tDon’t Move” game, a child assumes the role of a policeman and stands at the front.

When the policeman shouts, "Thief, do not Move," and abruptly turns around, any child who moves must quit the game, continuing until only the last thief and the policeman remain. Children's engagement in pretend play and games with rules indicates their active participation in social environment opportunities. The results parallel those of Madondo and Tsikira (2022), which show that social affordances enhance children's social skills and language competence through engagement in cooperative play, group games, and the negotiation of game rules (Madondo and Tsikira, 2022).

As Table 3 shows, the category of flat, relatively rigid, smooth surfaces provides the third most affordances. This category included sidewalks, green strips, open paved areas, and mezzanine-level spaces. Based on observation, a total of 19 affordances in Case 2, whereas Case 1 provided 17 affordances. These surfaces are fundamental to children's daily school journeys, as they support essential modes of movement such as walking, running, cycling, jumping, and skipping. In parallel with Zamani's (2017) study, hard-surfaced and coherent paths were closely associated with physical play, as they provide suitable conditions for activities such as cycling, running, and walking (Zamani, 2017). A 10-year-old girl commented, "I like to be in here because of the beautiful, colored pavement..." These underscore the significance of coherence and aesthetic qualities in shaping children's play preferences and emotional responses to street environments. This finding aligns with previous research highlighting the role of surface texture and visual appeal in enhancing children's engagement with outdoor environments (Aminpour and Bishop, 2021; Loebach and Cox, 2022). Coherent sidewalks improved the walkability of neighborhood street environments (Wei et al., 2021).

CONCLUSION

The study findings effectively respond to the research question by highlighting the pivotal role of the home-to-school journey in influencing children's travel and play behaviors within dense street settings. Activities such as running and chasing, engaging in commercial activities, and playing group games showcase a diverse range of skills and experiences. These activities not only contribute to children's physical, social, and cognitive development but also reflect distinct play patterns shaped by their behaviors in the street environments. The results highlight the importance of the school-to-home journey as a crucial arena for children to showcase and develop their abilities through interactions with their environment. This research also carries several tangible implications for urban planners and policymakers. This study underscores the importance of coherent sidewalks, accessible open spaces near the street, and well-integrated natural and design elements. Recognizing the influence of environmental design on children's experiences enables urban planners to develop street environments that

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prioritize children's health, well-being, and activities, thereby fostering their independence and self-confidence.

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ETTHICAL STATEMENT
This study received ethical approval from the Human Research Ethics Committee of Universiti Sains Malaysia (USM) under protocol number USM/JEPeM/PP/24060503. Informed consent was obtained from all participants and their legal guardians prior to the commencement of data collection.

CONFLICT OF INTEREST
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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EVALUATION OF SATISFACTION LEVEL TOWARDS URBAN PARKS PHYSICAL ATTRIBUTES IN TAMAN AMAN PARK, PETALING JAYA, SELANGOR, MALAYSIA

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Abstract

Urbanization causes people to experience mental health issues, but urban parks can help alleviate stress levels. Parks should have diverse physical attributes and greenery to support health, aesthetics, and ecology. Thus, evaluating user satisfaction levels is crucial to ensure that urban parks' physical attributes meet expectations and needs. A study was conducted to evaluate user satisfaction levels towards the performance and importance of Taman Aman Park's physical attributes. Using a qualitative descriptive approach, data were collected from 86 respondents obtained through the accidental sampling method. The variables used in this study cover aspects of accessibility, facilities, amenities, safety, and natural features. The collected data is analysed through Importance-performance analysis (IPA) to evaluate the level of importance and performance of 19 park physical attributes. The study result indicates that most respondents interpret the park's physical attributes in Taman Aman Park as being at a "fair" level. Subsequently, the IPA quadrant results are used to determine the priority of improving the park's physical attributes. The IPA analysis revealed that 9 park physical attributes are considered important and perform well, while 4 attributes are deemed important but have low performance and require improvement.

Keywords: Satisfaction Level, Urban Park, Physical Attributes, Importance-Performance Analysis (IPA)

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INTRODUCTION

By 2045, the world's urban population is projected to reach 6 billion, representing a 1.5-fold increase from the previous levels. In Malaysia, urbanization has risen from 36.8% in 1974 to 78.7% in 2023, growing at an average annual rate of 1.57%. However, rapid urbanization and increased population density have led to congestion, pollution, crime, and poor housing conditions, which can negatively influence people's mental and physical health (Mohd Shobri et al., 2021). Most employed urban residents face high stress due to workloads and long working hours (Hibrahim, 2021). Consequently, a healthy urban environment is crucial for their well-being. Numerous studies have shown that urban green spaces, notably parks, confer a range of mental health benefits. Park spaces can mitigate stress levels, improve physical health, alleviate anxiety and depression, provide restorative experiences, and foster social interactions (Mohd Shobri et al., 2021). Knowing Park users' satisfaction is a significant indicator of whether an urban park can meet community expectations and function as a safe and enjoyable public space.

Taman Aman Park is a notable recreational facility in Petaling Jaya City. The park provides various facilities for users' recreational activities, including social interaction, study and play areas, and promotes ecological balance. However, the functionality of the park is currently beset by various physical attribute damage that compromises the user experience and reduces the park's appeal as a comfortable and safe recreational space. Such damage includes damaged pathways, unsafe play facilities, inadequate lighting, and neglected landscaping. Therefore, it is important to conduct a study to evaluate the level of user satisfaction towards the park's physical attributes provided in Taman Aman Park based on their performance and importance. The objectives of the study are: i) to determine which attributes are deemed important and performance by users, and ii) to identify the park's physical attributes that necessitate prioritization for improvement. The findings of this study are expected to provide a valuable reference for future studies of the local authorities responsible for developing urban parks.

LITERATURE REVIEW

An urban park constitutes a green open space within a metropolitan area that functions as a green lung and helps break the concrete jungle monotony. They are equipped with physical attributes such as walking paths, benches, playgrounds, and sports fields to cater to both the active and passive recreational needs of urban residents (Melanira & Rudianto, 2023). The parks are classified into five categories: national parks, regional parks, town or local parks, neighborhood parks, and children's playgrounds. The physical attributes of a park are the most

important pillar in ensuring the park remains vibrant and active for users, encouraging them to revisit the park. Research has identified four main physical attributes that should be considered when designing and developing a park to create an inclusive, safe, and enjoyable environment for all park users. These attributes are accessibility, safety, natural features, amenities, and facilities:

Accessibility: Urban parks should be easily accessible, with locations near major roads and parking areas. It encourages people of all ages and abilities to visit the park. The park should be visible from afar or near and well-connected to its surrounding areas. To achieve this, accessible parking, paths, bike lanes, ramps, and entrances are necessary (Fatiah et al, 2021; Abd Majid et al., 2023).

Safety: Fear and insecurity can discourage visitors from enjoying even the most well-designed urban parks. By prioritizing safety features, urban parks can create a safe environment and promote the use and enjoyment of green spaces (Nada & Ischak, 2022). Attributes related to safety include adequate lighting at nighttime hours, fencing, signage, paths, surveillance cameras, and security personnel.

Amenities and facilities: Refers to any man-made structure explicitly designed to cater to the diverse needs of users, both active and passive. The amenities and facilities include picnic areas, playgrounds, sports fields, courts, fitness equipment, trails or walkways, seating, shelters, waste receptacles, drinking fountains, restrooms, food stalls, and parking. Wi-Fi and free internet access are increasingly important as they allow visitors to stay connected while enjoying outdoor spaces (Abd Majid et al., 2023).

Natural features: The presence of natural elements can enhance aesthetic appeal and comfort, provide opportunities for people to appreciate nature and observe wildlife (Nada & Ischak, 2022). These natural elements encompass green spaces, trees, shrubs, flowers, water features, and wildlife habitats.

The four main attributes of accessibility, amenities and facilities, safety, and natural features must meet the satisfaction of park users (Fatiah et al, 2021). Their satisfaction can help to improve the quality of urban parks. The Importance Performance Analysis (IPA) method is an effective instrument for evaluating a park's physical attributes' importance and performance (Alamri & İnceoglu, 2021). Involving Park users in development and decision-making fosters a sense of ownership and pride through their contributions.

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RESEARCH METHODOLOGY

Study Area

The location studied is Taman Aman Park in Section 22, Petaling Jaya district in Selangor (Figure 1). Astronomically, Taman Aman Park is located at coordinates 3°6'10.2564"N and 101°37'31.9872"E, spanning an area between 2 and 7.9 hectares. The park is managed by the Petaling Jaya City Council (PJCC) and has a history of being a disused tin-mining pool-turned recreational lake for the public's enjoyment. The park's characteristic is a recreational park surrounded by housing, schools, and commercial areas, providing recreational activities, sports, and social activities for all ages. Taman Aman Park offers various facilities to park users, including seating areas, playgrounds, jogging tracks, walking trails, courts, and a reflexology path. Landscape features include mature trees, a lake, benches, and shaded structures.

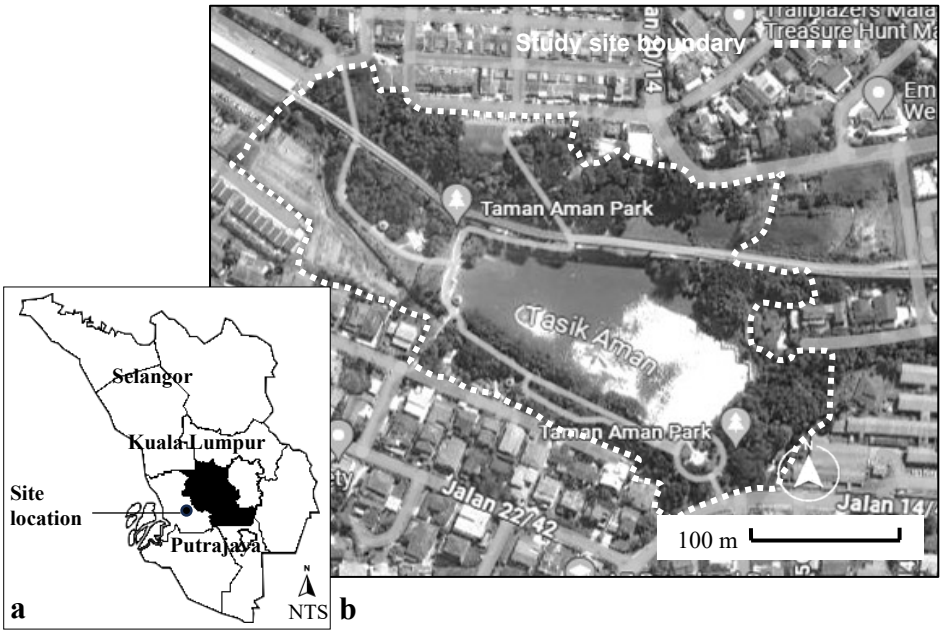


Figure 1: Location of the study area: (a) in the state of Selangor, and (b) Taman Aman Park
Source: Google Map (2024)

DATA COLLECTION

The study employed dual methods for data collection, encompassing both primary and secondary data. The primary data collection took place over a fortnight at the end of April 2024. Researchers observed and documented the

physical attributes present in the park to use as indicators/sub-variables for a questionnaire. Subsequently, a survey was conducted in mid-May 2024 through a direct questionnaire to gather information on park users' satisfaction levels regarding the performance and importance of existing physical attributes in Taman Aman Park. The data obtained will be quantitatively analyzed using the IPA method. The secondary data involved collecting information pertinent to specific study topics from sources such as research journals, articles, theses, books, and data on research sites.

Identification Variables & Indicators

To evaluate the satisfaction level of park users, a literature review was performed to determine the independent variable, which in this case is the urban physical attributes - accessibility, safety, natural features, and amenities & facilities. Thereafter, these attributes were identified as their respective indicator and sub-variables obtained from on-site observations (Table 1)

Table 1: The attributes 19 parameters in Taman Aman Park

Dependent variables	Independent variables/ Attribute	Indicators/sub variables
To evaluate the level of park user satisfaction towards urban park attributes provided in Taman Aman Park.	Accessibility	Gateway & parking condition
	Facilities and amenities	Badminton court, takraw court, skatepark, outdoor fitness gym, playground, reflexology path, jogging track/pathway, lavatory, signage, rubbish bin, gazebo, bench and table.
	Natural features	Vegetation and lake
	Safety	Lighting, bollards & CCTV

Source: Author (2024)

Development of Questionnaire

The study aims to gauge user satisfaction towards the physical attributes of public parks, necessitating the use of a close-ended survey questionnaire for data collection. The questionnaire, developed via Google Forms, comprises two sections. Section I gathers demographic variables of gender, age groups, and motives for visiting the park. Section II presents close-ended questions regarding users' satisfaction with the importance and performance of four main park physical attributes: accessibility, facilities & amenities, natural features, and safety. The questionnaire was disseminated randomly among users of Taman Aman Park. Park users were asked to evaluate the park's performance and importance by scanning a QR code provided by the researcher to access the questionnaire. They needed to select, on a Likert scale, from 1 (low importance) to 5 (very important/high importance) to evaluate the level of importance, and

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from 1 (very dissatisfied) to 5 (very satisfied) to evaluate the level of performance (Table 2). Data from these park users will be further analysed using the IPA method.

Table 2: The Likert Scale: Level of Importance & Level of Performance

Level	Answer Criteria	Score	Level	Answer Criteria	Score
Importance Level Score	Very unimportant	1	Performance Level Score	Very dissatisfied	1
	Unimportant	2		Dissatisfied	2
	Moderately	3		Neutral	3
	Importance	4		Satisfied	4
	Very Important	5		Very satisfied	5

Source: Author (2024)

Determination of Sample Size

The population in this study consisted of all park users of Taman Aman Park. The Time Linear Function Formula was employed to determine the sample size because the population size is not always the same, and there is uncertainty about the population size. This formula calculates the number of samples based on estimated time constraints as follows:

$$n = \frac{T - T_0}{T_1} \qquad \text{Eq. 1}$$

Information:
$n = number\ of\ samples,$
$T = time\ available\ for\ study\ (14\ days\ x\ 24\ hours\ =\ 336\ hours)$
$T_0 = planned\ time\ in\ study/day\ (hours)\ \ (5\ hours\ x\ 7\ days\ =\ 35\ hours)$
$T_1 = time\ used\ to\ fill\ out\ the\ questionnaire\ (hours)\ (½hour/day\ x\ 7\ days\ =\ 3.5\ hours)$
$n = \frac{336-35}{3.5} = 86\ users/respondents$

Based on Eq. 1, the sample size in this study was 86 users in Taman Aman Park. The sampling technique used was accidental sampling or convenience sampling. This technique entails the researcher distributing questionnaires to anyone who visits Taman Aman Park and is willing to answer.

Validity Test

A validity test measures the legitimacy of measuring instruments, such as questionnaires. The validity of user responses was analysed using SPSS Version 28.0 by comparing the R count (Pearson correlation value) with the R table (obtained from the R table). An indicator is considered valid if the R count >R table and invalid if R count < R table. This study used a significance level of 5% (0.05) and the number of samples (N)=86. The R table used was 0.212 (Muhammad Abdul Rohman, 2020).

Reliability Test

A measuring instrument is reliable if it produces consistent results even if the calculations are repeated multiple times. Reliability assessment requires validating the research instrument. If an instrument is invalid, there is no need to carry out a reliability test calculation. The study conducted a reliability test using Cronbach's Alpha analysis with a value>0.6, where an indicator value is reliable if > 0.60 or higher and vice versa (Aithal & Aithal, 2020).

Importance Performance Analysis (IPA)

The IPA method was first introduced by Martilla & James in 1977. This method was developed to measure customer satisfaction based on service performance in business and marketing. Presently, IPA is employed across diverse fields, including tourism, health services, green practices, and education (Alamri & İnceoglu, 2021). In this study, the IPA was used to evaluate the satisfaction level of park users. Satisfaction levels are obtained by comparing the average performance level with the average importance level (Martilla & James, 1977). The formula for determining the satisfaction level is as follows:

$$T_{ki} = \frac{Xi}{Yi}\ x\ 100\% \quad \text{Eq. 2}$$

Information:
$T_{ki} = Satisfaction\ level,\ Xi = Performance\ level\ score,\ Yi = Importance\ level\ score$

Table 3: Interpretation for Satisfaction Level

Level Satisfaction	Interpretation (T_{ki})
0%-32%	Very Dissatisfied
33%-66%	Dissatisfied
67%-99%	Fair
100%	Satisfied
>100%	Very Satisfied

Source: Ramadhan et al. (2020)

After determining the level of satisfaction, a Cartesian diagram with four quadrants is to be plotted. This diagram is used to group and prioritize the indicators that can influence user satisfaction. The x-axis denotes performance value, and the y-axis denotes importance value. Each quadrant will be populated with indicators using the following formula:

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$$\bar{X} = \frac{\sum Xi}{n} \text{ Eq. 3}$$
$$\bar{Y} = \frac{\sum Yi}{n} \text{Eq. 4}$$

Information:
$n = Number\ of\ users,\ Xi = Average\ score\ of\ performance\ level$
$Yi = Average\ score\ of\ importance\ level$

A Cartesian diagram consists of four quadrants that are divided by two perpendicular lines intersecting at the point ($\bar{\bar{X}}$, $\bar{\bar{Y}}$) (Figure 2). The intersection point is determined by the following formula:

$$\bar{\bar{X}} = \frac{\Sigma_i^N = 1^{\overline{Xi}}}{k} \text{ Eq. 5}$$
$$\bar{\bar{Y}} = \frac{\Sigma_i^N = 1^{\overline{Yi}}}{k} \text{ Eq. 6}$$

Information:
$\bar{\bar{X}} = X - Axis\ limit\ (performance\ level), \quad \bar{\bar{Y}} = Y - Axis\ limit\ (importance\ level)$
$k = Number\ of\ indicators\ studied$

Quadrant 1 (Concentrate Here): This quadrant contains indicators with high importance but low performance. The variables in this quadrant require immediate attention for improvement.

Quadrant II (Keep Up the Good Work): This quadrant contains indicators with high importance and high performance. The variables in this quadrant are major strengths that must be continuously maintained.

Quadrant III (Low Priority): This quadrant contains indicators with low importance and low performance. The variables in this quadrant do not require additional effort.

Quadrant IV (Possible Overkill): This quadrant contains indicators with low importance but high performance. The variables in this quadrant must be maintained to remain of good quality.

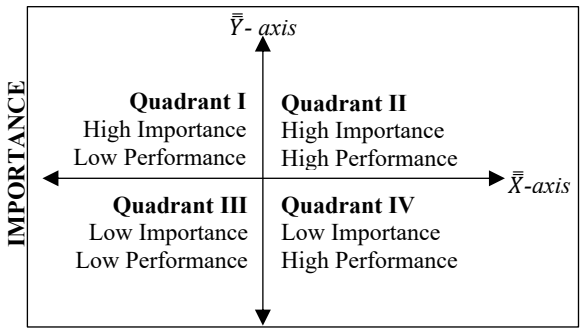


Figure 2: Cartesian Diagram IPA

Source: Martilla & James (1977)

ANALYSIS AND DISCUSSION

Result of the Field Analysis

The availability of physical attributes of Taman Aman Park was assessed through on-site observations, and the results are presented in Table 4. Each indicator is coded to facilitate data analysis.

These indicators serve various functions, including sports, recreation, and education.

Table 4: Availability of park physical attributes

No	Indicator	Total	Photo	No	Indicator	Total	Photo
Accessibility				**Facilities and Amenities**			
A1	Parking condition	6772.28 m		F3	Basketball court	1 (480 m^2)	
A2	Archway	2 nos		F4	Takraw court	1 (81.74 m^2)	
F5	Skatepark	206.79 m^2		F13	Gazebo	12 nos	

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No	Indicator	Total	Photo
F6	Outdoor fitness gym	26 nos	
F7	Integrated playground	796.74 m^2	
F8	Reflexology foot path	93.19 m^2	
F9	Jogging track/ pathway	3433 m^2	
F10	Lavatory	2 nos	
F11	Signage	19 nos	
F12	Rubbish bin	30 nos	
F14	Benches and picnic table	15 nos	
Natural Features			
N15	Variety of vegetation (trees, shrubs, g/covers)	38116.99 m^2	
N16	Water features (lake)	22,300.54 m^2	
Safety			
S17	Park lighting	30 nos	
S18	Bollards	74 nos	
S19	CCTV	6 nos	

Source: Author's Inventory (2024)

Results of the Survey

To determine the respondents' background, user profiles were analysed, including gender, age group, and motive to park (Table 5). In terms of gender, 51.2% of respondents were male, and the remaining 48.8% were female. The age

group of 21 to 30 years (50%) and under 20 years (17.4%) frequented Taman Aman Park, with the remaining 32.6% between 31 and 60 years of age. Meanwhile, for the purpose of visiting the park, most respondents mentioned sightseeing or reducing stress at 34.0%, playing sports at 29.0%, jogging or running at 17.4%, and 15.0% socializing with family or friends. The rest mentioned fishing (2.3%), and it being the best and closest place to their home (2.3%). These results indicate that sightseeing or reducing stress, and sports are the main purposes for visiting the park.

Table 5: User Profile (n=86)

Item/Variable	Frequency	Percentage
Gender		
Male	44	51.2%
Female	42	48.8%
Age Group		
Below 20	15	17.4%
21 – 30	43	50.0%
31 – 40	14	16.3%
41 – 50	9	10.5%
51 – 60	5	5.8%
61 and above	0	0
Motive/purpose to park		
Jogging/running	15	17.4%
Playing sports (skate, basketball, and badminton)	25	29.0%
Fishing	2	2.3%
To sightseeing/reduce stress	29	34.0%
To socialise with family or friends	13	15.0%
It's the best and closest place to my home	2	2.3%

Source: Author (2024)

Validity Test

Calculations carried out with SPSS software revealed that all 19 indicators of the performance level and importance level had an R count > R table, indicating that all indicators are valid. Therefore, the reliability test can be conducted.

Reliability Test

Based on Table 6, the reliability test results indicate an r alpha value of 1.007 for the performance and 0.978 for the importance, which is considered reliable as it is greater than the standard r alpha value of 0.6. The data analysis can proceed to the next step.

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Table 6: Reliability test

Variable	Cronbach alpha coefficient	No of indicators	Test
Performance level	1.007	19	Reliable
Importance level	0.978	19	Reliable

Source: Author's Calculation (2024)

Importance Performance Analysis (IPA)

The satisfaction level towards Taman Aman Park is obtained by comparing the average score of the performance level ($\bar{X}$) and importance level ($\bar{Y}$) using IPA. Both levels can be calculated using Eq. 3 and Eq. 4, with satisfaction level calculated using Eq. 2. Below is an example calculation using these formulas for the parking condition indicator.

$$\bar{X} = \frac{\sum Xi}{n} \quad \bar{Y} = \frac{\sum Yi}{n} \quad T_{ki} = \frac{Xi}{Yi}\ x\ 100\%$$
$$\bar{X} = \frac{343}{86} = 3.98 \bar{Y} = \frac{347}{86} = 4.03 T_{ki} = \frac{3.98}{4.03}\ x\ 100\% = 98\%$$

Next, to calculate the total average for the level of importance and performance, use Eq. 5 and Eq. 6 as shown below.

$$\bar{\bar{X}} = \frac{\Sigma_i^N = 1 \bar{Xi}}{k} \bar{\bar{Y}} = \frac{\Sigma_i^N = 1 \bar{Yi}}{k}$$
$$\bar{\bar{X}} = \frac{69.7}{19} = 3.67 \bar{\bar{Y}} = \frac{75.9}{19} = 3.99$$

These two total averages are also used to determine the intersection points $\bar{\bar{X}}$ and $\bar{\bar{Y}}$ in the IPA Cartesian diagram (Figure 3).

Table 7 indicates the highest score for the satisfaction level was 113%, attained by indicator A2 (gateway), which falls under the "very satisfied" category. Conversely, indicator S19 (CCTV) received the lowest satisfaction level score of 77%, categorized as "fair." Overall, the satisfaction level for Taman Alam Park users across 19 park indicators averages 92%, which is categorized as "fair." Therefore, to achieve an overall "very satisfaction" level, attention should be focused on improving several park physical attribute indicators. The Cartesian diagram IPA (Figure 3) displays of performance and importance level of Taman Alam Park.

Table 7: The satisfaction level (T_{ki}) of the Performance level and importance level

No	Indicator	Xi	Yi	n	$\bar{X}$	$\bar{Y}$	T_{ki}	Interpretation
Accessibility								
A1	Parking condition	343	347	86	3.98	4.03	98%	Fair
A2	Gateway	309	274	86	3.59	3.18	113%	Very satisfied
Facilities & amenities								
F3	Basketball court	311	312	86	3.61	3.62	100%	Satisfied
F4	Takraw court	299	295	86	3.47	3.43	101%	Very satisfied
F5	Skatepark	293	291	86	3.40	3.38	101%	Very satisfied
F6	Outdoor fitness gym	321	336	86	3.73	3.91	96%	Fair
F7	Playground	333	359	86	3.87	4.17	93%	Fair
F8	Reflexology path	322	351	86	3.74	4.08	92%	Fair
F9	Pathway/jogging track	323	360	86	3.76	4.19	90%	Fair
F10	Lavatory	299	364	86	3.48	4.23	82%	Fair
F11	Signage	315	349	86	3.66	4.05	90%	Fair
F12	Rubbish bin	327	362	86	3.80	4.21	90%	Fair
F13	Gazebo	319	339	86	3.70	3.71	94%	Fair
F14	Bench & table	327	361	86	3.80	4.20	91%	Fair
Natural elements								
N15	Vegetation	343	392	86	3.98	4.56	88%	Fair
N16	Lake	318	360	86	3.69	4.19	88%	Fair
Safety								
S17	Bollard	318	395	86	3.70	4.59	81%	Fair
S18	Lighting	303	345	86	3.52	4.01	88%	Fair
S19	CCTV	277	358	86	3.22	4.16	77%	Fair
Total					**69.7**	**75.9**	**92%**	**Fair**
Total average					**3.67**	**3.99**		

Source: Author's Calculation (2024)

Information:
$Xi = Performance\ level\ score$
$Yi = Importance\ level\ score$
$n = Number\ of\ users$
$\bar{X} = Average\ score\ of\ performance\ level$
$\bar{Y} = Average\ score\ of\ importance\ level$
$T_{ki} = Satisfaction\ level$

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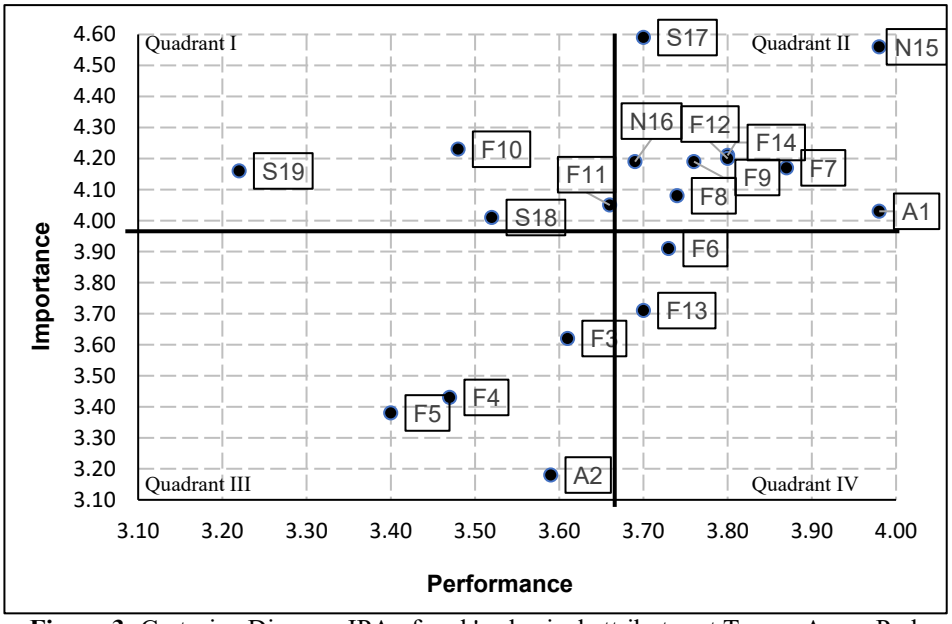


Figure 3: Cartesian Diagram IPA of park's physical attributes at Taman Aman Park
Source: Author's calculation (2024)

Based on the IPA results (Figure 3), nineteen physical attributes of the park are categorized into four Quadrants.

Quadrant 1 (Concentrate Here): This quadrant is an indicator recognized as very important by users, yet its performance level is relatively low. The indicators encompass lavatory F10, signage F11, lighting S18, and CCTV S19, all of which face various maintenance issues that need to be addressed immediately. Therefore, enhancement strategies will focus on these indicators to improve user experience and ensure sustainable park management.

Quadrant II (Keep Up the Good Work): This quadrant contains indicators that park users consider highly important and perform well, including parking condition A1, playground F7, reflexology path F8, pathway or jogging track F9, rubbish bin F12, bench and table F14, vegetation N15, and lake N16. Maintaining these indicators through regular inspection, cleaning, and enhancement is crucial to upholding their status as key attractions and enhancing the park's overall appeal.

Quadrant III (Low Priority): This quadrant shows indicators that are considered of low importance and performance by park users, including gateway A2,

basketball court F3, takraw court F4, and skatepark F5. Indirectly means that park users do not prioritize these indicators. As these indicators are in Quadrant III, no improvement measures are necessary. However, ongoing monitoring and maintenance are essential to ensure that the overall quality of the park's physical attributes meets user satisfaction.

Quadrant IV (Possible Overkill): This quadrant shows that indicators such as outdoor fitness gyms F6 and gazebos F13 are perceived as low importance by park users, even though they are of high performance in terms of quality and functionality. This discrepancy indicates a possible misunderstanding between users' expectations, the actual usefulness of these indicators, and the prioritization of other park indicators by users. Even though they are perceived as of low importance, they still contribute to the overall park experience and should be maintained at a good standard to ensure park user satisfaction.

Table 8: Recommendations for improving the physical attributes of Taman Alam Park

Quadrant	Independent variable	Indicator/ park's physical attribute	Existing condition	Recommendation
Quadrant 1 (Concentrate Here)	Facilities and amenities	Lavatory	• Plumbing problems occur, such as pipe leaks, low water pressure, and slow drainage due to the valve not being repaired • Clogged toilets and drains • The lavatory floor is slippery/dirty, with leakage in the ceiling and roof damage	• Improved lavatory facilities maintenance to address all pertinent issues. • Implemented better management practices through regular inspections. • Promote sustainable lavatory practices by incorporating water-efficient features such as dual-flush toilets and sensor-based water faucets to reduce water usage.
		Signage	• Lack of signage at the entrances/exits. • Many signs are damaged, with unclear and rusty writing. They appear dirty or mossy and are not well-maintained.	• Added signage in areas where there is currently none to reduce users' confusion, improve safety, and enhance the park's image. • Replaced the regularly maintained signage to keep it clean, in good condition, and legible. This includes cleaning, minor repairs, repainting, and replacement if necessary. • Designed accessible and inclusive signage with braille/pictograms, to ensure that all users, including those with disabilities, can navigate the park independently and safely.

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Quadrant	Independent variable	Indicator/ park's physical attribute	Existing condition	Recommendation
	Safety	Lighting	• Numerous lights sustained damage. • Dim lighting at night with an insufficient number of lights poses a safety and security threat to park users.	• Repairs/replacements of the damaged lights should be done as soon as possible. • Additional lighting is placed along pathways and parking areas to ensure safety and security for users during nighttime hours. • Implement a regular maintenance schedule to ensure existing lights are properly maintained and functional. • Upgrade the lighting with an outdoor solar lighting system to contribute to environmental stewardship and community well-being.
		CCTV	• Several CCTVs are not functioning properly.	• Replaced damaged and outdated CCTVs with the latest generation models, higher resolution, larger storage, and equipped with AI analysis to improve surveillance capabilities in the park. • Implement a regular maintenance schedule to ensure all CCTVs are in optimal working condition.

Source: Author's analysis (2024)

CONCLUSION

The evaluation of user satisfaction with the physical attributes of Taman Aman Park was conducted based on four independent variables: accessibility, facilities and amenities, natural elements, and safety. The analysis revealed that the overall user satisfaction level towards the urban park attributes in Taman Aman Park is categorized as "fair," with an average satisfaction level of 92%. Attributes such as parking conditions, playgrounds, reflexology paths, pathways or jogging tracks, rubbish bins, benches and tables, vegetation, and lakes are considered important and perform well. These attributes were identified as key strengths under Quadrant II, serving as the primary attractions to park users in the future. Conversely, park physical attributes like lavatories, signage, lighting, and CCTV-despite being regarded as important-exhibit low performance and are in Quadrant I. Therefore, to achieve a "very satisfaction" level from park users, the park's physical attributes in Quadrant 1 should be prioritized for improvement efforts.

A useful comparison can be drawn with the Titiwangsa Lake Gardens in Kuala Lumpur. A study conducted on the level of liveability assessments of park spaces found that the park achieved strong levels of user satisfaction. Most

of the park's physical attributes enhance user satisfaction, particularly comfort and visual aesthetics, which are the primary influencing factors (Iman 2021). In contrast, for Taman Aman Park to raise its satisfaction level from "fair" to "very satisfied," priority should be given to improving lavatories, signage, lighting, and CCTV, which will enhance functionality, safety, comfort, and enjoyment. These findings highlight the value of using successful models, such as Titiwangsa Lake Gardens, as benchmarks in future comparative studies of Malaysian urban parks. Such an approach will provide valuable insights into best practices for outdoor recreational space design and management, guiding urban planners and policymakers in fostering sustainable, inclusive, and user-centered urban park development.

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ETHICAL STATEMENT

This research was approved by the UiTM Research Ethics Committee (REC) Guidelines (Revision 2025). All participants provided informed consent before starting the interviews, including understanding data confidentiality, anonymity, and the use of information for research publication purposes.

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RIGHTS OF STRATA HOUSING PURCHASERS DURING DELIVERY OF VACANT POSSESSION: AN OVERVIEW

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Abstract

The delivery of vacant possession (VP) in a strata housing scheme marks a pivotal stage in the transfer of ownership and use of property. In Malaysia, this process is governed by a series of housing and land-related statutes aimed at safeguarding purchasers' rights. This paper provides an enhanced legal overview of the rights of strata housing purchasers during the delivery of VP, integrating the historical evolution of Malaysia's strata property framework and analyzing relevant statutes, including the Housing Development (Control and Licensing) Act 1966 (Act 118), the Strata Titles Act 1985 (Act 318), and the National Land Code (Act 828). The paper critically evaluates the legal protections and identifies persistent challenges in areas such as encumbrances, utilities readiness, strata title issuance, defect liability, and the completion of common property. By tracing the development of Malaysia's strata legislation and case law, this article calls for targeted reforms to improve enforcement, regulatory coordination, and consumer awareness.

Keywords: Strata Housing, Vacant Possession, Purchasers' Rights, Housing Law, Malaysia, Consumer Protection

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INTRODUCTION

The rapid urbanization and demand for high-density residential developments in Malaysia have led to a significant increase in strata housing developments, where multi-storey buildings are subdivided into parcels with shared ownership of common property. Since the 1970s, strata living has transitioned from an urban planning solution to a dominant residential model. However, with this evolution came the need for a legal framework that protects the interests of individual purchasers while managing collective property ownership.

One of the most critical legal junctures in the lifecycle of a strata property transaction is the delivery of vacant possession (VP). The delivery of VP occurs when a buyer receives the legal right to occupy their unit, marking a crucial legal milestone governed primarily by the Housing Development (Control and Licensing) Act 1966 (Act 118) (HDA 1966) and the Strata Titles Act 1985 (Act 318) (STA 1985). These laws, together with their regulations, outline a purchaser's rights to unencumbered ownership, access to utilities, timely delivery, common facility completion, and post-handover defect redress.

Section 3 of Act 118 defines 'purchaser' as anyone buying housing accommodation or having any dealings with a licensed housing developer in respect of the acquisition of housing accommodation (Act 118). This definition applies to both types of housing development, whether build-then-sell or sell-then-build, but not to sub-sale property. The rights of housing purchasers buying from licensed developers are defined under Act 118, and for stratified housing under construction, the statutorily prescribed Sale and Purchase Agreement appears in Schedule H of the Housing Development (Control and Licensing) Regulations 1989. (Lieu, 2023).

In the context of Act 118, delivery of VP is considered as complete for stratified property under construction where all conditions stipulated in Clause 27 of Schedule H are fulfilled; namely, issuance of a certificate of completion and compliance (CCC), issuance of strata title, water and electricity are ready for connection and payment of all monies by purchasers (Shuhaimi et al., 2024).

This paper provides a comprehensive overview of the rights accorded to strata housing purchasers under Malaysian law during the VP stage. The discussion draws on the statutory framework provided by Act 318, Act 118, and associated regulations, as well as relevant judicial interpretations. The paper identifies key challenges faced by purchasers, including delays, defective workmanship, and lack of access to common property, and evaluates the adequacy of current legal protections. The study concludes with recommendations to strengthen the legal and institutional safeguards for strata homebuyers.

The Historical Evolution of Strata Development in Malaysia

Malaysia's first strata-specific legislation emerged with the Strata Titles Act 1985 (Act 318), which provided a legal mechanism for subdividing buildings into individual parcels and common property. However, the roots of strata development trace back further. In the 1960s and 1970s, as cities like Kuala Lumpur and Penang faced land scarcity and rising demand for housing, developers began offering multi-storey units without a clear legal mechanism for ownership. Purchasers were issued Provisional Block Titles under the National Land Code 1965, but lacked clear ownership rights over individual parcels. This led to widespread issues involving disputes over maintenance, delayed titles, and a lack of transparency (Amin et al., 2015).

To address this, the government introduced Act 318 in 1985, supported by the Housing Development (Control and Licensing) Act 1966 (Act 118), which regulates sale transactions, developer licensing, and delivery obligations. The Housing Development (Control and Licensing) Regulations 1989, with Schedules G and H, standardized contractual terms for purchasers and developers. Further amendments to the National Land Code (Act 828) helped integrate strata administration with state land offices. Despite this legal development, issues such as late delivery, utility delays, encumbrances, and poor workmanship remain prevalent that necessitate more vigorous enforcement and reform (Shuhaimi et al., 2024).

METHODOLOGY

This study employs doctrinal legal analysis, drawing on statutory interpretation and a review of case law. The primary statutes examined include the HDA 1966, STA 1985, and Strata Management Act 2013 (SMA 2013) (Act 757), with additional reference to the National Land Code and various subsidiary regulations. Secondary sources include academic commentaries, parliamentary debates, tribunal statistics, and housing-related judgments from Malaysian courts.

This study further adopts a qualitative legal research methodology, utilizing library-based research and content analysis to examine the adequacy of statutory and judicial protections provided to housing purchasers during the delivery of vacant possession in Malaysia. This approach is consistent with the nature of doctrinal legal research, which emphasizes critical analysis of statutes, case law, regulations, and authoritative secondary sources (Suaree et al, 2024).

Fidishun (2002) asserts that library-based research enables a comprehensive exploration of data by examining legal texts, scholarly literature, and various documentary materials. George (2008) further emphasizes that this research method facilitates the analysis of factual information, expert perspectives, and legal developments relevant to the study's objectives. In line with this, the present study draws on a broad range of legal sources, including the Housing Development (Control and Licensing) Act 1966, the Housing

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Development (Control and Licensing) Regulations 1989, relevant judicial decisions, parliamentary debates, academic publications, and media reports.

Beyond statutory analysis, this research also employs content analysis to interpret key legislative provisions and judicial reasoning related to the rights of housing purchasers. As highlighted by Harwood et al. (2003) and Kleinheksel et al. (2020), content analysis is particularly valuable in legal research as it uncovers patterns and insights across diverse textual sources. Within this framework, the study examines specific legal clauses, namely Clauses 3, 22, 25, 29, and 30 of Schedule H, as well as landmark court rulings such as PJD Regency, Ang Ming Lee, and Kuching Plaza, to assess the evolving judicial approach to protecting the rights of strata housing purchasers.

While comparative analysis is a useful methodological tool in broader legal research, this paper confines itself to the Malaysian legal framework and does not engage in cross-jurisdictional comparison. The focus remains on assessing the coherence, clarity, and enforceability of existing laws within the Malaysian context, with the aim of proposing regulatory and institutional improvements.

DISCUSSION

Free From Encumbrance

Clause 3(1) of Schedule H stipulates that a property must be free from encumbrance before vacant possession is delivered to the purchaser. In this context, "free from encumbrances" means that the parcel must not be subject to any legal or financial restrictions such as charges, private caveats, or interests that could impede the transfer of ownership to the purchaser. In practice, however, it is common for developers to use unsold or undelivered parcels as collateral to obtain bridging loans from financial institutions. This practice can pose significant risks to purchasers, especially when disputes arise over the redemption of these encumbered properties.

A notable example is the case of *Kuching Plaza v Bank Bumiputra Malaysia Bhd [1991] 3 MLJ 169*. In this case, the bank refused to release a charged property to the developer on the grounds that the developer had not yet delivered vacant possession, which the bank argued was a condition precedent under the loan agreement. The Federal Court, however, ruled that the obligation to deliver vacant possessions and the obligation to release the collateral were distinct contractual duties. Therefore, once the developer had met its obligations under the financing agreement, the bank was legally required to release the collateral, regardless of whether vacant possession had been delivered.

The Federal Court’s decision affirmed that financial institutions are not entitled to withhold the release of encumbered property if the developer has fulfilled its obligations under the financing agreement. This underscores the legal

principle that contractual obligations between developers and financiers must be distinguished from the rights of bona fide purchasers, who should not be adversely affected by third-party financing arrangements. In essence, while developers are permitted to use unsold properties as collateral for financing, it becomes the duty of the bridging financier to release the collateral once the agreed conditions, excluding the delivery of vacant possession, are satisfied.

Despite this legal clarity, practical challenges continue to arise. A prominent case in Georgetown (Nambiar, 2020) involved a purchaser who had fully paid for her unit but later faced foreclosure because the developer failed to redeem the charge from RHB Bank. The bank demanded that the purchaser, rather than the defaulting developer, bear the cost of the redemption sum, including accrued interest and penalty charges. In a similar incident in Taiping, buyers were compelled to pay up to ten times the original purchase price to prevent foreclosure due to the developer's failure to settle its loan obligations (Loong, 2021).

These cases expose the critical vulnerability of purchasers in the event of developer default and highlight a major gap in enforcement. In response, the National House Buyers Association (HBA) has publicly advised buyers to avoid making property purchases in cash unless there is official confirmation that the unit is completely free from any encumbrance. Such incidents reinforce the urgent need for stronger legal safeguards and transparency mechanisms to protect purchasers from bearing the financial consequences of the developer's liabilities.

The cases highlight several critical gaps in the relationship between purchasers, developers, and bridging financiers. While developers may enter into financing agreements with banks to secure loans using the property as collateral, the terms of these agreements are typically not disclosed to purchasers, even though purchasers are contracting parties with the developers. This lack of transparency places bona fide purchasers in a vulnerable position, as they may be unfairly held liable for the developer's financial defaults, despite the statutory obligation imposed on developers to deliver properties free from encumbrances at the point of vacant possession. At present, there is no effective legal mechanism in place to compel bridging financiers to release encumbered properties once the developer has fulfilled its obligations under the financing agreement. As a result, purchasers may be exposed to foreclosure risks and forced to pay redemption sums that should rightfully be borne by the developer.

The only existing legal safeguard for purchasers in such scenarios is provided under Regulation 13 of the Housing Development (Control and Licensing) Regulations 1989, which stipulates that developers who fail to deliver a property free from encumbrances may be subject to a fine not exceeding RM50,000, imprisonment for a term not exceeding three years, or both. However, this penalty is directed solely at the developer and does not provide immediate

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relief or protection to the affected purchaser, thereby underscoring the need for stronger regulatory intervention.

Secondly, drawing from the Kuching Plaza ruling, it is imperative that contracts between developers and bridging financiers reflect the underlying intent and protective spirit of Act 118 and its subsidiary legislation. This principle aligns with the Federal Court's decision in *Ang Ming Lee & Ors v Menteri Kesejahteraan Bandar, Perumahan dan Kerajaan Tempatan & Anor and other appeals [2020] 1 MLJ 281*, where the Court affirmed that Act 118 and its regulations constitute social legislation designed to protect the interests of homebuyers. Accordingly, in any conflict between housing purchasers and developers, the rights of the purchasers must take precedence.

This interpretation is consistent with the legislative intent expressed during the passing of the original Housing Developers' Bill in 1966. As recorded in the Parliamentary Proceedings (1966), the Minister stated:

> *"Legislative measures should be taken to protect the people from bogus housing developers. Hence, this Bill."*

Such historical context reinforces the view that consumer protection is the central objective of housing law in Malaysia. Therefore, any private contractual arrangement, such as those between developers and financiers, must not undermine the statutory safeguards afforded to purchasers under Act 118.

Considering this principle, it has been proposed that a mandatory clause be included in all agreements between housing developers and bridging financiers, requiring developers to ensure the delivery of vacant possession to purchasers. This clause would serve as an added layer of protection for purchasers, safeguarding them from unknowingly acquiring encumbered properties.

However, implementing such a requirement poses challenges, as facility agreements between developers and financial institutions are private contractual arrangements not currently governed by statute. Unlike the statutory sale and purchase agreements prescribed under Act 118, which are binding and enforceable on both developers and purchasers, no equivalent legal framework exists to regulate developer-financier contracts. Recognizing this legal gap is the first step toward meaningful reform. Several legislative and regulatory options could be considered to address this issue:

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- The government could amend the HDA 1966 to regulate facility agreements by prescribing them as statutory contracts subject to public oversight;
- A new provision could be introduced under Clause 3(4) of Schedule H mandating that developers provide confirmation of such a clause in their loan agreements with financiers; and/or
- Bank Negara Malaysia, as the regulator of financial institutions, could issue circulars or guidelines requiring all banks and bridging financiers to incorporate this mandatory clause into their financing agreements with housing developers.

Such reforms would enhance legal clarity, prevent conflicts, and uphold the core objective of the HDA 1966, which is to protect housing purchasers from undue risks arising from third-party financial arrangements. Another viable solution is the adoption of a tripartite agreement involving three parties, namely the housing purchaser, the housing developer, and the bridging financier (the bank). Such agreements clearly outline the rights and obligations of each party concerning the sale and financing of the property (Property, 2023). In this context, tripartite agreements would ensure that purchasers, as beneficial owners of their units during the pre-sale period, are fully informed of the encumbrance status of the property and can take appropriate steps to facilitate the release of any charges or restrictions.

The concept of tripartite agreements is not a new one. For example, India has successfully implemented this model to protect homebuyers by requiring developers and banks to disclose all relevant financial dealings that may affect the property. This practice helps ensure that units are free from encumbrances and that developers remain accountable for any outstanding arrears (Mutero, 2011; Kruthi, 2025).

Another common form of encumbrance relates to the issuance of strata titles. This was evident in the case of *Kwan Kwok Kwong & Anor v Trenolo Resources Sdn Bhd [2000] 3 MLJ 731*. In this case, the plaintiffs entered into an agreement with the defendant to purchase a commercial unit in Wira Court and fully paid the purchase price in December 1966. However, the defendant failed to transfer the parcel, resulting in the strata title not being issued. The defendant argued that they were facing financial difficulties and retained rights over the parcel until the strata title could be issued later.

The plaintiffs, in turn, relied on Section 33 of the Contracts Act, which stipulates that a contract depending on an uncertain future event cannot be enforced. The court held that since the plaintiffs had fulfilled their contractual obligations by paying in full, the defendant was legally bound to discharge the encumbrance and facilitate the transfer. This case reinforces the principle that

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purchasers should not suffer the consequences of a developer's financial shortcomings, particularly when they have already performed their obligations in full.

Water, Electricity and Sewerage Mains Are Ready

The second right is provided under Clause 22(1) of Schedule H, which requires that water, electricity, and sewerage mains be "ready for connection" to the parcel at the time of delivery of vacant possession. However, the phrase "ready for connection" has historically been subject to differing interpretations. From the developer's perspective, this phrase has often been understood to mean that all internal installations, such as electrical wiring, water fittings, and sanitary fixtures, must be in place, allowing purchasers to apply for utility activation themselves. This view was notably upheld by the developer in *Remeggious Krishnan v SKS Southern Sdn Bhd [2023] 3 MLJ 1*, where it was argued that vacant possession was properly delivered since all necessary infrastructure had been installed, enabling utility applications to be made post-handover.

Purchasers, on the other hand, have long held a contrary view: that "ready for connection" implies that water and electricity must be immediately available and flowing at the time vacant possession is delivered. The absence of running water or electricity at the time of handover has often led to disputes and frustration among buyers.

This legal ambiguity was finally resolved by the Federal Court in Remeggious Krishnan, where the Court clarified that "ready for connection" means the actual supply of water and electricity must be available at the time of delivery of vacant possession. In other words, the utility services must not only be physically installed but also fully operational. As a result of this definitive ruling, it is now the developer's clear legal obligation to ensure that all utility connections are fully functional at the point of handover. Failure to do so may expose the developer to liability, including the obligation to pay compensatory damages to the purchaser for breach of contract.

Accordingly, developers are strongly advised to complete all necessary preparations in advance of delivering vacant possessions. This includes securing approvals, settling required fees with utility providers, and confirming that all utility services are active and ready for immediate use by the purchaser on the day of handover.

Delivery Period

The third key right of purchasers is established under Clause 25(1) of Schedule H, which states that "vacant possession shall be delivered to the Purchaser within thirty-six (36) months from the date of this Agreement." This clause guarantees that the purchaser has a contractual right to receive a completed and habitable

unit within a maximum of 36 months from the date of the Sale and Purchase Agreement (SPA). Failure by the developer to meet this timeline constitutes a breach of contract and obligates the developer to pay Liquidated Ascertained Damages (LAD) to the purchaser, as stipulated under Clause 25(2). LAD serves as a pre-agreed compensation mechanism that enables purchasers to recover losses arising from delayed handover. The principle behind LAD is to provide timely and predictable redress without requiring purchasers to prove actual damages in court.

Data from the Tribunal for Homebuyer Claims (THC) over the past five years reveals that claims related to non-technical issues, particularly late delivery and LAD claims, significantly outnumber those related to technical defects such as poor workmanship or structural issues. This trend highlights the persistent problem of delay in delivering vacant possession and the widespread reliance on the LAD provision for consumer protection.

Based on Table 1 below, the high volume of LAD cases indicates that it is almost common for every housing purchaser to experience late delivery of vacant possession.

Table 1 : Number of Issues Filed in Tribunal for Homebuyer Claims

Year	Technical	Non-Technical	Total cases	Percentage of LAD cases
2019	211	2,145	2,356	91%
2020	200	1,130	1,330	85%
2021	401	951	1,352	70%
2022	192	1,156	1,348	86%
2023	413	863	1,276	68%

Sources: Ministry of Housing and Local Government Statistics

The consistently high proportion of LAD-related cases suggests that delays in delivering vacant possession are not isolated incidents but a systemic issue within Malaysia's housing development industry. It also underscores the importance of enforcing Clause 25 and enhancing oversight mechanisms to ensure that developers fulfill their contractual obligations within the prescribed timeframe. Returning to the provision under Clause 25(1), housing developers and housing purchasers have different views regarding whether the calculation of LAD starts from the date of signing the Sale and Purchase Agreement (SPA), or from the date of collection of the booking fee. The interpretation or view is crucial

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since it will affect the calculation of LAD that housing purchasers are entitled to if delivery of vacant possession exceeds thirty-six months.

The Supreme Court in the case of *Faber Union Sdn Bhd v Chew Nyat Shong & Anor [1995] 2 MLJ 597* followed the precedent set in *Hoo See Sen & Anor v Public Bank Berhad [1988] 2 MLJ 170,* which similarly held that the calculation of LAD starts to run from the date the purchaser paid the booking fee. However, court in the case of *PJD Regency Sdn Bhd v Tribunal Tuntutan Pembeli Rumah & Anor* [2019] MLJU 2067 took a literal approach and ruled that the wording "this agreement" in a statutory contract could not refer to anything but the contract between the parties themselves, i.e. the SPA, and thus, LAD should be calculated from the date of signing the SPA.

While the collection of booking fees is explicitly prohibited under Regulation 11(2) of the Housing Development (Control and Licensing) Regulations 1989, it remains a common industry practice and is considered necessary for developers to secure purchasers. In the case of *PJD Regency Sdn Bhd v Tribunal Tuntutan Pembeli Rumah & Anor and other appeals [2021] 1 MLRA 506*, the Federal Court ruled that the calculation of LAD should commence from the date of collection of the booking fee, although the court acknowledged the fault of the practice. The court in this case also ruled that LAD shall be calculated based on the agreed purchase price as stipulated in the SPA, and not the rebated price.

However, in the case of a housing developer seeking an Extension of Time (EOT) subsequently granted by the Housing Controller under Regulation 11(3) of the Housing Development (Control and Licensing) Regulations 1989, the result would be akin to the housing developer compromising the rights of the housing purchaser to LAD. EOT is possible when the Housing Controller is satisfied that, owing to special circumstances, hardship, or necessity, compliance with any of the provisions in the contract of sale is impracticable or unnecessary, and he may, by a certificate in writing, waive or modify such provisions. This situation may put housing purchasers at a disadvantage. However, the government assured that EOT is not an excuse for a housing developer not to pay LAD (Parliamentary Proceedings, 2023). This is in line with the ruling in the case of *Vignesh Naidu Kuppusamy Naidu v Prema Bonanza Sdn Bhd & Another Appeal [2023] 4 CLJ 715*, where it was held that housing developers are liable to pay LAD to housing purchasers despite having approval to delay the delivery of vacant possession.

Completion of Common Facilities

The fourth fundamental right is mentioned in Clause 29(1) of Schedule H, which provides that delivery of vacant possession must include CCC, which encompasses the completion of common facilities. In a typical housing

development with multiple phases, the first phase may be completed earlier than subsequent phases. Housing purchasers for the first phase have the right to enjoy the common facilities shared with other housing purchasers in other phases, such as swimming pools, gyms, lifts, and water features (depending on the offer by the housing developers), thus it must be completed beforehand.

They shall not be handed only a Certificate of Practical Completion, which indicates that several facilities may have yet to be completed (partially completed), but are safe to reside in; therefore, purchasers may be forced to wait until all remaining phases are completed before fully enjoying common facilities. Failure to do so by the developer may subject them to liability to pay liquidated damages to housing purchasers. The partially completed phase may cause numerous problems for all stakeholders of the unit, i.e., housing purchasers, owners, and occupants (Wong, 2021). The incomplete development will cause distraction to owners or occupants, as it involves the security and safety of construction work around their property area.

Furthermore, there is a possibility of abandoning the next phase of the project, which could cause existing occupants to lose their enjoyment of common facilities forever. As discussed in the case of *PJD Regency Sdn Bhd v Tribunal Tuntutan Pembeli Rumah & Anor and other appeals [2021 1 MLRA 506]*, the developer argued that LAD should be calculated from the date of issuance of the certificate of practical completion (CPC), and not from the date of issuance of the CCC. The court has clearly stated in the judgment that CPC was never mentioned in the Act, thus should not be relevant to be considered. The only certificate that is valid is the CCC; therefore, the period for LAD calculation must commence from the date the CCC is issued.

Issuance of Strata Title

Strata title serves as proof of exclusive ownership and is used as the primary document in transactions such as the transfer of ownership, charging, leasing, and distribution of a small estate (JKPTG, 2025). Housing owners may only be recognised under the law as having an indefeasible title and rights over a property where there is a registered title in their name (Act 828). Strata title is commonly used for multi-storey buildings that are subdivided into smaller parcels derived from the master title (Donohan, 2020). Clause 12 of Schedule H provides that housing developers shall apply for issuance of strata title to the Director of Lands and Mines (PTG) within one month after issuance of Certificate of Proposed Strata Plan (CPSP) from the Department of Survey and Mapping Malaysia (JUPEM).

In Selangor state alone, there are more than 600 cases, affecting more than 12,000 buyers, for whom a strata title could not be issued (Nair & Chan, 2022). The primary reason for this issue was the insufficient funds available for

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developers to submit the application. While in Johor, a study conducted reveals the following reasons: delay in superstructure completion, failure of the developer to pay fees and taxes, technical error in the application, delay in CPSP approval, and delay in strata registration (Katithasapathy et al., 2023).

These administrative and financial shortcomings not only hinder the issuance of strata titles but also have a direct impact on residents' satisfaction with the overall performance of the management bodies. In affordable strata housing schemes, such delays are often symptomatic of weak governance structures and systemic inefficiencies in strata management, as highlighted in recent empirical findings (Aripin et al., 2024).

While it remains the statutory duty of developers to initiate and complete the application process, housing purchasers are correspondingly required to make payment within 14 days of title issuance. Only through the coordinated fulfilment of responsibilities by both parties can the perfection of title be achieved in a timely and effective manner.

Defect Liability Period

When vacant possession is delivered, the so-called warranty period, commonly referred to as the Defect Liability Period (DLP), will commence. According to Clause 30 of Schedule H, any defects, shrinkage or other faults in the purchased parcel within twenty-four (24) calendar months from the date of handover shall be repaired and made good by the developer at their own cost. Housing purchasers are advised to have a reliable home defect inspector to check the entire unit before they officially move in. Once every defect is identified, they have two options: either send a written notice to the developer to fix it within thirty (30) days or fix it themselves and claim reimbursement from the developers. For the latter, developers are required to release payment within thirty (30) days from the date of the claim.

As discussed in the case of *Pang Keng Long & Anor v Sunway PKNS Sdn Bhd [2023] 2 SMC 299*, the plaintiff had brought an action against the defendant for failure to repair water leakage, absorption of water in the walls, and persistent odour issues in sanitary fittings. The defendant rebutted the claim, arguing that they had repaired the issue accordingly and contended that the second occurrence of the defect had occurred after the DLP had expired; therefore, any subsequent repairs would be made based on their goodwill. In deciding the case, the court held that no professional assessment was conducted by developers to assess the pre- and post-defects, thus allowing the plaintiff's claim and awarding RM 1 million.

While housing construction continues to increase every year, satisfaction with housing quality does not show a downward trend. Housing purchasers, on the other hand, still lack awareness of their legal rights during DLP

(Saufi et al., 2023). For instance, not all homebuyers are well-equipped with the knowledge to conduct house defect checks and have the budget to appoint external defect inspectors. Although the Malaysian government agency, the Construction Industry Development Board (CIDB), developed the Quality Assessment System in Construction (QLASSIC) in 2006 for measuring and assessing the quality of construction, a study shows that housing purchasers are not familiar with the system. It is designed for contractors and housing developers, but it is not user-friendly for housing purchasers, as it employs technical jargon. Therefore, developing new standards and laws to protect housing purchasers and providing a medium for effectively conveying information is needed.

In Singapore, the quality assessment system is known as the Construction Quality Assessment System (CONQUAS), which has been in place for over two decades and is widely applied to government and private building projects within and outside Singapore. However, given that both systems are intended for use by a professional inspector with specialised tools, there must be self-assessment measures that can be used proactively by housing purchasers.

It is acknowledged that one of the challenges for the Housing Ministry is to ensure that housing developers make timely repairs within the specified timeframe (Parliamentary Proceedings, 2023). This aligns with the findings of a 2023 study, which noted that problems with rectification quality and the promptness of developers' responses to house defect complaints are also challenging for housing purchasers. There are times when contractors tend to delay the rectifications until the DLP ends. The delay in rectification can cause defects to remain unrectified for a very long time and may lead to new defects or the recurrence of rectified defect areas being voided once DLP ends. Therefore, a stronger enforcement mechanism must be established to ensure that housing developers make the necessary repairs within a specified timeframe.

CONCLUSIONS AND RECOMMENDATIONS

Based on the foregoing discussion, it can be concluded that the existing legal provisions and judicial decisions are generally sufficient to address the issues concerning the rights of housing purchasers during the delivery of vacant possession. However, with respect to purchasers ’rights to receive property free from encumbrances, there remains considerable room for legal reform and institutional enhancement. The Ministry of Housing and Local Government must take a proactive role in evaluating and implementing the most suitable legal options to ensure that no housing purchaser is burdened by unnecessary encumbrances resulting from the negligence or misconduct of housing developers.

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Regarding access to utilities such as water, electricity, and essential fixtures, these must be fully connected and operational at the time of vacant possession. To achieve greater clarity and consistency, amendments should be made to Clause 22 of Schedule H and Item No. 3 in the Third Schedule (Schedule of Payment of Purchase Price). These amendments should ensure alignment between judicial interpretations and statutory provisions, thereby minimizing inconsistencies and confusion among stakeholders. Additionally, clearer legal language is needed to establish the obligation of housing purchasers to settle all payments necessary for the preparation and provision of such amenities. In relation to the right to claim liquidated ascertained damages (LAD), the Federal Court's ruling in the PJD Regency case has provided much-needed clarity.
Legislative amendments should follow suit, including reintroducing a clause that gives legal recognition to the collection of booking fees. Concerning the right to completion and access to common facilities, the law must unequivocally state that the CCC is the requisite document for delivering vacant possession. While professionals such as architects and engineers may accept the CPC for compliance with building safety and regulatory standards, legal provisions must clearly endorse the CCC as the official document to prevent misinterpretation. For strata title rights, housing developers must ensure full regulatory compliance to avoid delays in the issuance of strata titles. Lastly, during the DLP, it is essential that housing purchasers are provided with clear, concise, and easily understandable guidelines for identifying and reporting building defects. Such guidelines should be user-friendly and accessible to all purchasers, regardless of their background or experience, to ensure their rights are effectively protected and enforced.

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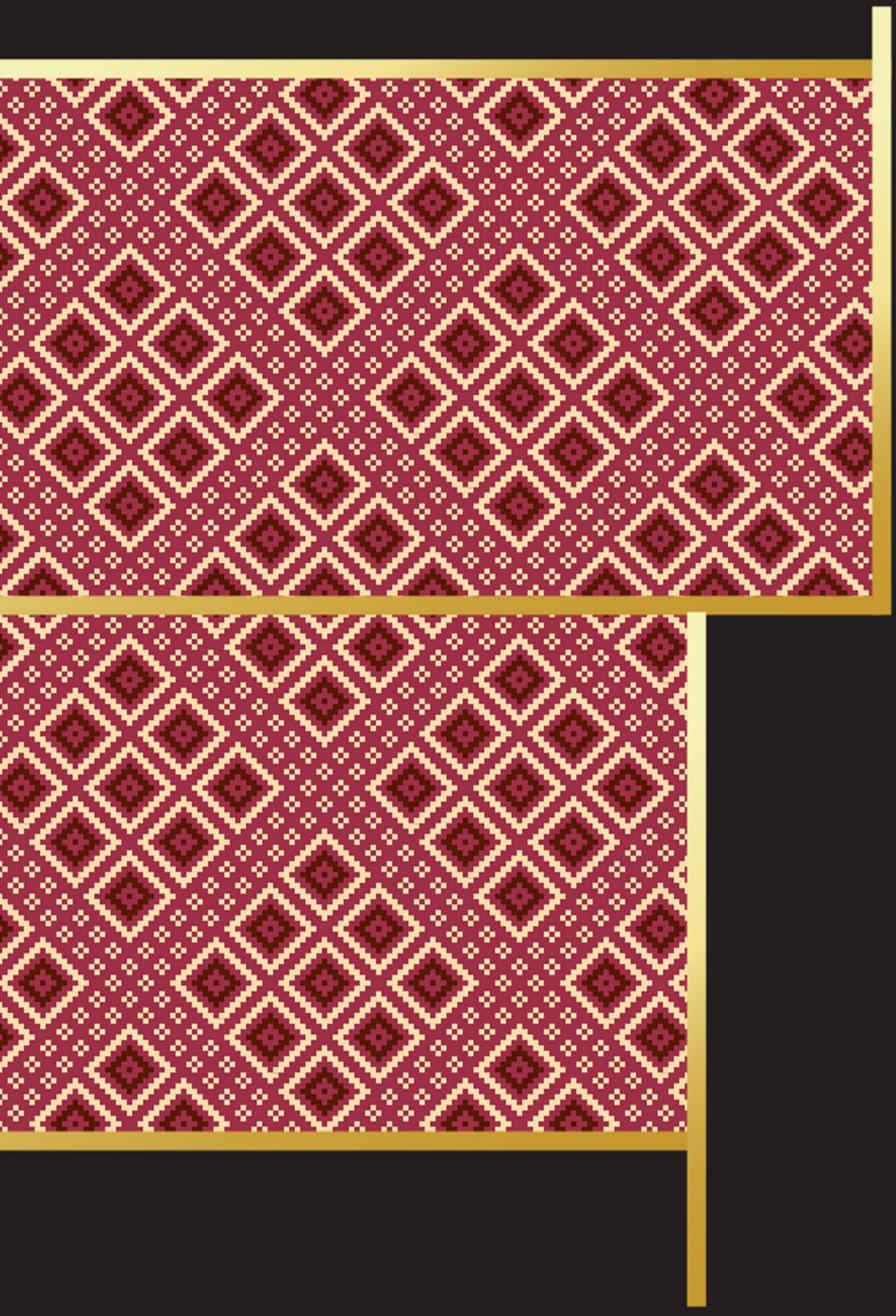
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